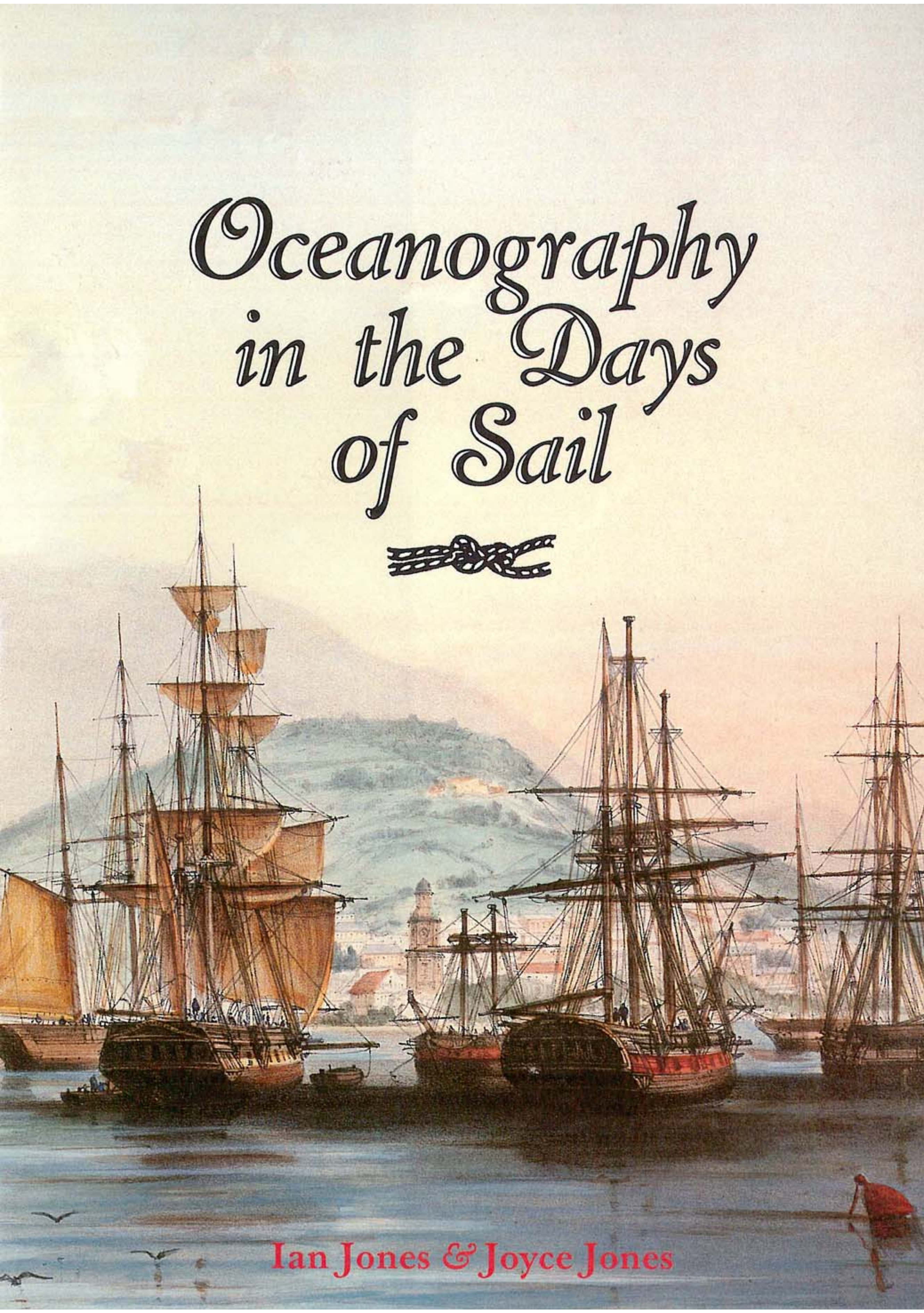


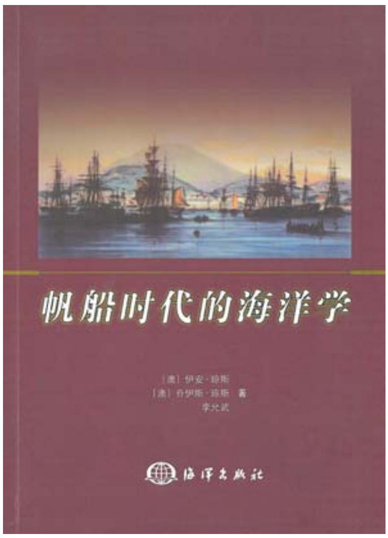
Oceanography in the Days of Sail

Ian Jones & Joyce Jones

OCEANOGRAPHY IN THE DAYS OF SAIL

Ian S. F. Jones and Joyce E. Jones

Second English Edition



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Cover: **Sailing ships in harbour at Hobart-Town in 1840. Sketched by Louis le Breton, artist with the French exploring expedition 1837-40 in the *Astrolabe* and *Zélée*, led by Jules Sébastien César Dumont d'Urville.**
Lithographers Mayer and Gulaud

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Location maps

Acknowledgments

The authors' debt must be expressed to the late Sir George Deacon, who visited Sydney as a Senior Queen's Fellow in 1981. Sir George's early career had been involved with physical oceanographic studies in the cold southern waters. Later he undertook research on ocean waves and was knighted for his contribution to oceanography. On the occasion of his visit to Sydney University, he not only showed us Hurley's hand-cranked movie of Mawson's *Discovery* under sail, but also drew our attention to Prestwich's 1875 compilation and appraisal of the deep sea thermometry of the predecessors of the *Challenger* expedition of 1872 to 1876. To this, Sir George's last visit to the Antipodes, we owe the inspiration for this account of the contribution to oceanography of investigations in the South Seas.

We would like also to take this opportunity to thank both Cynthia Jones and Alexander Jones for their assistance and encouragement during this project. Bruce Hamon, formerly of the CSIRO in Sydney kindly read our manuscript and made many valuable suggestions.

While the records of many of the labours of earlier oceanographers are difficult to retrieve, the holdings of the Mitchell Library in the Library of New South Wales and the Fisher Library of the University of Sydney have proved invaluable to us. Many long neglected reports and measurements are to be found in scattered papers and articles, but here we have attempted to draw together into one volume the story of the development of physical oceanography in the waters of the Pacific Ocean.

PREFACE

Man lives on a planet of which almost two thirds is covered by ocean. This ocean has been the main means by which products, faiths and ideas have spread from one continent to another. In maritime societies, the natural history of the seashores had long aroused the interest and curiosity of those who lived near the sea. The behaviour of the coastal waters upon which our ancestors sailed and fished had a very practical importance. Scientific interest in the sea dates back at least to Greek and Roman times. Tidal behaviour, in particular, being very visible, became an early subject of interest and observation in early China.

As observation and experimentation increased in importance as a source of knowledge, and the study of 'natural history' advanced and then subdivided into separate sciences, the study of the sea advanced within each of these sciences. As European communities, in particular, sent their sailing vessels further and further afield, the curiosity of the scientifically inclined found an ever enlarging source of nourishment in the observations that were now possible of the wider oceans and distant seas. Supported by those with the practical goals of improving navigation and reducing the risk of foundering, the inquisitive were able to build a description of the oceans. With improved instrumentation, and the capacity to measure and record came the interest in the physical aspects of oceanic behaviour and the beginnings of the science of physical oceanography.

The waters of the Pacific have played an important part in the development of the science of oceanography, not so much because of the contribution from littoral scientists but because Oceania was the focus of many European scientific expeditions in the enlightened eighteenth and nineteenth centuries. These expeditions, organised in the days of sail power, were conducted in the face of hardships and dangers unknown today. The narratives of their voyages were eagerly read in their day and still have the power to excite our interest and admiration.

While we may be well acquainted with the stories of the most famous of these explorers, of Bougainville and Lapérouse for France and of James Cook for England, we are not so familiar with the efforts of the many others who surveyed the coastlines and probed the deeper ocean in the nineteenth century when European penetration of the southern hemisphere was reaching its peak. We here propose a review of the work of the most important contributors to our knowledge of the seas, a review in which we shall tell chiefly of their work in the physical sciences and in the South Seas.

Considerable advances in scientific knowledge were achieved before the search for *Terra Australis* and the exploration of the Pacific became a subject of interest to Europeans and a focus for the study of marine science. For those who wish to know of the earlier developments in geographic knowledge and the knowledge of the tides, currents and waves, the article by Murray (1895) in the HMS *Challenger* reports provides a good starting point. The discoveries by civilisations other than European are not so readily available.

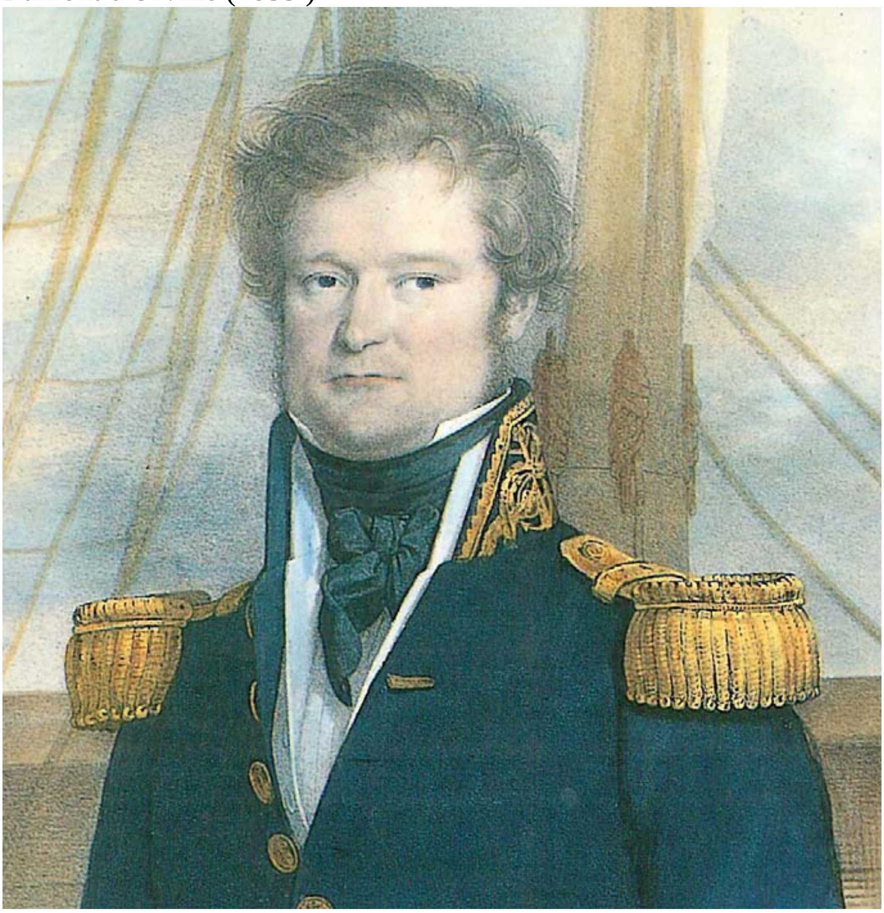
This book will be of interest to those drawn by the romance of the sea: to sailors, yachtsmen, marine officers, hydrographers and marine scientists. They may wish to know of the adventures associated with exploring and measuring the southern seas in the days of sail, and of the qualities of persistence and leadership displayed by those in charge of the expeditions. The accomplishments of their predecessors will be of interest to contemporary environmentalists and oceanographers, as will the legacy they have left us.

Measurements of the ocean were mostly made to satisfy curiosity. Only some few questions were of immediate practical consequence. Now, more than a century later, we are able to use the result of labours of the past to answer many economically important questions that would not have occurred to our ancestors. Can oil platforms withstand the waves and currents? How do fish stocks respond to surface currents? Or, more recently, what is the correlation between sustained droughts and the temperature of the tropical ocean surface? From a study of the measurements of the past comes the opportunity to assess questions such as the rate of climate change, since the deep ocean represents a large reservoir of heat that smooths the seasonal and inter-annual fluctuations in temperature. We should continue to build on the base of the curiosity-driven research of previous generations to ensure the sound management of the environment of our planet.

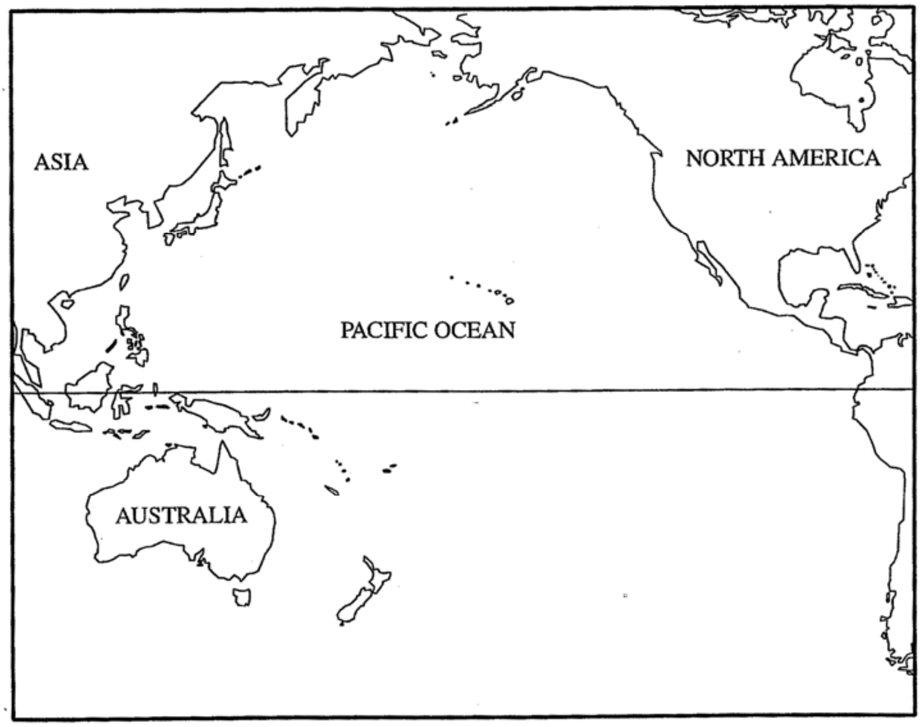
University of Sydney Institute of Marine Science
NSW, 2009

'Revolutions pass, political opinions can vary endlessly, but facts gained for science endure to honour the memory of those who have contributed to their acquisition. They are all landmarks set up by the generations which attest the gradual improvement of the spirit of man.'

Dumont d'Urville (1833)



Portrait of Dumont d'Urville



Map of Pacific

1

In Search of Terra Australis Incognita

Early Marine Knowledge

Knowledge of the seas and oceans became of practical importance to mankind when trade, conquest and the imposition of religion became driving forces in the affairs of nations. Reliable travel by water depended upon knowledge not only of coastlines, reefs and shoals, but of tides, winds and currents. The possession of this information represented a strong commercial advantage. Competition for trade often precluded the passing of such information to others.

Early mercantile civilisations in Europe, such as those in Crete and Phoenicia, relied upon trade for their prosperity by means of short-distance sailing routes within the enclosed Mediterranean Sea. As mercantile activity expanded out of the Mediterranean, knowledge of the tides, winds and currents of the oceans became more important. In the Persian Empire to the east, larger ships were built for use in the Indian Ocean and a grading system for sailors was introduced, based on their knowledge of the sea.

In 55 BC the importance of information about the behaviour of the ocean was brought home to Julius Caesar during his first invasion of Britain. The Roman ships, drawn up on the beach or anchored in shallow water, were severely damaged by the combination of a storm and the high Spring Tides. 'It happened to be full moon that night, at which time the Atlantic tides are particularly high - a fact unknown to the Romans', wrote Caesar, the invader from the almost tideless Mediterranean sea. The Romans were similarly surprised the next year when their second invading fleet was carried far off-course by the strength of the tidal stream in the English channel, and only by hard rowing, when the set of the stream changed, were they able to make the part of the island where they had found the best landing places the year before.

Similarly the attempted invasion of Japan across Korea Strait by Kublai Khan in the thirteenth century was foiled by unexpected spring typhoons which led to the loss of hundreds of thousands of lives as the ships foundered in the tumultuous seas.

In the centuries in which the wind was the power-source for ocean voyages, the accumulated knowledge of the wind and current patterns of the oceans was crucial to the expansion of trade and colonisation. In the first millennium seafaring Scandinavians made surprisingly long trans-Atlantic voyages, relying on their experience of the winds and sometimes the currents to carry them on round trips to North America. Chinese records of the Tang dynasty record that it was possible to reach Aden and the mouth of the Euphrates River by seaway. Buddhist monks were able to travel between China and India. After the twelfth century, when navigation by the compass became possible, the Kuroshio current and the monsoon winds were used by traders to venture beyond the visible coastlines and pursue routes through the open seas [Song et al (1990)]. Great fleets of Chinese vessels sailed into the Indian Ocean for trade and tribute, well before Magellan’s celebrated voyage around the world. Their sailing directions (reproduced in 1621) showed they knew of the seasonal set of the currents in the West Indian Ocean. These voyages under the direction of Zheng He showed the desire to spread one’s views to others. Levathes (1994) pointed out that the Ming Emperor Zhu Dhi sent out 10,000 copies of the polemic “Virtuous Women” by Xiang Liu which described the exemplary lives of selected Chinese women. The emperor hoped to enlighten the barbarians that the fleets visited along their route.

It was the knowledge of the seasonality of the monsoon winds of the Arabian Sea which allowed the expansion of European influence to India and beyond. In summer the monsoon winds blow from the southwest, allowing sailing ships to reach India from the African coast. This knowledge was acquired by the Arabs and the Indians in very early times and eventually passed to venturesome navigators from Western Europe. In the fifteenth century the Portuguese, having found their way around the southern point of Africa, then took advantage of the seasonal monsoon wind patterns long known to the Arabs to sail between the eastern coast of Africa and the trading post they established on the coast of India at Goa. Through the vision of Prince Henry the Navigator and his successors, they had the advantage of expert navigators. In the Portuguese schools of oceanography pilots were trained in all the known navigational skills. For more than a century the Portuguese were able to keep secret from other Europeans their knowledge of the sailing routes to India. This gave them a monopoly of the carriage of Asian goods to Europe.

This monopoly, however, was challenged in the sixteenth century by the merchants of the Holland, who learned details of the Portuguese route around Africa from their sailors who were recruited onto Portuguese ships. Eventually, with the aid of some cartographical espionage, the Dutch replaced the Portuguese as the premier traders in the Spice Islands of the Indonesian archipelago. Unable to follow the route between the island of Madagascar and the coast of Mozambique because of the well-established Portuguese forts there, they first pioneered a more easterly route through the Indian Ocean. This, however, involved a slow passage through the doldrums around the equator and increased the risk of sickness among the crew. A new and faster route was opened up in 1610 by making use of the strong westerly winds which by now were known to blow regularly over the open ocean below latitude 35°S. The new southern route was pioneered by Hendrik Brouwer in this year with two ships of the Dutch East India Company. From the port at the Cape of Good Hope he sailed south to the latitudes of 35° and 40°, where the Roaring Forties carried him eastward. When he estimated that he had reached the longitude of the Sunda Straits between Sumatra and Java, he turned northwards to reach the Dutch trading post at Bantam (Banten) in Java. By this new route he reached his destination in a little over six months, which represented a remarkable saving in time on a voyage which commonly took twelve months. In 1616, after the route had been used very profitably by several ships, it was laid down by the directors of the East India Company in their sailing instructions.

The Dutch ships were taking best advantage, of the wind and current systems of the Indian Ocean. The return voyage from Indonesia was effected by completing a circuit of the Indian Ocean, much as the Portuguese had developed a figure-8 navigation pattern for the North and South Atlantic Ocean. The returning Dutch ships could sail west with the Equatorial Current, and south to the Cape of Good Hope with the

Agulhas Current. The prosperity of the Dutch nation was greatly dependent on their knowledge of the prevailing conditions along the ocean routes traversed by their merchant fleets.

The “Spanish Lake”

In the sixteenth century, the Spanish established themselves in Central America by making use of the wind streams and currents of the North Atlantic Ocean. Following Ferdinald Magellan’s voyage around South America into the Pacific Ocean they extended their influence to the Philippines. From these colonies established in the 1560s and 1570s a highly successful trade route was established between Manila and Mexico that enriched the coffers of Spain and lasted for more than two hundred years. An annual voyage became possible using the prevailing winds of the North Pacific. Leaving Manila at the end of June when the north-east winds changed direction to a south-westerly monsoon, Spanish galleons laden with exotic Asian goods sailed north as high as latitude 40° where the prevailing westerlies carried them towards the coast of North America. From there they sailed south-east down the coast to Acapulco. The credit for the discovery of this route is given to Andres de Urdaneta who suggested it after living in the Spice Islands for ten years and gathering local oceanographical knowledge. The circuitous northerly voyage to Acapulco took five to seven months but by sailing for the return trip in January and keeping in low latitudes with the trade winds behind them the galleons could return to Manila in three months. The success of these commercial voyages depended greatly upon the accumulation of knowledge about the wind and current systems of their ocean route.

Soon the treasure fleets of the Spaniards on the Manila run and along the American seaboard attracted the attention of raiders and pirates such as Francis Drake. In time, despite strong Spanish efforts to conceal the details of their routes and trading opportunities, the South Seas became known to rival seafaring nations of Europe who began to stake their claims to newly discovered or rediscovered territories

For centuries the motivation for such long voyages from Europe could be summed up as greed or glory. Trading in the spices, textiles, jewels and fine porcelain of Asia was highly profitable and, as a bonus, for the

Christian mariners there was the prospect of everlasting reward in the afterlife for the conversion of savages and heathens to the “true faith”.

In the fifteenth and sixteenth centuries rivalry between Portugal, Spain, Holland and England occasioned the suppression of much nautical information gained by the navigators of these nations. Our story concentrates on succeeding centuries when knowledge was pursued and disseminated in a spirit of 'enlightenment'. Voyages of discovery sent out from Europe became increasingly scientific in their nature and more and more observations were made at sea. As techniques improved with the advent of better materials with which to make scientific instruments, these measurements became more accurate and more frequent. A surprisingly large number were made in the Pacific Ocean.

In the eighteenth and nineteenth centuries the great voyages of trade and exploration to the southern seas provided the impetus for the publication of much reliable information about the oceans. The incentive for some of the eighteenth century voyages of exploration included the continuing search by Europeans for a legendary '*Terra Australis Incognita*', or 'Undiscovered Southland'.

Terra Australis Incognita

The theory of the existence of a great continent in the southern hemisphere was developed by the school of Aristotle, which concluded that there had to be a large landmass in the southern hemisphere to balance the land of Europe and Asia. About 150 AD the cartographer Claudius Ptolemy sketched in such a landmass on a world map and even added names of his own devising. The legend grew of great riches to be found there. As theories about this Southland persisted, cartographers continued to sketch in a large hypothetical continent and added names such as *Provincia Aurifera* - the gold-bearing region.

By the beginning of the sixteenth century the voyages of Bartholemeu Diaz and Ferdinand Magellan had shown that *Terra Australis*, if it existed, was not joined directly to either Africa or South America. The maritime nations of Europe, however, did not give up on the idea of a fabulous southern landmass, somewhere in between these known continents. After Magellan's passage in 1520 through the strait which bears his name, for a time Tierra Del Fuego, which lay on the southern side of the Strait, was thought to be a tip of the *Terra Australis*. In some maps of the late sixteenth century, that of Abraham Ortelius (1589) for instance, the hypothetical landmass was shown stretching from Tierra del Fuego to New Guinea

In 1567 from their settlements in South America the Spanish sent Alvaro de Mendana into the Pacific with two ships to search for the legendary Southland. Sailing westward from Callao he discovered the Solomon Islands, but not a landmass to represent *Terra Australis Incognita*. Mendana had no more success in this search on his second expedition, launched in 1595, but his chief pilot, Pedro Fernandez de Quiros, a Portuguese by birth, kept alive his faith in a Southland, waiting to be incorporated into Christendom, and returned to the Pacific in 1605. He reached some islands which he triumphantly hailed as the Southland, and named them *la Austrialia del Espiritu Santo* (now the New Hebrides). This archipelago, later became known as the New Hebrides.

The English were interested in the search also. In 1577 Francis Drake set out from Plymouth, England, with three ships to harass the Spanish shipping on the South American coast. He had instructions from Queen Elizabeth the first to look also for unclaimed lands in the south. After a passage of Magellan Strait, however, he was obliged to turn northward because of the strong winds from the west. He laid claim to the Californian coast for England, naming it *Terra Albion*, but found no great Southland.

By the end of the sixteenth century the Dutch had established a strong trading empire in the Spice Islands of the East Indies. When they discovered land to the south of these islands, they entertained the idea that this 'New Holland', as they called it, mightextend southwards and eastwards and be the edge of the fabulous Southland. Under the governor-generalship of Anthony Van Diemen considerable energy was devoted to expansion and exploration. In 1642 the council of the Dutch East India Company sent out an expedition under Abel Tasman to search for fertile regions to the south of the Spice Islands. It was hoped also that he might discover a southerly route towards the Spanish colony of Chile. Tasman's passage of the Southern Ocean in the track of the Roaring Forties led to the discovery of Tasmania and New Zealand which lay in the path of these winds. The results were considered disappointing by Governor Van Diemen for the explorers brought back no news of a land with rich mines or of people with whom they might trade.

The southern limits of New Holland had been revealed, but the puzzle persisted as to the location of the great landmass whose existence was still considered necessary to 'balance up the earth.' As the seventeenth century drew to its close, the Lords of the British Admiralty decided to organise an expedition to continue the search for the Southland. To command the expedition they appointed an able navigator, known to have considerable experience of the Indian Ocean and the South Seas - William Dampier.

William Dampier, Best-selling Author

William Dampier had served in the British Navy only briefly, at the age of twenty, as a seaman, during a period of war against the Dutch. Yet in 1698 at the age of 47 he was given command of a voyage of exploration to the South Seas. This appointment was based upon the reputation he had earned from the publication of a series of travel books recounting his experiences and observations during twelve years sailing on the far side of the world.

William Dampier was born in 1651 the son of a Somerset tenant farmer. He received an education at what he called a Latin school, probably with the idea of a career in trade, but, having lost both his parents, he persuaded his guardians to apprentice him to a ship’s master at the age of eighteen. Thus he followed his inclination to go to sea and see the world. He spent one summer on a North Atlantic voyage to Newfoundland, and then, he tells us, gratefully accepted the offer of a warm voyage into the Indian Ocean and to the Dutch East Indies. While he was a seaman in the Royal Navy, being of a curious and observant nature, he had taken the opportunity to learn all he could of mathematics and navigation.

When, however, after a period of recuperation from ill-health, he was offered a position as assistant manager on a sugar plantation in Jamaica, he sailed across the Atlantic to the West Indies, working his passage before the mast. He spent many years in the Caribbean in a variety of occupations, including work with English log-wood cutters in the steamy coastal forests of Spanish-held Mexico. He also tried a spell at buccaneering where his navigational skills were put to good use. He joined a fleet of English and French buccaneers preying upon Spanish shipping along the coast of Panama. From the West Indies his new career led to cruises on the Pacific coast of South America, continuing raids upon the Spanish merchant fleets. Eventually he joined a small vessel named the *Cygnet* and sailed from Mexico across the Pacific Ocean to the Ladrones (Marianas) Islands and the Philippines.

After some time spent raiding on the coasts of South China the *Cygnet* cruised amongst the Spice Islands of the Dutch East Indies. In December 1687 they sailed south to the nearby coast of New Holland. This region had been known for most of the century to the Dutch, ever since Willem Janszoon's voyage to the Gulf of Carpentaria in 1606 and Dirk Hartog's charting of part of the western coastline in 1616. Quite a few Dutch vessels, making for Batavia touched accidentally upon the west coast of New Holland. This was the result of the uncertainty prevailing about distances covered at sea. The route, pioneered by Hendrick Brouwer, took the Dutch fleets along the 40 degree South parallel but travelling too far eastwards across the Indian Ocean before turning northwards for Java was the cause of several shipwrecks. There had been some rescue attempts. All reports were that the area was barren, the people sparse and unapproachable and producing nothing of value for trade.

In 1688 the crew of the *Cygnet* spent two months on the northern coast of New Holland. The purpose of their visit was to careen their vessel which they were able to do in a small bay just inside the large opening now called King Sound. They saw very few native inhabitants. Dampier spent much of his time writing up his observations on the exotic flora and fauna of the new lands he had visited He included his observations about conditions at sea. Possessed of a keen and curious mind, he noted details about the tides, the currents and the winds. He included the observations of others, when he considered them reliable. After the stay in King Sound, he was fortunate to preserve his precious journal, sealed in a bamboo capsule, when, with a few companions he parted company with the *Cygnet* and swam ashore at the Nicobar Islands. From there he made his way by a native canoe to Sumatra. and eventually found work as a master-gunner of the English East India Company's fort at Bencoolen (now Bengkulu). It was not until 1691 that Dampier returned to England, after an absence of twelve years He was then able to found a new career as a travel writer.

There was a new spirit of inquiry abroad in seventeenth-century England, instanced by the charter granted in 1662 for the establishment, under the patronage of Charles II, of the Royal Society of London, a body of scientific men who would examine and publish new discoveries in a regular journal printed in the vernacular. The science of ocean navigation was one of their areas of interest. They had already published *Directions for Seamen Bound for Far Voyages*, urging them to bring back useful information about conditions at sea and at anchorages in distant places. Many members of the Royal Society also shared Dampier’s interest in plants and natural history, including the society’s curator of experiments, Robert Hooke.

Dampier’s journals provided the material for the *New Voyage Round the World* which he published in 1697. The book was dedicated to Charles Montague, the President of the Royal Society of London. It was highly informative and proved a great success. Within months three new editions were published in London and members of the Royal Society and the English East India Company were eager to meet him. The *New Voyage Round the World* became a travel 'best-seller' and ran through three printings within nine months. His works were very popular on the continent as well as in Britain, arousing interest in the unexplored parts of the globe. Editions in French, German and Dutch were published between 1701 and 1715 and were highly regarded. In 1699 he published a second book, *Voyages and Discoveries* which appeared in three parts. The third section was a treatise entitled *A Discourse on Winds, Breezes, Storms, Tides and Currents in the Torrid Zone.*

When Dampier's *Discourse* on the physical phenomena of the atmosphere and oceans of the Torrid Zone appeared in it provided valuable empirical information to supplement the theoretical arguments of natural philosophers, who at this time were pondering the explanation of winds and currents. The movements of the air and the seas were generally ascribed to the rotation of the earth, if one adopted Copernicus's heliocentric view of the solar system, or to the movement of the heavens, if one still clung to Aristotle's vision of a stationary earth around which the heavens revolved. Tides were often confused with the ocean currents in the thinking of natural philosophers. Dampier, however, drew a clear distinction between tides and currents:

> *By Tides I mean the Flowings and Ebbings of the Sea, on or off from any Coast. Which Property of the Sea seems to be universal; though not regularly alike on all Coasts, neither as to Time nor the Height of the Water.*
>
> *By Currents I mean another Motion of the Sea, which is different from the Tides in several Respects; both as to its Duration, and also as to its Course.*
>
> *Tides may be compared to the Sea and Land-Breezes, in respect of their keeping near the Shore; tho' indeed they alternately flow and ebb twice in 24 Hours. Contrarily the Sea-Breezes blow on the Shore by Day, and the Land-Winds off from it in the Night; yet they keep this Course as duly in a manner as the Tides do. Neither are the Tides nor those Breezes far from the Land.*
>
> *Currents may be compared to the Coasting Trade-Winds, as keeping at some farther Distance from the Shore, as the Trade-winds do; and it is probable they are much influenced by them*. [Dampier, ed Masefield (1906) p.306]

There were, Dampier pointed out, some very practical advantages to be obtained from his observation of tidal phenomena:

> *In all my cruisings among the Privateers, I took notice of the Risings of the Tides; because by knowing it, I always knew where we might best haul ashore and clean our Ships.* [Dampier, ed Masefield (1906) p.311]

Tidal Phenomena - Dampier's Discourse

Dampier's books are of significance in the development of oceanography. They added considerably to the eighteenth century's store of knowledge about conditions at sea. He brought a critical approach to the accumulated lore of seafarers and the advantage of being himself a keen observer of natural phenomena

He had not, he said, been on any coast in the world but where tides ebbed and flowed, either more or less. He had observed that the greatest in-draughts of rivers or lagoons commonly had the strongest tides, and that the tides were not so noticeable on or about islands remote from the mainland.

> *At New Holland I had two months time to observe the Tides. There the Flood runs E. by N. and the Ebb W. by S. And they rise and fall about five Fathom.* [Dampier, ed Masefield (1906) p.312]

This 30-foot tidal range off the north-western shores of Western Australia, now calls for the construction of very long jetties. When Dampier was visiting King Sound (near present day Broome) in January 1688, some alarm was occasioned amongst the ship's company by the behaviour of the tide when their careening was complete and the time came to refloat the ship. They were relying on the extra height of the Spring Tides for this exercise and

> *expected to haul off the Ship the third Tide after the Change; but our Ship did not float then, nor the next tide neither, which put them all into an Amazement and a great Consternation too: For many thought we should never have got her off at all, but by digging away the Sand; and so clearing a Passage for her into the Sea. But the sixth Tide cleared all those doubts; for the Tide then rose so high as to float her quite up; when being all of us ready to work, we hauled her off; and yet the next tide was higher than that, by which we were now all thoroughly satisfied, that the Tides here do not keep the same time as they do in England.* [Dampier, ed Masefield (1906) p.312]

Dampier's observation of the strength and direction of the tides in this area led him to conclude that there was most likely a passage between New Holland and New Guinea, or at least a large and deep inlet.

There was still speculation about whether New Guinea was part of a presumed larger landmass of '*Terra Australis Incognita*' as drawn on some speculative maps. The Governors-General of the Dutch East India Company (the V.O.C,) had equipped several expeditions to see if a passage eastward existed south of New Guinea, but with negative results.

The Dutch were convinced from Janzoon's explorations in 1606 and Abel Tasman's in 1643 that no strait existed between New Guinea and “New Holland”. Although the V.O.C. did not know it, there was already proof to the contrary, for Torres Strait had, in fact, already been discovered, some suggest 'rediscovered', in 1606 by Luis Vaez Torres and Diego de Prado in the ship *San Pedro,* but the information had not been published on charts or made public by the Spanish. The Portuguese, also, in that era, not only jealously guarded their knowledge of navigation routes, but were anxious to conceal from Spain any territory they happened to discover in the half of the globe which had been designated as the Spanish domain by the Pope (The Tordesillas or 'Pope's Line').

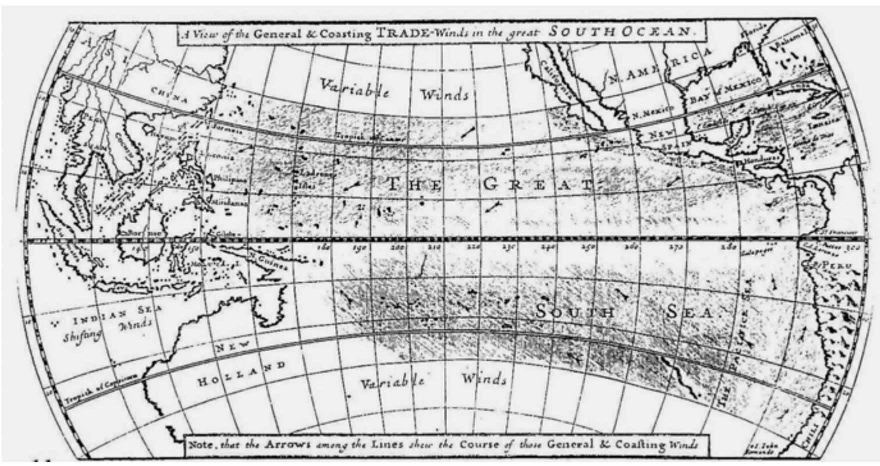
Winds and Currents - Was There a Connection?

By Dampier's time, sailing vessels from European ports had penetrated all of the oceans of the world, except the Antarctic, but the ocean most traversed was the Atlantic. Navigators there had discovered that, particularly in the Tropics, there were areas of 'doldrums' where their ships could be becalmed for weeks at a time. There were. other regions where steady winds could usually be encountered to speed them to their destination in the New World. The favouring Trade Winds of the North Atlantic, for example, blow steadily from the north-east between approximately latitude 35°N and 11°N in winter and 26°N and 3°N in summer, particularly over the open ocean away from landmasses. They are usually associated with fine, clear weather and navigators would plot their courses to take best advantage of them. Columbus on his first voyage to the New World in 1492 caught the North-East Trades so effectively that his sailors, he reported, grew anxious lest there should be, in these seas, no winds which ever blew in the direction of Spain. Natural philosophers were interested in theories of their origin.

The English scientist, Edmund Halley, from a base on the island of St Helena, had studied the direction and strength of the South-East Trades in the South Atlantic. He spent over a year there between 1676 and 1678, making meteorological and astronomical observations and as a result was able to present to the Royal Society a description of the behaviour of these important winds, and also to offer an explanation of their cause, which was based on differences of temperature and density in the atmosphere.

Dampier was not given to theorising about the cause of the natural phenomena he observed. His contribution was objective information based on first-hand experience over a wide area of the Torrid Zone, including the Pacific Ocean. He did however suggest, from his observations of a correlation between these winds and the equatorial currents, that there was probably a causal relationship between them. He is probably the first to have published such conclusions:

> *'Tis generally observed by Seamen, that in all Places where Trade-winds blow, the Current is influenced by them, and moves the same way with the Winds; but 'tis not with like Swiftness in all Places; neither is it always so discernable by us in the wide Ocean, as it is near to some Coast.* [Dampier, ed Masefield (1906) p.314]



1.1

Of great importance to early navigators in the days of sail were the steady Trade Winds blowing over the tropical and subtropical ocean waters. They blow from the north-east in the northern hemisphere and the south-east in the southern hemisphere, but their world-wide distribution only gradually became clear as the knowledge of seamen was gathered together. William Dampier's 1699 chart of the Trade Winds in the Great South Sea (Pacific Ocean) was a product partly of his own experience and partly of knowledge gleaned from other sixteenth- and seventeenth-century navigators into that ocean. His 'shifting winds' in the Indian Ocean describe the monsoon. *Dampier ed Masefield (1906)*

The *Discourse on Winds, Breezes, Storms, Tides and Currents in the Torrid Zone* includes two charts of the oceans between latitudes 40° North and South, drawn at Dampier’s direction by the cartographer, Herman Moll. One is centred on the African continent. The other shown in Figure 1.1, covers 'The Great South Sea', as the Pacific was then generally called. The direction of the winds is shown with arrows and there is fine line-hatching on the oceans to indicate the areas in which they had been reported.

Dampier made a clear distinction between diurnal tidal streams near the shore and surface currents, of a more constant direction, further out to sea:

> *Currents and Tides differ many ways; for Tides run forward and back again, twice every twenty-four Hours: on the contrary Currents run a Day, a Week, nay sometimes more, one way: and then, it may be, run another way.*
>
> *In some particular Places they run six Months one way, and six Months another.*
>
> *In other Places they constantly run one way only a day or two, about full Moon, and then they run strong against the former Course; and after that, return the same way again.*
> *In some places they run constantly one way and never shift at all.* [Dampier, ed Masefield (1906) p.314]

Having spent more time in tropical, island-studded seas, subject to monsoonal influences, than in the open oceans, Dampier seems more impressed by the variability in direction of some currents than by their constancy. He made no mention of their temperature. It was not yet the practice to measure the temperature of the ocean waters with a thermometer, a procedure which later became a common navigational aid.

The *Discourse* attracted the attention of the learned members of the Royal Society and the Lords of the Admiralty, who were at that time interested in sponsoring an official voyage of exploration into the South Seas. Fresh interest in the South Pacific had been sparked by the recent publication in London of a summary of the journal of Tasman's historic

1642 voyage of discovery to Van Diemen's Land (Tasmania) and New Zealand.

There had been nothing in Dampier's reports of the area of New Holland he had seen in 1688 to arouse the interest of any European government in colonising or trading there. New Holland was not considered to be the legendary *Terra Australis*. It fulfilled none of the expectations of prosperous peoples and fruitful forests. Interest was still high in London to discover the truth about the legendary Southland and such was Dampier's reputation as a seaman and a scientific observer that, despite the fact that he had not pursued a career in the navy, he was chosen by the Admiralty to command their expedition in search of this fabled *Terra Australis Incognita*.

The Voyage of the *Roebuck* in Search of *Terra Australis*

We can read Dampier's account of this expedition in his next book *A Voyage to New Holland*, which appeared in two parts, the first in 1703 and the second in 1709. His account of his voyage in the *Roebuck* is still full of interest as a travel tale of the age of exploration.

The original plan was for him to round Cape Horn into the Pacific as Francis Drake had done in 1577 and James Cook was to do seventy years later..It was hoped he would search the South Pacific from Tierra del Fuego to New Holland. In fact, because of the lateness of the season at which he set out - the depths of winter, January 1699 - Dampier realised he could not weather a passage around Cape Horn and informed the Admiralty that he must round the Cape of Good Hope instead. He had hopes, however of reaching the South Seas by sailing beyond New Holland.

Dampier had asked for two ships, but was granted only one. He rejected the first ship offered to him and was probably unwise to have accepted the second, the *Roebuck*, for, by all accounts, the ship was old and decrepit and the brief refit was insufficient to make her seaworthy. The *Roebuck*, twelve guns, 290 tons, with a crew of fifty, carried provisions for twenty months. It was designed to be a voyage for both exploration and science, and carried an artist to record new findings in natural history His route across the Indian Ocean, brought him again to the barren shores of Western Australia, this time to shelter in the large shallow inlet which he named Shark's Bay. This inlet had already been visited by Dutch navigators.on their way to the Indies. In 1616 Dirk Hartog had sheltered there, Willem de Vlamingh in 1696. Dampier had hopes of watering his ship but, despite a thorough search, which included digging wells to a depth of more than nine feet, he could find no fresh water. He followed the coastline for a while, anchoring among the waterless islands now called the Dampier Archipelago and also in Lagrange Bay, south of Broome, At a location given as latitude 18°21'S, the party ventured onto the mainland, and this time met up with some of the natives. The English set out to capture one of these to see if he could lead them to a supply of fresh water, but the encounter ended in a spear wound for an English sailor and a gunshot wound for an Aborigine. The next day while a shore party continued to dig for water, Dampier, who stayed on board, observed the swift flowing of the tide, which he estimated had a range of about five fathoms or thirty feet. The location was not far from the part of New Holland that he had visited in 1688 and described in the *Discourse*. Once again Dampier commented that, by the height, strength and direction of the tides, there could possibly be a passage or strait going eastward to the Pacific Ocean.

After a vital visit to the island of Timor for water and fresh food, Dampier next sailed north and along the northern coast of New Guinea, hoping that he might that way discover the eastern extent of New Holland. He did not test out his theory of a passage to the south of New Guinea. His big achievement was the discovery to the north east of New Guinea of the green and pleasant island which he named *Nova Britannia* (New Britain). By this time, however, the *Roebuck* was in such poor condition that he decided to venture no further. The fruitful eastern side of the Australian continent he was not destined to see, nor, approaching from the north would he have had much chance of negotiating the coral rampart of the Great Barrier Reef to do so.

Dampier returned to England by the way he had come, around the Cape of Good Hope. He spent two and a half months en route at Batavia (Jakarta) on repairs to the ship, but in the South Atlantic the *Roebuck*, its rotten planking giving way, sprang a leak and sank, fortunately within sight of Ascension Island. There was no loss of life. The crew was able to row to the island in the ship's boats. A few weeks later, since they were on a regular sailing route, a British squadron picked them up and took them home.

In England trouble awaited Dampier in the form of three courts-martial. The first, which concerned the loss of the *Roebuck*, exonerated him. The third charge was found to be unsubstantiated. The second court-martial was to consider his improper treatment of a career-officer of the Navy, his first lieutenant, George Fisher. Dampier, skilled navigator though he was, had not proved a very successful leader of men. The first lieutenant took a dislike to his ex-buccaneer captain. By open criticism of his seamanship and leadership, he aroused Dampier's fears of a likely mutiny to such an extent that he abandoned his cabin took to sleeping on the quarter-deck with officers he felt he could trust and with small arms at the ready. His solution was to confine Fisher to his cabin until they reached the port of Bahia in Brazil where he persuaded the Portuguese authorities to cast his chief officer into jail. This was done without any formal charge being laid against Fisher, who languished there for four months.

Dampier, who does not mention the incident in the narrative of his voyage, had written to the Admiralty with an account of Fisher's insubordination, but had not troubled to collect supporting evidence in defence of his action. The court, under the presidency of Admiral Sir George Rooke, involved thirty-four naval captains. When called upon to decide between the accusations of an ex-buccaneer and a regular officer of the Navy, they might, it has been suggested, reasonably be suspected of some prejudice. The president and some of the captains had been former commanding officers of Fisher's and had already given him testimonials of good conduct. Their conclusions were that Dampier was guilty of harsh treatment of Fisher, without any grounds for his behaviour. He was fined the whole of his pay for the voyage. The court declared that 'the said Captain Dampier' was 'not a fit person to be employed as commander of any of her Majesty's ships'.

Dampier found employment again in command of privateers during the War of the Spanish Succession. He spent the next seven years raiding Spanish ships and ports along the coast of South America. His last and best arrangement, was to sail in 1708, not as a commander, but as a navigator to Captain Woodes Rogers in the *Duke* and *Duchess* on a privateering venture to the South Seas.

Although Dampier produced popular works, full of adventure and the interest of the strange and the new, his intent was serious and it was not his aim to pass off fabulous tales as worthy of belief. He applied a critical judgment to any information he received from others. Instance, the stories about a subterranean connection of the sea under the Isthmus of Panama:

> *The great Tides in the Gulph of St Michael have doubtless been the occasion of that Opinion, which some hold, that there's a subterranean Communication between the N. and the South-Seas; and that the Isthmus of Darien is like an Arched Bridge, under which the Tides make their constant Courses, as duly as they do under London Bridge. And more to confirm this Opinion some have said that there are continual and strange Noises made by those Subterranean Fluxes and Refluxes; and that they are heard by the Inhabitants of the Isthmus; and also that Ships sailing in the Bay of Panama are toss'd to and fro at a prodigious rate. . .*
>
> *Sometimes (say they) they are by the boiling of the Water dash'd against Islands; and in a moment left dry there, or staved in pieces; at other times they are drawn or suck'd up, as 'twere in a Whirl-pool and ready to be carried under Ground into the North-Seas, with all Sails standing …… But if this were so,'tis much that I and those that I was with, should not have seen or heard something of it.* [Dampier, ed Masefield (1906) p.209]

If there were other seamen at this time as knowledgeable in meteorology and geography as William Dampier, they did not possess his literary ability or his willingness to write of his experiences and observations. His was a significant contribution to the growing body of geographic and navigational knowledge in the late seventeenth and early eighteenth centuries.

After his death in 1715, Dampier's writings continued to find a wide readership. In 1729 all his works were collected together and republished by James and John Knapton and served to interest men's minds in exploration of the Pacific. His books were treasured by later literary figures such as Daniel Defoe as well as explorers such as James Cook and scientists such as Charles Darwin. His navigational advice was consulted by those who sailed in his tracks.

Navigation before the Invention of the Chronometer

For early seafarers, such as William Dampier, navigation was full of uncertainties. Once beyond familiar coastal waters, establishing accurately one's location was very difficult. Often islands discovered in distant oceans could not easily be found again because of the inaccuracy of what was at best an estimation of their position. Today, with the range of navigational aids extending to satellites orbiting in space, the location of any point of the earth is known with an accuracy that would have been beyond the imagination of the navigator of earlier centuries.

A ship's course could be set with the magnetic compass, but a considerable margin of error was possible because of the likely 'magnetic variation'. A freely suspended compass needle does not point exactly towards true north or true south. In the ocean voyages of the fifteenth and sixteenth centuries, observations were recorded of the angle of variation of the compass. They were seen to vary from place to place. Dampier included in *A Voyage to New Holland* a table of all the variations of the compass that he had observed in over a hundred locations in the southern hemisphere on both the outward and the return voyage.

> *But what was most Shocking to me, I found that the Variations did not always increase or decrease in Proportion to the Degrees of Longitude East or West; as I had a Notion that they might do to a certain number of Degrees of Variation East or West, at such or such Meridians.* [Dampier, ed Williamson (1939) p.69]

The irregularities he had observed were a puzzle to him, for at this period there had long been the hope that lines of magnetic variation could be used for determining position. It was hoped that these lines, when combined with coordinates based on the dip of the magnetic needle, which was observed to vary largely with latitude, might be used as a global grid to establish a ship's position: In the late 1690s Edmund Halley was commissioned by the British Admiralty to measure and chart the magnetic variation in the North and South Atlantic. He published a chart of the 'isogonic lines' (lines of equal variation) for the year 1770. Dampier hoped his information might be useful for Halley's researches. The hope of navigating by compass variation was abandoned about this time, when it was realised that isogonic lines were not static, but subject to change. Both compass variation and compass dip vary from year to year. The great difficulty of establishing accurate longitude before the use of the chronometer is highlighted by the fact that Dampier, in his table of compass variations, expresses his longitude in degrees east or west of the nearest previously defined meridian, such as that of Cape Salvador in Brazil, the Cape of Good Hope, Dirk Hartog Island, and the island of St Helena.

Latitude was determined by measuring the angle of the sun to the horizon at noon. Simple instruments such as the astrolabe, the quadrant and the cross-staff, had given way to the back-staff. To use this instrument the navigator turned his back on the sun and aligned a shadow cast by the sun with the horizon. By the end of the fifteenth century tables for calculating latitude had been drawn up and were widely used.

But determining one's longitude, or distance from a prime meridian, involved an estimation of the distance travelled in an easterly or westerly direction and was not so easy. This was, as we have noted, a great drawback of Brouwer's route out to the Dutch East Indies: how to determine one's amount of easting with the prevailing Roaring Forties of the Indian Ocean before turning northwards for the Sunda Strait. Miscalculations of the distance covered were the cause of many Dutch shipwrecks on the western coastline of New Holland.

To calculate the speed of a ship, use was made of a board, weighted in such a way as to make it float upright and remain almost stationary in the water. Attached to it was a long line which was knotted at regular intervals. The log was thrown overboard and, as the ship drew away, a seaman counted the number of knots that passed through his hand in a measured interval of time. Recording regularly the ship's speed, thus calculated, along with the course taken, would, in theory at least, allow a calculation of one's longitude position. The capacity for error, however, was considerable. As well as the vagaries of cross-winds and currents, the only shipboard means of measuring the time for many centuries was the sand-glass, devised to measure hours or minutes or parts thereof. For the deficiencies of the sand-glass let us return to Dampier and his comments as he approaches the Cape of Good Hope on his voyage to New Holland in 1699:

> *For I found, soon after, that I was not then above 25 or 30 Leagues at most from the Cape. Whether the fault were in the Charts laying down the Cape too much to the East from Brazil, or were rather in our Reckoning, I could not tell: But our Reckonings are liable to such Uncertainties from Steerage, Log, Currents, Half-Minute-Glasses; and sometimes want of Care, as in so long a Run cause often a Difference of many Leagues in the whole Account. Most of my Men that kept Journals imputed it to the Half-Minute-Glasses. . . A Ship ought therefore to have its Glasses very exact; and besides, an extraordinary Care ought to be used in heaving the Log, for Fear of giving too much Stray-Line in a moderate Gale.* [Dampier, ed Williamson (1939) p.68]

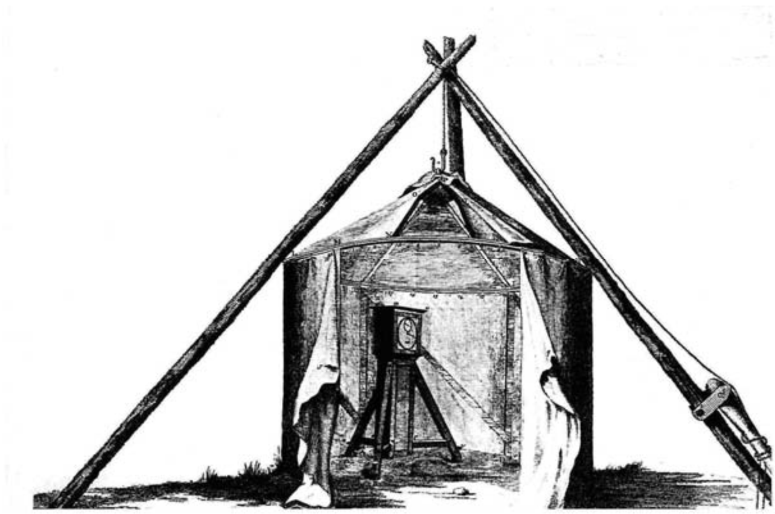
The problem of determining one's longitude accurately on long voyages still awaited solution. Three quarters of a century passed before a more accurate method was available. During this time the astronomers of Western Europe were encouraged in their efforts to improve the science of navigation, which was recognised as crucial to the mercantile ambitions of the maritime nations. At the Observatory of Paris, inaugurated in 1672 under the auspices of the Academy of Sciences, the astronomer G. D. Cassini from Italy undertook the calculation of tables forecasting eclipses of Jupiter's satellites for use in determining longitude at sea, an idea first suggested by Galileo Galilei. These tables were put to good use by the French Navy. In London the scientific minds of the Royal Society were similarly active on the task, supporting the astronomers of the Flamsteed observatory in the production of improved astronomical tables. The tracks of the planets were mapped and the times of eclipses and occultations of these planets by the moon's disc were calculated. Information about the distances between the moon and the sun at prescribed dates and locations was also produced. These lunar tables first appeared in the *Nautical Almanac* of 1767.

Meantime work was proceeding also on the improvement of timekeepers and particularly towards the production of a reliable, transportable, marine chronometer.

As a result of the improvement in astronomical tables it became possible in the later decades of the eighteenth century, on Cook’s first voyage and that of Lapérouse for instance, to determine longitude to an accuracy of less than one degree. Foreknowledge of eclipses and occultations, provided by almanacs, could be used for astronomical 'fixes', as could the lunar tables of distances between the moon and the sun. Their use entailed making angular measurements from a rolling deck, a difficult procedure, and then laborious calculations, of several hours' duration. Accuracy was also improved by the development of the reflecting sextant, devised by John Hadley in 1730 and adopted soon thereafter by the British Admiralty.

James Cook and the Voyage of the *Endeavour* 1768-1771

The three voyages of James Cook are famous for their achievements in exploration, cartography and science. They mark a new, scientific era in voyages of circumnavigation. Of particular significance for Australian history was Cook's first voyage in the *Endeavour* 1768-71, since the charting of the eastern coastline of New Holland led to the establishment of European settlement there eighteen years later.



1.2
Cook's portable observatory in which Shelton's pendulum clock was assembled. Land-based astronomical observations were necessary to supplement shipboard observations. Engraving by R. Benard

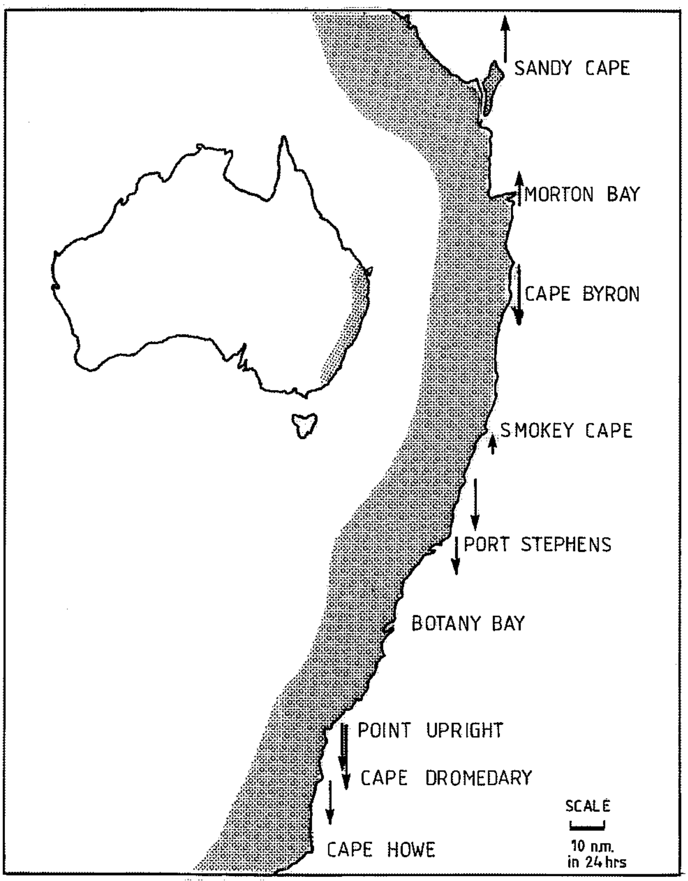
The details of this voyage to observe the transit of Venus at Tahiti are well known. There was much interest at this time in determining the dimensions of the earth and the solar system. It was known that the planet

Venus in its orbit crossed the face of the Sun at calculable intervals and Edmund Halley had suggested many years earlier that the observation of this event from a variety of locations world-wide would allow the use of the principles of triangulation to calculate the distance from the Earth to the Sun. A great cooperative international venture to access this opportunity was organised in 1761 by observers in France, England, Italy, Germany and other countries. The results were inconclusive. For the next transit of Venus in 1769 James Cook was chosen to observe from the island of Tahiti in the South Pacific. This gave his voyage a distinctive scientific aspect, that was to mark a great change in the nature of exploration organised by the maritime powers of western Europe.

The *Endeavour* carried, as well as Joseph Banks's entourage of scientific gentlemen, an astronomer, Charles Green, whose task it wasto make good use of the improved astronomical tables now available in Maskelyne's *Nautical Almanac* of 1767. Green also had available on the *Endeavour* a Shelton pendulum clock which, although it was unsuitable for use on shipboard because of the motion of the deck, could be assembled and set up on a land base (See Figure 1.2).

The First Observations of the East Australian Current

At the time of the voyage of the *Endeavour* in the second half of the eighteenth century a considerable body of general information about the distribution of ocean currents had accumulated. The Gulf Stream of the North Atlantic was the best known, followed by the westward-flowing North Equatorial Stream, by which the Spanish conquistadores had found a very favourable route to the Caribbean. At the time of Cook's voyage in the *Endeavour* it was possible to estimate the speed and direction of an ocean current encountered by a vessel. This was useful information since a steady current rate of two knots an hour, for instance, could assist or delay a ship's progress by some forty miles a day. The ship's 'set' could be calculated by comparing its position as determined by 'dead reckoning' with that determined by an astronomical 'fix'. Dead reckoning required an estimation of the vessel's speed through the water and for that the ship's 'log' was used. The log was deployed over the stern of the vessel and the result used to estimate the distance run for twenty-four hours. The



1.3
James Cook coasted the New South Wales shore in 1770 and recorded the difference between his position at the end of the day's sailing with that predicted by the ship's speed through the water. Dr. P. J. Mulhearn has plotted these observations to show the southward-flowing East Australian Current . We now know, two centuries later, as a result of Bruce Hamon's work that the current is stronger offshore and is sometimes associated with a north flowing inshore current. This can be seen from Cook's observations in the north.

distance could be compared with that calculated from the previous and the present astronomical fixes. The difference was attributed to current 'setting the ship'. Astronomer Green on the *Endeavour* assisted in making the many calculations needed to provide reliable sets. This technique for determining surface currents has persisted to the present and is the one still used by the authors with only the substitution of an electronic log for the Admiralty-issue log used by Cook. A significant phenomenon in the dynamics of the western South Pacific is the southward-flowing current which follows the coastline of south-eastern Australia. As Cook sailed along this coast in 1770 (see Figure 1.3), he was set mostly to the south by this current, the existence of which was to be observed and noted by later navigators also. The complexities of the behaviour of this boundary current are still under investigation.

Tidal Observations

Tidal information was useful for ships negotiating straits or entering harbours and where available, was included in published directions for seamen. Tidal phenomena were also of interest to scientists. By this era an explanation of the cause of tides had already been provided by Isaac Newton. Usually it was only at anchorages where some time was spent that navigators could gather tidal information. By a coincidence of fate, James Cook was provided with such an opportunity when the *Endeavour* struck the coral reef off the coast of Queensland at high water. He was obliged anxiously to measure the rise and fall of the tide as he waited to refloat his ship. When the ship could not be refloated at the next high tide he observed that there could be considerable diurnal inequality in the height of tides, a phenomenon that he had not noticed previously.

The Marine Chronometer Tested on the Voyage of the *Resolution* and *Adventure* 1772-1775

During the span of Cook's first voyage, John Harrison's work on marine timekeepers was finally successful in producing a reliable marine chronometer. Increased accuracy in determining one's position was important not only for geographic discovery, but for the recording of oceanic behaviour. An accurate shipboard timekeeper was needed to carry the prime-meridian time of Greenwich (or Paris). Then determination of longitude would be possible by a comparison with local sun-time. As one travels east the sun rises earlier and earlier on a clock set to Greenwich Mean Time. The achievement of eighteenth-century science was the production of such an instrument, which was tested on voyages by the French 1769-72 and by Cook on the *Resolution* and *Adventure* 1772-75. The success of these efforts caused historians to declare that 'the overcoming of time' was amongst the greatest achievements of the seventeenth and eighteenth centuries. The coming of the clock spelt the end of their 'ancient civilisation of the more-or-less'.

The importance attached to the invention of a reliable marine timepiece can be gauged by the 1714 Act of the English Parliament which offered a substantial reward of £20,000 for an instrument accurate enough to determine longitude at sea to within half a degree, or, expressed differently, with an error of not less than 30 nautical miles at the end of a voyage to the West Indies. Even such a large prize did not immediately produce a solution.

On the adjudication of the Board of Longitude, the prize was eventually awarded to clockmaker, John Harrison, for a spring-driven instrument. He received part of the reward in 1765 for his fourth version and the rest in 1772. It was a replica of this invention, made by John Kendall, and costing £450, which was taken on the *Resolution* in 1772 for testing. (In a few years' time chronometers, devised by Earnshaw, were produced for less than a tenth of this price.) Meanwhile, on the continent, a maritime timepiece had been developed in France by a precision mechanic, Julien Leroy, and for this he was given a prize by the French Academy of Sciences in 1767. A Swiss watchmaker, Ferdinand Berthoud, produced another marine timekeeper which was tested in 1768. For this he was given a pension valued at £3000 and the title of Watchmaker Mechanic to the French King and the Navy. Such was the value assigned to this important invention which made navigation a precise science and paved the way for truly scientific exploration of the oceans.

To test the Harrison chronometer, two of Britain's best astronomers, William Wales and William Bayly, were appointed by the Board of Longitude to the *Resolution* and the *Adventure*. Wales had helped compile the *Nautical Almanac* used in Cook's first voyage. They were paid £400 per annum each by the Board of Longitude. The valuable 'longitude watches' were housed in specially constructed boxes, each fitted with three locks, for their 'safe keeping and proper management'. The keys were in the charge of the commander, the officer next in command to him and the astronomer of each sloop. Instructions to Wales required him to test the rate of these chronometers (John Kendall's and John Arnold's, made on Harrison's principle):

> *You are to wind up the Watches Every Day, as soon after the times of Noon as you can conveniently, and compare them together and Set down the respective times, and you are to Note also the times of the Watches when the Sun's Morning & Afternoon altitudes, or the Distances of the Moon from the Sun and fixed Stars, are Observed; and to compute the Longitude resulting from the Comparisons of the watches with the Apparent time of the day inferred from the Morning & Afternoon Altitudes of the sun, and as often as you shall have opportunities, you are to Compare one of the said Watches with one of those which may be under the care of Mr. Bayly in the other Sloop, and Note down the respective times Shewn by the said watches.* [Beaglehole (1969) Vol 2, p.725]

The expedition carried twelve copies of the *Nautical Almanac* for the years 1772, 1773, 1774 and such as was printed for 1775:

> *You are every day, if the Weather will admit, to observe Meridian altitudes of the Sun for finding the Latitude & also other altitudes of the Sun both in the Morning & Afternoon, at a distance from Noon, with the time between measured with a Watch and the Sun's bearing by the Azimuth Compass at the 1st Observation in order to determine the Apparent time of the Day and Latitude in case the Sun should be clouded at Noon; You are moreover to Observe distances of the moon from the Sun & fixed Stars with Hadley's sextants from which you are to compute the longitude by the Nautical Almanac.*

The astronomers had requested that they be furnished with a movable observatory. A model designed by Bayly was chosen and wherever possible the astronomers set up shore-based observatories to carry out checks on their instruments. After a voyage of over three years, the error of the Kendall-Harrison timekeeper on arrival at Portsmouth was less than 17 minutes of arc of longitude. The value of the astronomers' observations for navigation was recognised by the Board of Longitude, which published their *Astronomical Observations* in 1777.

Probing the Ocean Depths

Knowledge of the subsurface waters of the open oceans was also advanced by experimentation on the *Resolution* and the *Adventure***.** This was an expansion of experimentation which had begun in the enclosed waters of the Mediterranean Sea. At the turn of the eighteenth century a series of experiments had been conducted by an Italian Count, Luigi-Ferdinando Marsigli, to compare the temperature and salinity of the lower levels of the Gulf of Lyons with that of the surface. His conclusions were included in his regional study, the *Histoire Physique de la Mer* (1725), the first book devoted entirely to marine science. We shall be referring to his findings later.

In the same era in England, the ingenious Stephen Hales, Rector of Teddington, devised not only a sounding machine for coastal waters but also, more successfully, a device for sampling deep-ocean water and measuring the temperature. It consisted of a covered bucket with a Fahrenheit thermometer fastened in it. The bucket was fitted with valves top and bottom which allowed a sample from a deep layer to be brought to the surface. In 1751, on Hales's behalf, Henry Ellis, Captain of the *Earl of Halifax,* lowered the bucket to a variety of depths in tropical waters at 25°N, off the coast of Africa. Ellis reported an amazing decrease in temperature with depth. Although at the surface the water was 84°F (29°C), at a depth of 5,346 ft (1630m) it was only 53°F (11.6°C), a decrease of 31°F. He also experimented with the hydrometer and found that the water grew more salt with depth.

Such measurements as these were prompted purely by scientific curiosity. They were of no practical value for navigation. Although, as if to reinforce the possibility of the unforeseen utility of scientific investigation, Captain Ellis reported jubilantly that the cool water which could be drawn from the depths proved useful for refreshing baths in the tropical heat and as a means of cooling their wine or water [Deacon (1971) p.183].

It is not surprising then to find, in the new spirit of inquiry alive in Europe, that the instructions for Cook's 1772-76 voyage in the *Resolution* and the *Adventure* included: ''Experiments of the saltness of the Sea and the degree of Cold . . . at great Depths'. Nine such measurements were made in the Atlantic and the Southern Ocean in the early stages of the voyage by Wales and Bayly at depths of around 600ft (100 fathoms). The naturalist on board the *Resolution*, Johann Reinhold Forster, also participated in the experiment. A Fahrenheit thermometer was enclosed in a protective container fitted with valves which was lowered from the side of a boat and left down fifteen to thirty minutes to allow the thermometer to take on the temperature of the surrounding water. The retrieval time for the first experiment, according to Forster, but refuted by Wales, was an over-long twenty-seven minutes. For subsequent experiments the time was reduced to six or seven minutes to minimise heat transfer during the passage of the thermometer to the surface. Although limited in number and depth, the measurements covered a range of latitudes. One was taken very close to the equator, one in the tropics, another about the latitude of Cape Town and others in high southern latitudes. Those in tropical or temperate regions showed a decrease in temperature with depth, as had been observed by Captain Ellis, but the measurements in the icy Southern Ocean surprisingly revealed a small increase in temperature below the surface layer of cold, relatively fresh water. This phenomenon was soon to be observed by scientific investigations in the Arctic Ocean also. When ice forms from sea water in winter the salt is excluded causing the ice to be non-saline. When this melts in summer, the fresh water forms an overlay of lighter, less saline water which floats on the more saline water. Water density depends on both temperature and salinity and so the cold fresh water can float on top of the warmer saline water below. As a result a slight increase in temperature with depth is a feature of high-latitude seas.

Cook's temperature-cast near the equator showed a sharp decrease in temperature with depth. It was not long before scientists were speculating about the origin of this cold water so close to the surface at the equator, water colder than the atmosphere above. The next documented subsurface measurements in equatorial waters were obtained on the Baudin expedition to *terres australes,* at the opening of the nineteenth century (see chapter two), and as observations such as these multiplied with the advance of the century, a theory that there must be a deep flow of polar water towards the equator gained strength and awaited onfirmation.

'A litigious, quarrelsome fellow'

The cramped quarters and rigorous conditions on board the sailing vessels which explored the distant oceans provided ample opportunity for stress and dissension among the crew. On board the *Resolution* the relations between William Wales, the astronomer, and Johann Forster, the chief naturalist, deteriorated to a very low ebb. Wales refused Forster access to scientific data he desired to record, claiming the measurements to be the exclusive property of the Board of Longitude. On their return, they engaged in an exchange of acrimonious debate in print.

The presence of the well-read, multi-talented but censorious German philosopher on the British scientific voyage did prove to be somewhat of a problem. Forster, shown in Figure 1.4, was appointed to this expedition in the last weeks of planning, only after Joseph Banks withdrew his support from the venture, and he proved a difficult member of the party. In the negotiations for his last-minute addition to the expedition, King George III made a grant for his equipment, which the naturalist saw as a personal appointment by royalty, freeing him from subordination to the orders of the expedition's commander. He had no written instructions and received a payment of £4000 for the three- year voyage, some of which he used to buy equipment and to support the assistance of his artist son, George, and of a Swedish naturalist, Anders Sparrman, who came on board at Cape Town. The amount seems quite generous. James Cook, who had now risen to the rank of Commander, received, it is worth noting, six shillings a day (£110 a year) as his naval pay.

Forster’s suspicious and dogmatic ways were not popular with Cook or his astronomers, according by Beaglehole. Perhaps his foreign accent did not help his social relations, but there had been other personnel of foreign extraction on British ships who did not inspire such dislike. Forster felt himself to be 'the object of envy'. His feelings are revealed in a personal journal: 'They hinder me in the pursuit of Natural History, where they can, from base and mean, dirty principles'. Most of the acrimony between the German naturalist and the English astronomer was occasioned by the scientific work, including the depth measurements of temperature. There was disputation about the 'ownership of' or responsibility for the results of the experiments. On the Continent the credit for the subsurface measurements was generally accorded to the two Forsters, as a result of the younger Forster's publication of an account of the voyage, in which the experimentation was mentioned but not ascribed specifically to anyone. Wales claimed the experimentation was entirely his work and in a polemical exchange with George Forster denigrated the senior Forster's scientific competence. It is now clear, with the publication [Hoare (1982)] of the elder Forster's journal that Forster had indeed participated in the work and carried out some measurements with equipment of his own devising. These early subsurface ocean temperatures are reviewed in Jones and Jones (1989A).

1.4
Johann Reinhold Forster, naturalist with James Cook on the voyage of the* Resolution *and* Adventure *1772 – 1775

At the conclusion of the voyage there was dissension also about the rights to authorship of the official account of the expedition and its findings. There was great interest in accounts of voyages of discovery. Forster had hoped, as chief naturalist, to write the narrative of this voyage on his return, but the Admiralty, who favoured authorship by Cook, required that his contribution should cover only the natural history and moreover that Forster's submissions be edited. Forster, who by now had managed to antagonise most of those associated with the expedition, refused to submit to what he saw as an indignity ‘to have my performance treated like a theme of a School-boy'. He feared 'the ignominy which must have followed', had he published in his own name, 'the frittered remnants' of his manuscripts, after they had been altered by the editor [Hoare (1976)].

Forster refused to compromise. His son George, from his father's journals, produced a narrative which he published first in English in 1777 and then in German. It gained wide readership, especially on the Continent. Alexander von Humbolt acknowledges the inspiration he received from the account. The elder Forster had to content himself with writing up his scientific and philosophical observations only, and publishing them, at his own expense, to little financial gain, as *Observations made during a Voyage round the World, on Physical Geography, Natural History, and Ethic Philosophy* (1778). This thoughtful publication, a systematisation of knowledge, disproved William Wales's accusation of scientific incompetence. It included a section on the science of the ocean, *Remarks on the Water and the Oceans*, which discussed water salinity, the temperature of the seas and the formation of sea-ice. The latter topic was a matter of contemporary interest and discussion. It was commonly argued that sea-ice must have originated from the fresh water of the estuaries of rivers. From his own observations on the Antarctic voyage and the experiments of the physicist Edward Nairne, Forster argued correctly that ice could indeed form from sea water.

The route of the *Resolution* brought Cook again to New Zealand and the South Pacific, but not again to Australia. Speculation about the possibility of Van Diemen's Land being separate from the mainland, which dated from Cook's charting of the coast north of Point Hicks in 1770, was however tested by his colleague, Captain Furneaux, in the *Adventure*. After some time spent in Adventure Bay, Tasmania, Furneaux made an attempt to discover, in passing, whether the coastline was continuous, but reached the wrong conclusion: He decided 'that there is no Streights between New Holland and Van Diemen's land, but a very deep bay'. However, observation of the strong current and swell from the west had convinced his astronomer William Bayly otherwise who noted in his journal (17 of March, 1773): 'It seems very evident that this is the mouth of a strait which separates New Holland from Van Diemen's land' [Beaglehole (1969)].

The existence of Bass Strait was not established until 1798-99, by the voyage of Matthew Flinders and George Bass in the *Norfolk.* Another navigator, however, whose observations of ocean behaviour prompted the suggestion that such a strait existed was Bruni d'Entrecasteaux, coasting the southern shores of New Holland in 1793, of whom we shall speak later.

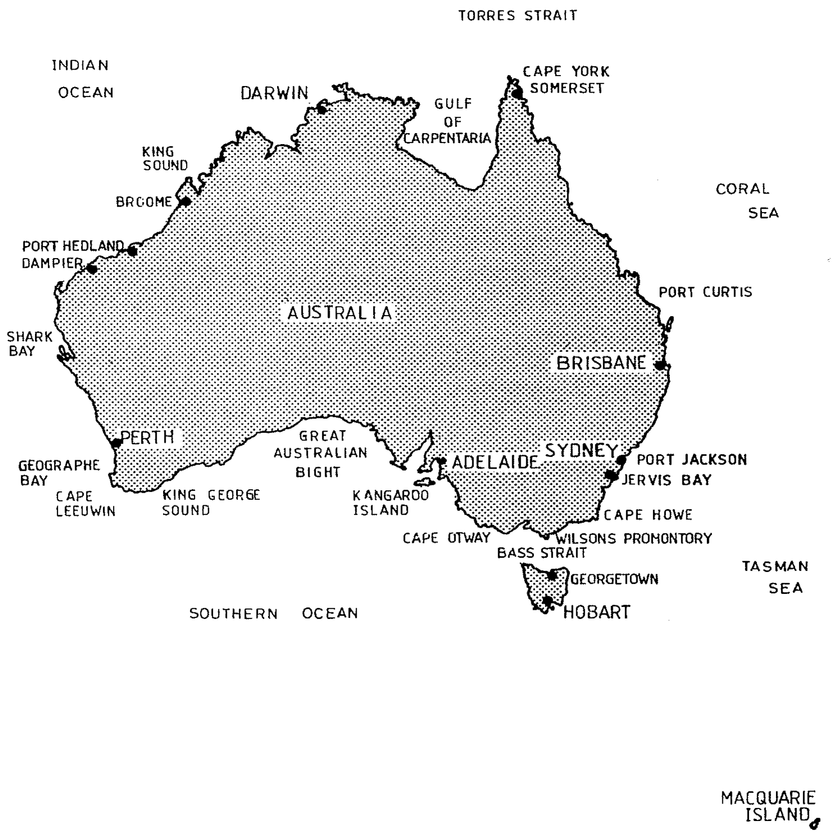
Measuring the Surface Temperature of the Sea

For Cook's third world-voyage in the *Resolution* and *Discovery* 1776-80, the British Admiralty instituted an oceanographic practice which, continued into the next century, was to provide a great mass of data for the study of the surface waters of the oceans. The ships' officers were given the task of recording regularly the temperature of the sea surface. Such systematic measurements, a fairly recent practice, had been pursued several times a day by Alexander Dalrymple in 1775 on a voyage to East Indies, and by Benjamin Franklin on his voyages between America and England in 1775 and 1776. It was seen that such observations of temperature could be a navigational aid by defining the boundaries of currents such as the warm Gulf Stream in the North Atlantic. On board the *Resolution* and the *Discovery* the surface temperatures were recorded regularly, but only as far as Cape Town. Why the practice was discontinued thereafter is not clear.

The main branch of the Kuroshio was first noted by the Europeans in 1779 on Cook's third voyage of exploration into the Pacific when Captains James King and John Gore in the *Discovery* and the *Resolution*, recorded its effect upon their daily reckoning as they sailed south from Kamchatka along the eastern coast of Japan. Although Cook had met a violent death earlier in the year at the Hawaiian Islands, the expedition had continued with the exploration of the Bering Sea in search of a north west passage to the Atlantic.

The British Settlement Established at Port Jackson, 1788

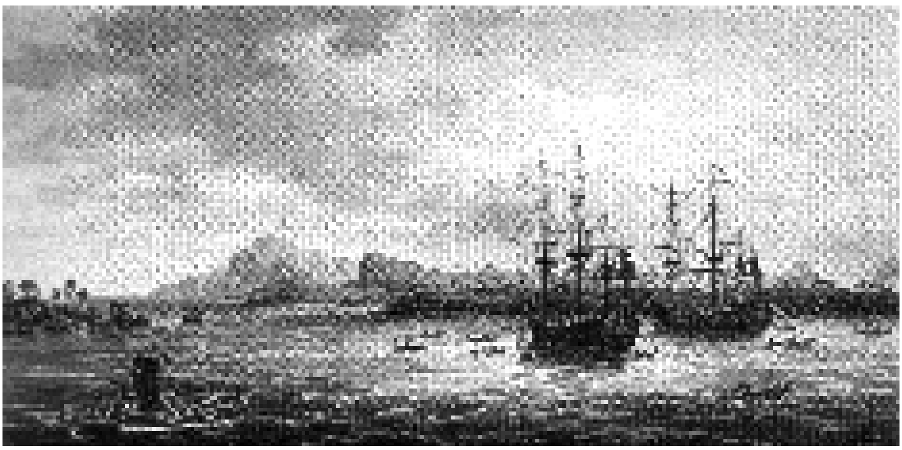
In 1788 the British Government, for reasons that are now considered to have been strategic as well as expedient, established an isolated convict settlement on the eastern coastline of all that remained of the long-sought elusive great Southland, *Terra Australis Incognita*. On the outward voyage of the First Fleet, systematic daily measurements of atmospheric temperatures were recorded by J. White (1790), but time was not devoted to collecting sea-surface temperatures. The voyage of the First Fleet was not, in any sense, a scientific voyage. It had the very practical aim of conveying some 750 convicts, with 200 marines to guard them, and the supplies for founding a distant colony. This settlement was so remote and established in such an unfamiliar environment, that it was only with great difficulty that it survived the privations of its early years. Its presence in the South Pacific occasioned the traversing of the oceans adjacent to Australia by more nineteenth-century scientific voyages of discovery than would otherwise have been the case.



1.5
Coastal locations of Australia

The Scientific Voyage of Malaspina, 1789-1794, Goes Unreported

In 1789, the Spanish court under Carlos IV financed an extensive voyage of discovery into the Pacific. The aim of this expedition was no longer merely geographic discovery for commercial advantage or colonisation. The search for *Terra Australis Incognita* was over. This was to be a voyage for science, for which two 350 ton frigates had been specially built at Cadiz. It was to combine an intensive hydrographic survey of the coastlines of South America with fact-gathering about conditions in the Spanish colonies. Both ships were especially manned and equipped to collect scientific data of current interest on the natural and physical sciences in such a way as to satisfy the requirements of the new enthusiasm for measuring and recording.



1.6
The Spanish ships Descubierta and Atrevida that carried Malaspina's expedition to the South Seas 1789-1794.

There was now considerable national prestige in scientific discoveries. The popular interest in the scientific voyages of James Cook's marked the new attitude of the European people. The French had undertaken the advancement of natural science by including naturalists and artists on the global voyage of the Comte de Lapérouse. The Spanish court had lately become more focused on the value of science. Carlos III had established the botanical gardens of Madrid.He supported the societies devoted to improvements in secular education, the *Amigos del Pais.* An institute of scientific research was established in Bogota to study the flora of the South American continent.

The expedition despatched from Cadiz in July 1789 was equipped with the latest instrumentation for measuring and recording astronomical and meteorological conditions at sea. An important acquisition was an Arnold chronometer purchased in London. This would allow the Spanish greater accuracy in the determination of location than was previously possible with astronomical measurements only.

1.7
Alessandro Malaspina, commander of the ambitious Spanish scientific voyage into the Pacific of 1789-1794. On his return to Spain he was imprisoned for seven years and his journals were not published until 1885.

The voyage had been suggested by its commander, Alessandro Malaspina (Figure 1.7) a 35-year-old, Italian-born career-officer in the Spanish navy who had previously circumnavigated the globe in 1784 in command of a Spanish frigate, *Astrea.* Malaspina was the product of a liberal education which included the study of the works of scientists and philosophers of the preceding century, such as Galileo Galilei and Isaac Newton. He intended to study the political and economic conditions in the Spanish colonies and for his personal library on board he included the works of Thomas Jefferson, and Adam Smith.

During the preceding century Isaac Newton had explained the universal gravitational force which accounted for the movement of the moon and the planets and had devised the equation for the behaviour of this invisible force. The gravitational force of the earth could be measured by the swinging pendulum. As a result there was, at this time, a major interest in studying the earth's gravitational field to aid theories about the shape of the globe. This topic became a major feature of Malaspina's inquiries. If, as was suspected, the earth was not a perfect sphere but rather squashed at the poles this would be reflected in variations in the gravitational pull at different points on its surface. The force of gravity increases slightly as the radius of the earth decreases. The period of the pendulum (the time for one swing) increases with the value of gravity and experiments with the pendulum were planned for a variety of shore locations as widely dispersed as possible.

The expedition carried scientific passports or letters of introduction from the English and French governments and the learned societies of both countries had contributed some scientific instruments. An economic object was to report on the condition of the Spanish possessions in the Pacific and to survey the best routes and ports for navigation. The corvettes *Descubierta (Discovery)* and *Atrevida (Undaunted)* were ready to sail in July 1789. The two ships carried naturalists, illustrators and engravers, as well as a complement of 86 men and 16 officers. The scientific components of the voyages of James Cook for England and the Comte de Laperouse for France were models for the planned schedules.

The Spanish corvettes called first at Montevideo and surveyed the Rio de la Plata where Magellan had once hoped to find a passage through South America. Then they rounded Cape Horn, and moved slowly northwards surveying along the Pacific coast as far as Mexico. Here they received an additional royal order to investigate a report of a possible sea route through North America to the Atlantic. The claim had been made by a mapmaker in a paper to the Academy of Sciences in Paris that such a passage had been travelled in 1588. The possibility of this being true was deemed worth investigating. This project led them further north to Alaska but, of course, no such passage way was found. Malaspina commented that mapmakers were too prone to theoretical geography and should wait for authentification before publishing.

Then, after a sojourn at the Philippines, which produced detailed charts of this extensive island group, the expedition sailed south to visit the west coast of the south island of New Zealand. This was an area where the coast was deeply indented by fiords. It had been visited twice by Cook, who on the second visit, spent several weeks in the inlet he called Dusky Sound. Malaspina’s main aim was to produce a measurement of the gravitational force but he also investigated and charted an adjoining fiord, Doubtfull Sound. There was at this time no European settlement in New Zealand but Malaspina’s report of the surroundings of the anchorage was not promising for this prospect.

Next the two corvettes sailed across the Tasman Sea to reach the British convict settlement at Sydney, in March 1793. This outpost of British power was then only five years old. During their month's sojourn in Port Jackson, the Spanish set up an observatory on the harbour foreshore at Bennelong Point for astronomical observations and for experiments with the pendulum. This was the first scientific expedition to visit the British settlement. The naturalists and illustrators were busy recording the unique fauna and flora of this newly discovered but ancient continent. Malaspina was appraising the success of the settlement.

In April the Spanish recrossed the Tasman Sea and skirted the North Island of New Zealand en route again for Callao and their colonies in South America. Rounding Cape Horn again, they arrived back in Cadiz in September 1794.

Such a well-planned, extensive expedition should have added lustre to the Spanish crown but its effect on contemporary science was minimal. There were plans to publish the charts, journals and drawings and Malaspina was working on the project with a Spanish friar when, soon after his return in 1794, he and the collaborating friar were arrested. Alessandro Malaspina was sentenced to ten years imprisonment on an island fortress.

This drastic action has recently been explained by John Kendrick (1999) as a reaction to Malaspina’s “misguided and ultimately futile advocacy of a new form of government and a new administration for Spain and its empire.” There were stirrings for greater autonomy and freer trade in Spain’s American colonies, which Malaspina correctly saw as a prelude to revolt. On his long voyage he had drawn up suggestions for change in the form of his *Axiomas politicos sobre America* which he intended to include in his voyage account. While the expedition had been away in the Pacific ideas of liberty and equality had led to the overthrow of the French monarchy. To the Chief Minister of State Malaspina’s ideas appeared seditious and dangerous for the Spanish monarchy.

It was sixteen years before even the briefest account of Malaspina's voyage was published in Spain, and this was just an outline of the hydrographic work of the expedition, by Fernandez de Navarrete in 1810. Nothing came of the pendulum measurements which had been taken at nearly all of his land stations at a time when this was of considerable interest to geographers, who were puzzling over the degree of ellipticity of the globe.

The botanical collections enriched the *Jardin Botanico* of the natural history museum in Madrid but the maps and documents had been impounded by the Spanish government and work on them was denied. A contemporary comment by the Comte de Fleurieu (1801) of the French Board of Longitude in 1801 expressed the hope that Malaspina's arrest might merely be the result of a court intrigue, and would be short-lived. [In fact he was held for seven years until released by order of Napoleon.] Fleurieu deplored the interruption to the publication of the results of the voyage. Was Spain, he pondered, still jealously guarding from the rest of Europe information about the outside world which was so important for the safety of navigation and the improvement of the lives of mankind?

No references to any oceanographic, gravitational or meteorological observations made on Malaspina's voyage are to be found in the contemporary scientific literature of France or Britain. A diary from the pen of one of his officers, Francisco Javier de Viana, appeared in 1849, and finally, in 1885, almost a century after the return of the expedition, Malaspina's account, edited by Novo Y Colson, was published in Madrid.

Without publication of the findings of the voyage, we look in vain for any impact on contemporary scientific thought of this ambitious Spanish venture. An essential feature of a voyage of scientific discovery was the publication of its observations. In the next century the French government published extensive illustrated reports of their voyages of exploration and research. When Dumont d'Urville returned to France in 1840 from his voyages in Oceania and the Antarctic they issued a handsome set of reports in the form of 14 volumes of text and 5 illustrated atlases - such was the value placed upon the work of their mariner-scientists. There was national and personal prestige to he gained from the publication of geographic discoveries.

2

In the Wake of Lapérouse

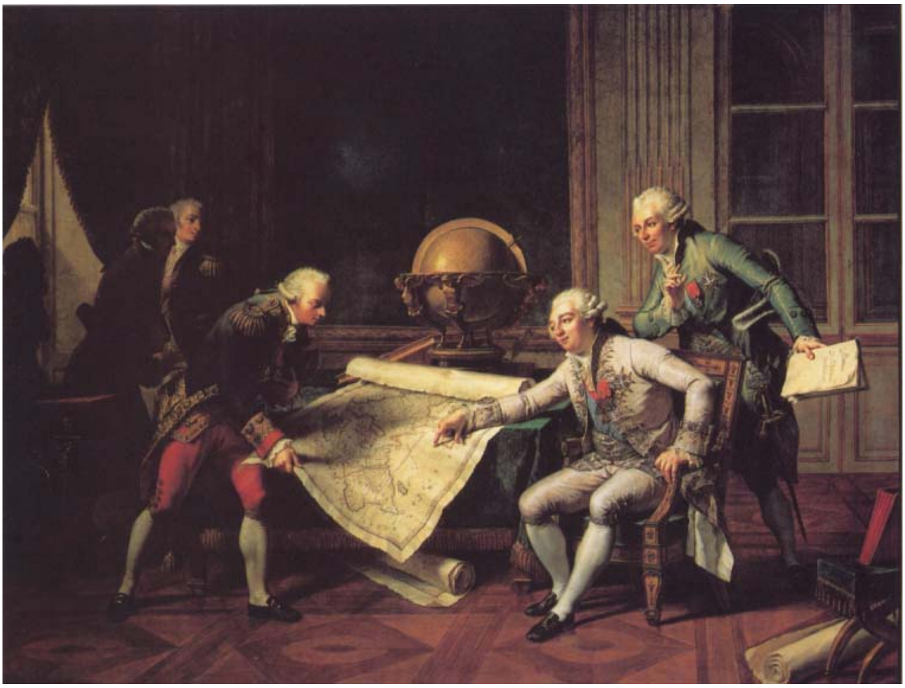
At every port or bay we entered, more especially after passing Cape Capricorn, my first object in landing was to examine the refuse thrown up by the Sea. [If] the French navigator, La Pérouse had been wrecked, as it was thought, somewhere in the neighbourhood of New Caledonia . . . the remnants of his ships were likely to be brought upon the coast by the trade winds, and might indicate the situation of the reef or island which had proved fatal to him.

Matthew Flinders (1814), surveying the Queensland coast of Australia in 1802

The Malaspina expedition had survived the many hazards of global exploration only to return to an unappreciative homeland. The great French scientific expedition led by Lapérouse, which preceded it, had failed to return, to the anguish of its supporters.

High hopes were held for the ambitious French expedition which sailed from Brest in August 1785 under the command of Jean-Francois de Galaup de La Pérouse. It represented that nations answer to the scientific and geographical achievements of their great rival, Britain. The accounts of Cook's voyages were widely read in France, where translations appeared in a very short time. Amongst the enthusiastic followers of these accounts was Louis XVI who succeeded to the French throne in 1774. There had already been five French expeditions into the southern hemisphere but none of them could equal the findings of James Cook. The last, that of the noble-born Yves Joseph de Kerguelen, had made fraudulent claims for which he was brought to trial and spent four years in gaol. French prestige would be enhanced by new geographic and scientific discovery. The idea of a scientific voyage had the support of

Charles Pierre Claret, Comte de Fleurieu, who as *Directeur-général des Ports et Arsenaux*, personally designed the itinerary not only of this but also, later, of the 1801 expedition led by Baudin. The route was planned to cover the North Pacific more extensively than Cook's third voyage, with special attention to the coasts of North America, Siberia and Japan.



2.1
Louis XVI gives his instructions to Lapérouse as the plans are formed for France's great eighteenth-century voyage of science and exploration. The minister for the Navy, Marechal de Castres, stands behind the King. In January 1793, it is said, the King enquired as he awaited execution: 'At least, is there any news of Monsieur de Lapérouse?'

In 1785 two ships, the *Boussole* and the *Astrolabe*, each of 500 tons, were outfitted with the best of equipment and the latest scientific instruments and placed under the command of an experienced naval officer, the Comte de Lapérouse. He chose many of the officers from amongst his well-born friends. Louis XVI took great interest in the planning of the voyage (Figure 2.1). He had some special instructions for the leader of an expedition from an enlightened country:

> *On all occasions, Sieur de Lapérouse will act with great gentleness and humanity towards the different peoples whom he will visit during the course of his voyage. . . His Majesty will consider it as one of the happiest events of the expedition if it should end without costing the life of a single man.*

The *Academie des Sciences* and the *Societe de Medecine* supplied advice and instruction for scientific investigation and there was no lack of volunteers from their numbers to join the prestigious four-year voyage. The expedition carried a strong scientific contingent of six specialists and three draughtsmen. The chaplains also were capable of scientific work. Records requested included regular measurements at all latitudes of sea surface temperature, of the declination (variation) of the compass and of the height of the barometer. Officers were sent to London to acquire precision instruments unavailable in Paris. When it was found difficult to buy the high quality dipping needles needed to measure the variation in intensity of the magnetic field, Sir Joseph Banks, President of the Royal Society, arranged for the English Board of Longitude to present two dipping needles which had been used on James Cook's third voyage. The scientific work pursued on this voyage became the model for that now planned by France.

It was during the Laperouse voyage that Robert Paul de Lamanon, "naturalist, physicist, geologist and meteorologist" was to discover that in the tropics barometric pressure at sea varied regularly throughout the day. He also found that the intensity of the earth's magnetic field is less in the tropics than at the poles. This deduction he made from the period of oscillation of the dipping needle. These measurements were pursued on subsequent French expeditions.

While exploring in the North Pacific, Lapérouse received additional instructions from Fleurieu to investigate the British intentions at Botany Bay in New Holland. He sailed into this bay on 26 January, 1788, just as the First Fleet was preparing to transfer to the better location of Port Jackson. Father Récéveur, the French naturalist and chaplain, died during their stay and was buried on land that is now within the Sydney suburb of La Perouse. The chaplain died of wounds received at the Samoan Islands, where the expedition had lost ten crewmen and the commander of the *Astrolabe* in an attack by the natives. Before he resumed his voyage six weeks later, Lapérouse left letters and reports with Governor Phillip, for despatch to France by the first available ship. The *Boussole* and the *Astrolabe* failed to return home.

The ships had disappeared mysteriously, without a trace. Years later, however, it was still hoped that the officers and men, last heard of at Botany Bay in March 1788, might perhaps be living somewhere on a tropical island. The fate of the gentlemen scientists who had sailed with Lapérouse was of particular concern to the Paris Society of Natural History. At their instigation, the Constituent Assembly of France in 1791 decreed 600,000 livres (francs) for the outfitting of a search expedition under the command of Antoine-Raymond-Joseph de Bruni d'Entrecasteaux, who was raised to the rank of Rear-Admiral when the expedition sailed. Additional money (100,000 livres} was allotted for scientific work to be carried out en route. The idea of the search mission combined with scientific investigation was strongly supported by Comte de Fleurieu, now the Minister of the Navy Department, whose interests were scientific as well as nautical. He had worked on the development of a marine chronometer to the extent of participating in an Atlantic voyage to test Leroy's timepiece.

D'Entrecasteaux's expedition was well equipped for scientific pursuits but its work was sabotaged by the revolution and war. The two armed research ships *Recherche* and *Espérance*, each of 500 tons, had departed from Brest in September 1791.with a combined complement of 222 men and carried between them five naturalists and a gardener-botanist. One naturalist served also as chaplain on the *Recherche.* The *Espérance* carried an astronomer who also served as chaplain. The surgeons and assistant surgeons were capable of scientific work also. Huon de Kermadec commanded the *Espérance*. The chief hydrographer was C. F. Beautemps-Beaupré. In later life he became the founder of a renowned school for training hydrographic engineers. It was an ambitious voyage with great potential. The Minister for the Navy suggested routes which might discover the fate of the *Boussole* and the *Astrolabe.*

Sailing into the southern hemisphere by way of the Cape of Good Hope the French reached Van Diemen's Land in April 1792. They were looking for Adventure Bay, which had been found by Captain Furneaux on Cook's second voyage but by chance they were driven into a sheltered deep-water inlet [D'Entrecasteaux Channel], hitherto uncharted. Here they spent a month in pleasant surroundings. Then they sailed north into the Tasman and Coral seas, making for New Caledonia, the Solomon and Santa Cruz Islands, which Lapérouse had intimated would be his next destination after Botany Bay. However nothing was learned of the fate of their compatriots. There had been a reported sighting of natives wearing French uniforms on the Admiralty islands, which they next visited, but the report proved to be false.

To combat an outbreak of scurvy on board, the French ships now visited the Dutch settlement at Amboina in the East Indies where a month's respite on land and reprovisioning with fresh foods restored many to health. Sailing further west into the Indian Ocean than they would have wished with unfavourable winds and currents the expedition finally returned to the Australian coastline at Cape Leeuwin. They followed the southern coastline of Australia for a while but were disappointed to find no watering places.

By January 1793 the navigators had returned to Adventure Bay in Van Diemen's Land. As their ships approached the island from the northwest, d'Entrecasteaux suspected from the westward set of his vessel that there might be a strait dividing this land and the mainland. He did not take time to explore this possibility even though, politically, this could have left France free to establish a colony on the island and threaten the supply lines to the British settlement at Sydney Cove.

In their month-long second visit to Van Diemen's Land the French were delighted with their friendly encounters with the native people. Beautemps-Beaupre perfected his survey of what is now known as D'Entrecasteaux Channel. It presented a fine site for a settlement should the French wish to challenge the British presence in the southern continent. Refreshed and reprovisioned with ample supplies of salted fish, the expedition continued north east into the Pacific to visit Tonga and New Caledonia and to cruise among the New Hebrides, Santa Cruz and Solomon islands. The commander of the *Esperance*, Huon de Kermadec died soon after leaving New Caledonia. They did not find any trace of Lapérouse's ships in any of the many islands that they visited.

The search for survivors or at least evidence of their fate was abandoned when scurvy again broke out. This time D'Entrecasteaux himself fell victim and he also died at sea. The acting commander was now A. Hesmivy d'Auribeau. With sixty seamen soon suffering form scurvy, he decided to recuperate firstly on Waigeo island and then at the Dutch settlement at Buru. When the party reached Surabaya in October 1793 there were also numerous cases of dysentery on board. By now the news had arrived that France and Holland were at war in Europe and there was some trouble in persuading the Dutch to give them shelter.

There was news also of revolution and civil war at home and of the execution of Louis XVI. Feelings ran high and officers and men divided themselves into two opposing factions, republicans and royalists. In February 1794 d'Auribeau flew the flag of the royalists and had dissenting republican officers and scientists imprisoned. It was impossible to continue the expedition with the crew thus divided. The royalists were now unsure of their fate if they returned to French territory and d'Auribeau struggled to keep control until he too succumbed to dysentery. The expedition broke up completely. The ships were impounded by the Dutch to pay for expenses incurred and surviving members left to find their own way home by any means they could. It was a disastrous end to an ambitious project

Sickness and death played a large part in the disintegration of the d'Entrecasteaux expedition, but some of the troubles can be explained by the unsettled state of the French Navy. Prior to the Revolution, officer progression in the Navy was open only to aristocrats. Young *élèves*, aspiring to officer rank were obliged to give proof of their noble status. The class distinction was emphasised by the colour of the uniform, red for those of noble rank, blue for the others. *Officiers bleus,* with limited chances of promotion in the Royal Navy, served mainly in the merchant service. Some reforms to the rigid class structure were effected in reforms in 1786. Officer rank was to be open to all entrants, but still with some restrictions. In the months before the departure of the *Recherche* and *Espérance* in September 1791 there had been disturbances in the seaports and on the fleets, which led to negotiations for further reforms. They were effected later in the year, but not before the departure of the expedition. The impatience of those anticipating the reforms was the cause of much friction on board and some of the civilian naturalists sympathised with the anxiety of the commoners to be accorded higher status. In the revolutionary ferment of the times, there was ample fuel for dissension amongst the personnel of the expedition. Jacques-Julien Houtou de Labillardière, the doctor and botanist of the *Recherche,* who had strong republican views, was particularly resentful of discipline at the hands of those officers who were of aristocratic birth and he gave leadership to the disaffected at Surabaya Labillardière's extensive collections were confiscated by the Dutch and sent to Britain. Fortunately, because of the good relations which continued to exist between the scientific societies of the warring countries, they were eventually returned to France through the intercession of Sir Joseph Banks. In 1799 Labillardière was able to publish his *Relation du voyage à la recherche de La Pérouse*, which included an album of beautiful engravings of the most important natural history discoveries.

The splendid charts made by the hydrographer Beautemps-Beaupré also fell into the hands of the British. They were being brought back by Lieutenant Rossel on a ship which was seized by a frigate of the British Navy. The British Admiralty had these copied and they were then available for Matthew Flinders when he sailed for New Holland in the *Investigator.* Rossel was not released by the British until after the Peace of Amiens in 1802 and it was not until 1808 that an official account of the voyage was published under his hand.

D'Entrecasteaux's humanitarian mission to discover the fate of Lapérouse and his men had failed. The voyage, although fruitful in accurate charts of Pacific archipelagos, had been very costly in human life. It had resulted in the deaths of three commanders and 84 others.

Shipboard Conditions

The vessels used for exploration in this era were usually of 300-400 tons, carrying a great deal of sail. On voyages of several years' duration, lodging in such a small space the large number of sailors necessary for the heavy work involved in handling the sails could cause very unhygienic conditions. It was especially difficult to keep food from spoiling. Even water eventually turned putrid. Biscuits became infested with grubs and insects; cockroaches multiplied. Labillardière, writing of the conditions on the voyage with d'Entrecasteaux, described the deterioration which overtook their dry food five months after their departure from Brest:

> *From the biscuits the maggots soon spread themselves throughout all the rest of our provisions, and it lasted a considerable time*

> *before we could conquer the disgust which it at first gave us, when we saw them swarming in all our food.* [Labillardiere (1801) Vol 1, p.88]

Salt pork or beef was a staple food for the earlier stages of the voyage, while it kept good. For some variation in diet, livestock (cows, goats, sheep and poultry) were often carried on board, which didn't improve hygiene. They too needed food and water and took up space. Labillardière commented upon the noisome smell coming from between decks when the scurvy-ridden sailors were allowed to take on pigs and poultry for their own use at Amboina. When illness, particularly scurvy, struck, it was believed that some fresh meat was essential for recovery. A gift of fresh fowl or flesh at an hospitable port of call was often reserved for the invalids, of whom on many voyages there were numbers. When the value of fresh fruit and vegetables was realised, experimentation with unfamiliar greens could prove disastrous. It was well known that the young shoots of the palm tree were edible, but it was possible for the wrong species of palm to be harvested. This happened on Dumont d'Urville's expedition in the *Astrolabe*, with fatal results.

In 1809 in France, Nicolas Appert demonstrated a means of preserving food in jars and cans by heat treatment. But such preserves could still be damaged by the great heat of the tropics. Iron bins were introduced by the British instead of wooden casks to store water. Watering places, however, had to be sought at intervals and the risk of hostile natives faced to replenish supplies. Wood for cooking was another resource that had to be renewed. Water was scarce along the barren west coast of New Holland, for instance, and on some voyages to that area apparatus for distilling sea water was carried.

Sailing vessels which carried scientists, civilian or naval, had the added disadvantage of the need to preserve zoological and botanical specimens, the collection of which formed such a large part of the agenda of the voyage. Specimens drying in the sun were unpopular with the crew and were often sabotaged or treated with scant respect. Edible creatures, dredged or fished from the sea, were hard to reserve from the hands of the ship's cook, however rare a species they might represent. There is the story, too, of the rare Antarctic species, which was found adhering to the ice on the bows of the *Terror* on the James Clark Ross expedition, which was sketched hastily by the artist, but consumed by the ship's cat before it could be preserved.

If the decks were crowded on these scientific voyages of discovery and encumbered with animal pens and botanists' greenhouses, between decks was also cramped and crowded and ventilation was poor. Cleanliness was difficult when water was scarce. Sea bathing was resorted to in the tropics and for sailors who could not swim, a ship's sail looped to a spar could serve both for recreation and bathing.

2.2
Even though in this era most sailors could not swim, recreation in tropical waters could be provided by a spar and attached sail.

Recruitment of sailors to serve on distant voyages was often difficult and there were always desertions to be countered at ports of call. Sometimes those suffering with scurvy, fever or dysentery had to be left in stopping places en route, to make their way home, if they recovered, by whatever means they could.

Marine Science at the Turn of the Nineteenth Century

At the start of the nineteenth century the science of astronomical navigation was now well advanced and expeditions were furnished with precise instruments. Other aspects of marine science however were still in their infancy. There were many questions of physical geography exercising the minds of the curious. Observations of the Trade Winds had been made by William Dampier and Edmund Halley, and Halley's explanation of these important winds had been enlarged upon by another Englishman, George Hadley, in1735. There had been some examination of the salinity of sea-water and its chemical composition. Collections of shallow-water animals were popular with gentlemen naturalists. Although there was acquired knowledge of some of the ocean currents encountered along trade routes, the general circulation of the oceans was still unclear. Greater knowledge was needed of the surface ocean currents for the benefit of navigation. The collection of information on oceanic winds and currents and the temperature of sea waters was seen to be useful. Thought was being given to the movement of subsurface waters, but, without government-funded voyages of exploration, those curious about the physical properties of the oceans, had little prospect of obtaining marine observations on which generalisations could be based. In France, at the turn of the century, Napoleon's territorial aspirations provided an opportunity.

Napoleon’s expedition for discovery and science, 1800-1804

The British had laid claim only to the eastern half of Australia. They called this territory New South Wales**.** The foothold established at Sydney Cove on Port Jackson was at first very precarious and although short exploratory voyages were made along the coast north and south of the settlement, twelve years passed before the British Government organised a complete circumnavigation and survey of the continent. They were not even sure at that time whether New South Wales and New Holland formed the one landmass. It was only in 1799 that Van Diemen's Land was shown to be a separate island. For a complete circumnavigation and survey of the 'continent' Matthew Flinders was sent out from Britain in charge of the *Investigator* in 1801. The interest of the British Admiralty in exploring the Australian coastline was doubtless spurred on by the news of d'Entrecasteaux's discovery of the excellent harbourage in eastern Van Diemen's Land and of the Baudin expedition despatched by the French to the same area in 1800.

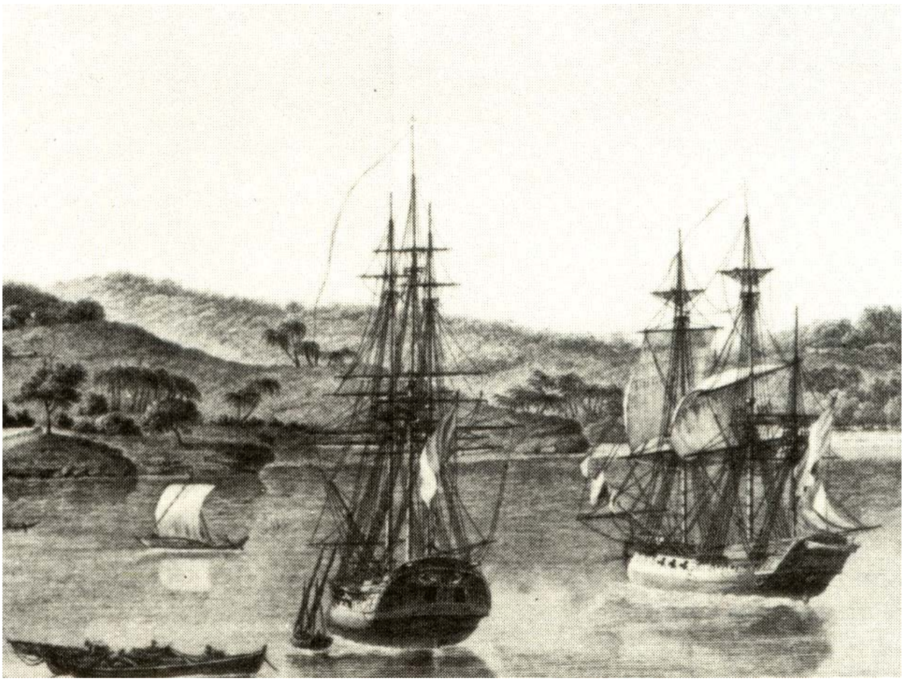
The suggestion of another French expedition into the southern hemisphere came originally from the man who became its leader, Nicolas Baudin. He had already distinguished himself as a collector of specimens for the Paris Natural History Museum on a two-year voyage in the *Belle Angelique* among the islands of the West Indies. The director of the museum, Antoine-Laurent de Jussieu, enthusiastically referred Baudin's proposal of a world-wide scientific expedition to the Minister of the Navy. There was no trouble in gaining the approval of the *Institut National* and of Napoleon Bonaparte, despite the losses sustained by the two previous ventures. Eventually, however, the original scope of the voyage was curtailed to embrace mainly the waters around New Holland.

Napoleon was impressed with the idea of an exploratory voyage to the southern continent. Only the northern and eastern coastlines had been charted and then in no great detail. There was no reason to accept that this newest landmass was the domain of the English alone. The First Consul was also a friend of the sciences, and a member of the newly-formed scientific society, the *Institut National.* One of his particular requests for the expedition about to set out for New Holland was for a representative collection of that country's animals and plants for the Malmaison gardens of his wife Josephine [Horner (1987) p.82].

There were plenty of *savants* eager to participate. The Committee of the Institute, set up to recommend the appointments had no difficulty in filling the positions they decided upon. The two ships on departure carried between them two astronomers, three botanists, five zoologists, two mineralogists, three artists, five horticulturists, and two geographer-hydrographers. The number far exceeded the scientific corps that had embarked with Lapérouse or d'Entrecasteaux. No one was titled 'oceanographer', but one of the five zoologists, François Péron, became, amongst the many roles he filled, a pioneer in oceanography.

This grand expedition with Nicolas Baudin in command sailed from Le Havre in October 1800 with an itinerary planned by Fleurieu expressly to explore 'the south-west, west, north-west and north coasts of New Holland'. The two ships fitted out were the *Géographe,* a 30-gun corvette of 350 tons and the *Naturaliste*, a slightly smaller vessel. Captain of the

Naturaliste was Emmanuel Hamelin. On board the *Géographe* as a midshipman was a future commander of a later Pacific expedition, Hyacinthe de Bougainville, son of the distinguished eighteenth-century explorer, Louis Antoine de Bougainville, who was now a member of the *Institut National.* The names of two sub-lieutenants are worth noting: Henri de Freycinet and his younger brother, Louis de Freycinet. The latter was to become joint-historian of the present voyage and leader of the next major scientific voyage to the same region.



2.3
***The* Géographe *and* Naturaliste*, the two ships sent out by Napoleon to chart the Australian coastline and study all facets of natural science. The ships were drawn by Lesueur. Taken from Péron (1807)* Voyage de découvertes aux terres australes.**

Much detailed planning had gone into the preparations before the *Géographe* and the *Naturaliste* sailed:

> *Our numerous instruments, astronomical, surgical, meteorological and geographical had been constructed by the most celebrated artists of the capital . . . A numerous library, composed of the best*

> *works on marine subjects, astronomy, geography, natural history, botany and voyages were collected for each ship. All the instructions relative to scientific researches were written and prepared by a committee of the Institute consisting of MM. Fleurieu, Lacépède, Laplace, Bougainville, Cuvier, Jussieu, Lelièvre, Camus and Langles, which is sufficient to prove how complete and valuable our instructions must have been.* [Péron (1809) p.14]

The civilian scientists who sailed with Baudin were, with one exception, all young men. Without the conditioning of naval discipline they were to prove disrespectful and troublesome to their autocratic 46-year old commander. The rigours of a long voyage, which did not go according to plan, were to take a heavy toll. At the conclusion of the report made to the French Government by the National Institute there is mention of the

> *lamentable catalogue of disasters which happened to the gentlemen who accompanied the expedition. OUT OF TWENTY -THREE PERSONS RECOMMENDED BY YOU TO THE FIRST CONSUL, ONLY THREE HAVE RETURNED TO THEIR COUNTRY, after performing the entire voyage. Some of them, being soon disgusted with their employment, were landed and left at various places - but the rest are no more!* [Péron (1809) p.8]

The expedition leader, Nicolas Baudin, also did not survive the voyage.

François Péron and his Study of Sea Temperatures

Clearly the outstanding scientific figure of the Baudin expedition was François Péron, who survived to become the official historian of the voyage. As a young man of twenty-two, he had joined the expedition at the last moment and occupied, as he said, 'fifth place of zoologists'.As two of these zoologists left the group at Ile-de-France and two others were taken ill at Timor and subsequently died, Péron showed remarkable stamina and zeal to complete, with Charles Lesueur, assistant gunner and artist, the valuable collection of the more than one hundred thousand zoological specimens mentioned in the report of the National Institute. As a result of this collection and his memoirs on a variety of scientific topics, Péron was enrolled as a member of the Institute. One of these memoirs has a notable place in the history of oceanography.

2.4
François Péron, drawn shortly before his death in 1810, by his artist friend and collaborator, Charles-Alexandre Lesueur. Péron made the science of the sea his study on the Baudin expedition to 'terres australes', 1800-1804. The chart on his desk depicts the first complete map of Australia. From Péron and Freycinet (1816)

A Memoir on the Temperature of the Sea

Péron's *Memoir on the Temperature of the Sea at its Surface and at Great Depths* was based on a regular comparison of the sea-surface and the atmospheric temperatures. which he had made systematically at six-hour intervals. These he had averaged each month and passed to the commander for inclusion in his *journal de mer.* The memoir presented to the Institute was included in Volume Two of the *Voyage de découvertes aux terres australes* [Péron and Freycinet (1816) p.323]. Its subject was a relatively new aspect of science. In the closing years of the eighteenth century some interest had been taken in observing the temperature of the sea surface, particularly on voyages across the North Atlantic where the warmer waters of the Gulf Stream had been subject to some scrutiny. Péron, who had just graduated from his medical studies at the Paris *Ecole de Santé,* had also attended many courses at the National History Museum and had attracted the attention of his professors for his enthusiastic pursuit of a wide range of scientific disciplines. Among his mentors were the botanist Jussieu, Director of the Museum, and the zoologists, Lacépède, Lamarck and Cuvier. It was Lamarck's contention, that the study of natural history should also entail observation of the environment in which creatures were found. The eager young scientist saw an opportunity, on the long months that would be spent at sea, for a study, in line with Lamarck's teachings, of the marine environment. Thus inspired, he was to be seen at regular intervals en route to New Holland busy with the thermometer, the hygrometer and the barometer, and on the few occasions when such activity fitted in with the routine of the voyage, he also experimented to measure the temperature of the deep ocean.

The systematic observations Péron had made on the voyage enabled him to formulate some general conclusions about the comparative temperature of the sea surface and the atmosphere above it:

> 1. *The temperature of the waters of the sea is generally less at midday than that of the atmosphere in the shade at the same hour.*
>
> 2. *It is constantly greater at midnight.*

3. Morning and evening the temperatures are generally more or less equal.

> *4. The average of a data set of observations comparing the temperature of the atmosphere and that of the sea surface taken four times a day, at 6 a.m., midday, 6 p.m., and midnight in the same latitude, is constantly greater for the sea water at each latitude that the observations were made; at least I have not seen any exception to this rule from 49°N to 45°S.*

While the first three points were reasonable generalisations, there are, in fact, many cold currents, not encountered on this voyage, in which the water, on the average, is colder than the atmosphere.

The conclusion that the average temperature of the sea was higher than that of the air above it seemed not to have surprised the *Géographe's* commander. Comments in his journal show him to have been rather sceptical of the value of the task to which the young scientist was dedicating himself:

> *From the note that citizen Péron gave me on his observations concerning the temperature of sea-water, it appears that he would never have suspected that it must be warmer than that of the atmosphere. Yet the many experiments that have been carried out on this point should have convinced him of the validity of this fact, although the reason is perhaps unknown. Nevertheless, as he is not convinced of it yet, he is waiting until he has collected a greater number of observations before accepting a truth which, to him, is still most uncertain, although not to anyone else.* [Baudin (1974) p.42]

Early in the voyage the activities of his scientific passengers and their reaction to the life at sea provided some amusement for Baudin:

> *Before midday we had two quite different diversions. The first arose from the sight of some flying fish. The scientists, no doubt seeing them for the first time, were so amazed by them, that each time the wash of the ship brought one out of the water, the person who saw it first became an object of respect for all the others; and the direction and extent of its leap gave rise*

> *to a scientific discussion which ended, without deciding anything, only when everyone's attention was caught by the sight of another fish.*
>
> *The second, disagreeable as it was for Citizen Péron, nevertheless did not fail to delight all his scientific friends and most of the officers who witnessed it. Towards midday he was in the port head taking readings on a thermometer. A wave washed right over him and carried away his observation book as well as his thermometer. This accident, caused by the very heavy seas, did him no apparent harm, but he thought he was drowned beyond hope. So when the water which had entered the head ran out again, he was quite amazed not only to find himself alive, but still in the same place, for he had thought himself washed right out to sea.* [Baudin (1974) p.37]

Monthly summaries of Péron's averaged readings are to be found in Baudin's journal up to the time of the arrival of the *Géographe* at New Holland but in the published account no tables of sea-surface temperatures were included. Such tables became common in the publications from expeditions of later decades. Péron died December 1810, aged 35 years, with only the first volume completed of the official account of the voyage. The manuscript of his marine data has not, to date, been found in the French archives. Péron's personal papers went to his artist friend and collaborator, Charles Lesueur.

Péron's generalisations about the inter-relationship between the sea and the atmospheric temperatures, given above, were for locations far from land. For waters close to shore he concluded that:

> *1. All other things being equal, the temperature of the water at the bottom of the sea along coastlines near a large land mass is greater, at the same depth, than that in the open ocean.*
>
> *2. The temperature of the sea seems to increase the closer one approaches continents or large islands.*

We now know that, on coasts where the winds are appropriate, coastal water can be colder than at the same depth in the open ocean. In these coastal locations upwelling from the depths can bring colder water to the surface. Such water, incidentally, can be nutrient rich and often supports coastal fisheries. Both the generalisations above may have been reached by Péron because, along both the east and the west coast of Australia, flow warm currents - the East Australian Current and the Leeuwin Current.

Ten Scientists Abandon the Voyage

When, five months after their departure from Le Havre. the expedition reached Ile-de-France (Mauritius) in the Indian Ocean, well behind schedule, there were large-scale desertions on the part of the crew. Some of the officers and ten of the civilian scientists as well decided not to continue. In his account of the voyage Péron attributed the blame to the commander. The participants were, he said, 'wearied by the ill usage they had experienced' at his hands or 'justly alarmed for their future'. And yet. it is worth remarking that Nicolas Baudin had had considerable experience in charge of scientific voyages. He had made three previous voyages to distant lands specifically to collect botanical and zoological specimens. It was his achievements on the latest of his voyages, among the islands of the West Indies, which had so impressed Jussieu, the Director of the Paris Natural History Museum. Three of the scientific collectors from this voyage had volunteered to sail with him to New Holland. They did not decide to abandon the expedition at Ile-de-France. It may well have been the flagging enthusiasm of some of the civilian experts, faced with the prospect of further rigorous and uncomfortable, possibly dangerous months, even years, at sea, that contributed to their change of purpose. Péron reported criticism of the route Baudin had taken through the Atlantic, a route by which they were delayed seventeen days in the equatorial doldrums. He claimed that a more westerly passage would have been speedier and yet, as Frank Horner Frank Horner 1987 [p93-96] has pointed out, the route followed and the time taken was similar to that of other experienced navigators of the era, such as Cook, and d'Entrecasteaux.

There had been considerable grumbling also among the naturalists about the quality of the food and liquor available to them. In this they were joined by the officers, some of whom now claimed to be ill and made the island hospital their official residence on land. Baudin claimed he went to enquire after them on several occasions but could never find them on the premises. The reduction in numbers of officers and midshipmen was more serious than the loss of the scientists. It was Baudin's belief that the expedition had set out with too many scientists any way. In his journal he had already written [Baudin (1974) p. 27]:

> *If, on the other hand, attention had been paid to the observations I made likewise on the uselessness of embarking so many scientists for which half the present number would still be too many, then, perhaps, the personalities might have been better suited and I should have had fewer worries.*

At Ile-de France there was little help forthcoming from the officials of the French colony, who, in fear of a British attack from India, showed scant interest in the scientific aims of the expedition. Nicolas Baudin was convinced that they actively encouraged the desertions. He had great difficulty in obtaining any fresh supplies and stayed longer than he had intended in his efforts to provision the ships.

The Comte de Fleurieu, who had drafted the instructions for the voyage, had set out a very precise itinerary, which prescribed a direct passage from the French colony to Van Diemen's Land, allowing the months of April, May and June for the examination of the southern coastline of the Australian continent westward from there. But Baudin was unable to leave Ile-de-France until April 1801. The slow voyage out and the prolonged stay in the French colony had lost him part of what was considered the most favourable sailing season for exploring the cooler latitudes. Baudin was aware of the inadequacy of the supplies he had managed to obtain and decided to head first for the south-western corner of New Holland, *Terre de Leeuwin*, instead of directly for Tasmania, This gave him the option to explore northwards towards Timor from there rather than the southern coastline and the decision so to do meant that Matthew Flinders, who had left England only in July 1801, preceded him in the surveying of the major part of the unexplored south coast. This probably displeased Napoleon and was one of the reasons for a general disparagement of Baudin's achievements in France. In *The French Reconnaissance*, Frank Horner reports the story, recorded by one of Nicolas Baudin's biographers, Audiat, writing in the 1850s, that Bonaparte had declared: 'Baudin did well to die; I would have had him hanged'. True or not, the quoted remark is indicative of the contemporary lack of regard for Nicolas Baudin's management of the voyage.

Temperature at depth

The *Géographe* and *Naturaliste* reached the south-western corner of Australia on 27 May, 1801, near the point now called Cape Naturaliste. While the ships lay-to off the coast, François Péron and a colleague were able to cast the drag-net at regular intervals and bring to the surface a variety of marine life from the continental shelf (a depth of 10-100 fathoms). He was surprised, not only by their phosphorescence, but also by the temperature of the dredged creatures, which he declared to be more than three degrees greater than that of the atmosphere and the surface water. Was it, surmised Francois Péron, an indication that the water at the bottom of the sea was being warmed by heat emanating from the earth's interior, or, perhaps, that this marine life possessed a heat of its own which gave warmth to its habitat? While the *Géographe* hove-to this first night in the coastal waters of New Holland, the opportunity was taken to lower a thermometer, packed in a wooden box, filled with tallow for insulation, and to leave it there, at a depth of 50 fathoms, until morning. The experiment revealed that, at that depth, the water had a temperature of 22.4°C, which was slightly higher than the temperature of the surface water at 21.25°C. (This observation could only have been correct if there were a compensating change in salinity, such that the bottom water was more dense than the surface water. Otherwise convection would have occurred, mixing the two regions.)

Proceeding northward from Cape Naturaliste, with the intention of sailing to Timor for supplies the French expedition now entered a large bay which they named for the *Géographe*. Here, at last, eager landing parties explored the shoreline and a small river and contacted a few of the local aborigines. When stormy weather developed, however, the longboat from the *Géographe* became stranded in the surf, and a large shore party had to wait out the night until they could be rescued the next day. And the rescue party, attempting to regain ship in the heavy seas, lost one member of the crew, a seaman called Vasse, who was swept away and never recovered. If he did struggle ashore, there was little chance for his survival except by the kind assistance of the native people. There was some speculation amongst the French that this might have been his fate. Meanwhile a gathering storm forced both vessels to head for more open water. At this point they became separated and did not meet up again until Timor. Captain Hamelin, in the *Naturaliste,* had taken shelter behind nearby Rottnest Island, but Baudin, in the

Géographe, made straight for Shark Bay, despite the fact that Rottnest Island had been agreed upon as the first rendezvous, should the vessels become separated. He left Shark Bay four days before the *Naturaliste* arrrived there, and three months passed before the expedition was reunited in Timor.

Hamelin spent seven weeks exploring and surveying Shark Bay and searching for the presence or signs of the visit of the *Géographe*. He showed more concern for the fate of his companion vessel than had Baudin, who had left no message on the island on which they had landed. This was Bernier Island at the mouth of Shark Bay where the *Géographe* party set up an observatory and checked their chronometers and astronomical instruments. Here the diet of the crew was greatly improved by the fish, crabs, oysters and clams which abounded.

Such was Péron's excitement at the opportunity at last to explore this strange land, that he twice risked his life by thoughtless behaviour and aroused the commander's ire by his failure to report back to the ship at the appointed time. In the first instance he wandered off on his own to cross Bernier Island, became disorientated by the featureless landscape, and kept a boat party out all night waiting for his return to the shore. Péron was grateful to sub-lieutenant Farcy Picquet for disobeying the commander's curt orders to abandon him and return to the *Géographe* without him. He was convinced this was the reason for Nicolas Baudin's harsh treatment of Picquet later on during the voyage. Baudin's order would strike us as unreasonable today, since there was no prospect of European contact on this distant shore. At Kupang on Timor Baudin found a reason to have the sub-lieutenant arrested and confined in a Dutch prison. On the second occasion, a week later, Péron, exploring again on his own, was dragged across a reef by a wave, and, battered and bleeding, lay for some hours on the shore, too weak to move, again causing anxiety by his late return.

Péron, we have already noted, was to comment on the commander's ill-will towards the scientists and their enthusiasms, but it is clear from Baudin's journal that, at least at the outset of the voyage, when his health was good, he was himself very interested in the natural history collections and quite enchanted by the new creatures and plants that were discovered. One might sympathise with the commander, who, responsible for the safety of his ship and its personnel on uninhabited, uncharted shores, grew impatient, when he perceived that safety endangered by the recklessness of enthusiasts such as Péron.

After some three months spent at Timor, the *Géographe* and the *Naturaliste,* their numbers reduced by twelve deaths, sailed southwards through the Indian Ocean in November 1801 directly for Van Diemen's Land. Here the two ships were again separated while surveying the east coast of the island. Captain Hamelin, after some time spent on detailed surveying in eastern Bass Strait, took the *Naturaliste* north to Port Jackson. Baudin, intending to explore the southern shores of the continent in the *Géographe,* struggled westward through Bass Strait despite the fact that his crew were becoming greatly incapacitated by scurvy and dysentery. He could do little detailed surveying for he had lost touch with a boatload of eight men, surveying on the east coast of Tasmania and amongst them was his hydrographer, Charles-Pierre Boullanger. He had searched for this party for several days and then given up hope of finding them. The overdue boat party was by chance picked up near the islands at the entrance to Banks Strait by Captain Campbell in the English brig *Harrington*, and they even were fortunate enough to soon meet up with Hamelin and the *Naturaliste*.

While sailing westward along the coast of South Australia Baudin met Matthew Flinders in the *Investigator* in the bay east of Kangaroo Island, which has been named Encounter Bay. Through interpreters they discussed their respective discoveries. Unaware of the English explorer's presence in the area, Baudin would have been disappointed to discover that Flinders had already charted the southern coast of the continent eastward of .Cape Leeuwin. This was one of his main objectives. From Encounter Bay, Baudin worked westward for a short time, examining Kangaroo Island and Gulf St Vincent, but against great odds for the *Géographe* had lost ten men since Timor and more than half the crew were now ill and unfit for duty. Supplies were needed desperately from Port Jackson, for which he now sailed, not through Bass Strait but around Van Diemen's Land again.

Respite in Port Jackson

The *Géographe* reached the latitude of Port Jackson now Sydney on June 10, but westerly winds and north-westerly currents made an entry into the port difficult and for more than a week Baudin tacked between Broken Bay to the north and Botany Bay to the south, with only six men per watch fit enough to handle the sails. When they were sighted at the heads, a pilot vessel was sent to meet them, much to the relief, at least of narrator Péron, whose description of their 'universal joy' at the arrival of the Governor's 'powerful reinforcement' has strengthened the picture he probably wished to paint of the piteous condition into which they had been allowed to fall through the poor judgment and mismanagement of their commander.

At Sydney there were fresh vegetables and bread and the facilities of the government tent-hospital available for the crew. Five months were spent restoring them to health. There was a shortage of fresh meat, but Governor King had some of the colony's breeding stock slaughtered for the visitors. Ships' provisions were scarce also, but fortuitously, before the French were ready to sail, an American brig arrived in port with salt beef and pork. The French ships lay at anchor in Port Jackson near Flinders' *Investigator*, and there was friendly contact between the officers of the rival nations. A strong friendship developed between Commander Baudin and Governor King.

With their sick recovered, their ships repaired and stocked with provisions, the Baudin expedition sailed southwards in November 1802. A magnificent collection of 40,000 natural history specimens was packed in 33 large cases on board the *Naturaliste* which, after a brief stay on King Island in Bass Strait, sailed directly for France. On board also was a collection of live animals and birds for Empress Josephine's gardens. Advance news of the expedition thus reached France before the return of the *Géographe*. News also arrived by way of the return home from Ile-de-France of some of the disgruntled naturalists and officers, who had left the expedition before even reaching New Holland. Their reports coloured somewhat the thinking about Nicolas Baudin's management of the expedition.

A smaller vessel, the 30-ton, 29-foot schooner *Casuarina*, had been purchased in Sydney to enable closer examination of the coastline. Louis de Freycinet was placed in command. The two vessels surveyed King and Kangaroo islands at the western entrance to Bass Strait and then the southern and north-western coastline of the continent in greater detail than had been possible the previous year. Freycinet had cause for bitterness when the two ships were separated near Kangaroo Island. It seemed to him that Baudin was careless about the survival of his small party in the *Casuarina,* which then, desperately short of water, made a thirteen-day dash alone for King George's Sound, where fortunately a rendezvous was effected. The incident figured prominently in Péron and Freycinet's narrative of the voyage.

The French expedition called again at Shark Bay and Timor. Ill health again dogged the crew despite, or because of, a month's respite there. Finally, on 7 July, Baudin, himself a sick man, sailed for Ile-de-France (Mauritus), abandoning his plans to survey the Gulf of Carpentaria. His journal ends abruptly two days before he reached that island, where he died of tuberculosis on 16 September. The *Géographe* sailed to France in the charge of Pierre Bernard Milius, who had been second in command of the *Naturaliste*. He had now obtained a passage to Ile-de France after a extended stay at Port Jackson because of ill-health. The *Géographe* arrived home to the port of Lorient in southern Brittany, on 24 March, 1804, after an absence of three and a half years.

Deep Sea Temperatures

The contribution of this expedition to the Natural History Museum of Paris delighted the professors. The contribution to knowledge of marine physics probably attracted less public attention. It was nevertheless of considerable significance for a slowly emerging science of the sea and was often referred to by marine scientists of later decades. Besides the comparative study of sea-surface and atmospheric conditions, zoologist Péron had taken the opportunity to explore the thermometry of the open-ocean depths. He had found this possible on only four occasions, thanks, he claimed, to the ill-will of his commander. The opportunity arose only when they were becalmed in the tropics. It is interesting to note the value Péron saw in his measurements of physical geography for other branches of science:

> *The meteorologist will obtain from them valuable data on atmospheric variations in the middle of the Ocean; they will provide the naturalist with vital knowledge of the habitat of various species of marine animals; the geologist and the physicist will each find information about the spreading of heat in the middle of the seas*

and on the physical state of the interior of the globe, of which the deepest excavations yet seen can scarcely scratch the surface; in a word there is not a single science which cannot with advantage use the results of experiments of this type.

Was there Heat Emanating from the Earth's Centre?

There was speculation among scientists at this time as to whether or not the earth's centre was hot and whether heat was permeating to the bottom layers of the oceans. The heat from volcanic activity on land was the origin of this theorising and also, the comparative warmth already perceived to pervade the bottom layers of the Mediterranean Sea. For in Europe, as early as 1706-07, the Comte de Marsigli, examining the waters of the Golfe du Lion had found there uniform bottom temperatures of 10° Réaumur (12.5°C). Similar results were obtained in the Adriatic Sea by Vitaliano Donati. However, in the 1770s and 1780s, the Swiss *savant*, Horace-Benédict de Saussure, had shown by experimentation over five years that there were, at varied seasons of the year, temperatures as low as 4° to 5°C at the bottom of Alpine lakes, even when surface temperatures reached 20°C in summer or when surface ice formed in winter.

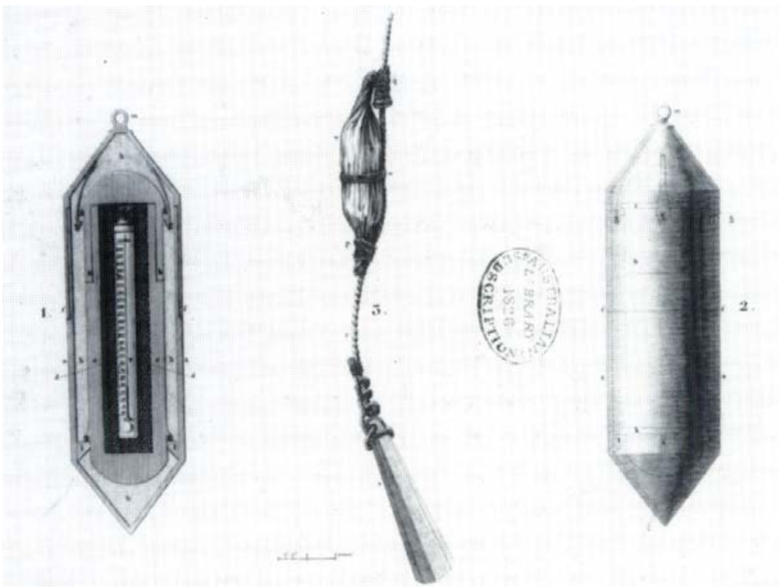
These findings nourished the theories of two rival schools of geological thought as to the interior of the earth. According to one, the earth had a molten centre from which heat constantly permeated and that this it was which kept the lower levels of the Mediterranean Sea at a c onstant temperature, although the surface would be affected by atmospheric conditions. According to a rival school of thought, however, the earth's centre was cold and this theory was supported by Saussure's measurements of 4° or 5°C in the depths of the Swiss lakes. Later, of course, the phenomenon was recognised as emanating from a surprising property of fresh water. While its density mostly increases as its temperature falls, below 4°C water becomes less dense with further decreases in temperature. At 0°C water freezes. Thus the observations in the Swiss lakes were an example of 'convective sinking', whereby surface lake water cools until the temperature of greatest density is reached at approximately 4°C. When the entire lake mixes and water temperatures are uniformly 4°C, the overturning ceases and the bottom water is protected against freezing, even when ice forms on the surface. Why, pondered the eighteenth and nineteenth century scientists, should the water be so much colder in the depths of the Swiss fresh-water lakes than in the Mediterranean Sea? Saussure doubted Marsigli's findings but his own measurement in two places in the Mediterranean, in 1780 revealed very similar temperatures of 13.25°C.

Such were the questions facing physical scientists of the day. Two decades later a French scientist Jean-Baptiste Joseph Fourier correctly deduced from experiments on heat diffusion that the surface temperatures of the globe were not determined from its moltern interior but essentially from solar radiation. François Péron, he tells us, used the stay of the *Géographe* in the waters over the continental shelf along the Western Australian coastline to compare the subsurface temperatures there with those found in the Mediterranean. In these shallow waters, he commented, the temperature was similarly moderate and, he added, different from the measurements hitherto observed in the subsurface waters far from land. In considering causes for the temperature differences between coastal water and open-ocean regions, Péron offered the suggestion, rather strained to our modern view, that, amongst other factors, the animals and plants which covered the bottom of the sea near the shore could themselves possibly contribute to the greater warmth of the bottom layers of coastal waters by the higher temperature which they appeared to possess.

There were not a great number of open-ocean submarine temperature measurements available for consideration in Péron's time. There were those measured in 1749 by the British Captain Henry Ellis, using the apparatus devised by Stephen Hales to bring up a water sample from the ocean depths. The experiment was described in a paper to the Royal Society and sparked speculation among the scientific gentlemen about the origin of water as cool as 11.7°C, discovered beneath tropical seas where the surface water was as warm as 20°-30°C. Since Ellis's time, the curiosity of scientists had been fed by the submarine measurements obtained in the southern hemisphere on Cook's second voyage and those in Arctic waters by Captain Constantine Phipps. The documented experiments, available to Péron, amounted, in all, to a total of only seventeen temperature casts; two by Ellis, six by Cook and nine by Phipps.

Measuring the temperature of the sea at depth.

By Francois Péron's time several methods had been tried to obtain accurate subsurface temperature measurements. In all cases the retrieval time for the water sampler was very significant. It was realised that therein lay the opportunity for heat gain. Péron gave considerable thought to minimising this gain by devising a well-insulated container for his thermometer. As described and illustrated (Figure 2.5) in his memoir, he made use of all the natural insulating materials available to him. A mercury thermometer on an ivory rod was enclosed in a glass cylinder of about three centimetres diameter and placed inside a larger wooden container, with charcoal filling the space between. Outside the wooden container a third covering of metal was recommended, with melted tallow filling the intervening space. A mechanism was devised to open swiftly the lids of these containers and the apparatus was enclosed in a double pouch of tarred canvas and attached to the sounding line. For their first attempts a simplified version of this apparatus had to suffice, the metal cylinder being difficult to construct on board ship.



2.5
The insulated thermometer devised by Péron for deep-sea temperature measurements. It was attached to a sounding line as shown, but the outer case of bronze was not used on the Baudin expedition. Reproduced from Péron and Freycinet (1816) **Voyage de découvertes aux terres australes.**

The concept employed by Péron was to allow the thermometer, with all its insulation, to come to the temperature of the surrounding water and then quickly to raise the apparatus to the surface before the thermometer, at the centre of the insulator, could change significantly. The time that his thermometer could be left submerged in the first experiment was only five minutes, which was all, he complained, the commander would permit. Thereafter he took advantage of the times that the ship was becalmed and was able to leave his apparatus submerged for more than an hour. At best the retrieval time for his apparatus was 12 minutes, at worst 45 minutes, on which occasion he deplored the ill-will of the crew who, he said, had not put enough effort into hauling in the heavy, hempen sounding line.

Two measurements were taken in the middle of the Atlantic Ocean in 1800 at latitude 8°N and 7°N, at depths of 500ft (152m) and 300ft (91m) respectively. The temperature was found to be 25°C in the first instance, (when the immersion time was only five minutes) and 16°C in the second. The surface water in both cases was 30°C. Two further observations were made in the Atlantic Ocean at latitudes 5°N and 4°N on the return voyage in 1804. These latter were at greater depths, 1200ft (366m) and 2144 ft (654m), and indicated the much lower temperatures of 9.2°C and 7.5°C respectively. The measurements thus were all within 10 degrees of the equator.

The results were very significant. Péron thought the temperatures measured in the deeper levels were startlingly low. With a progressive decrease in temperature with depth now confirmed, what, he wondered, would be the limit? How cold could the bottom waters of the sea be? As for the hypothesis that there was a uniform and constant temperature of about 10°Réaumur (12.5°C), in the deepest waters of the seas, must not the measurements to date, he claimed, cast some doubt upon that widely accepted belief.

There was another surprising situation. Péron's probing in waters closer to the equator and at a lesser depth than that probed by Captain Ellis, had revealed colder water beneath the surface water of the equatorial zone than beneath the surface water at higher latitudes. Here was an anomaly that called for an explanation. Why should this be so? Scientists pondering the physics of the oceans had need of more data of this nature.

Publication of the Scientific Discoveries

For the participants in a scientific voyage a great deal of work still lay ahead on their return home. It was vital, if their work for the natural sciences, for meteorology and for navigation was to have the desired impact, that funds be available for publication of their results. Often these funds were not assured at the outset of the voyage and, with changed political conditions on their return, there could be delay and doubt in their acquisition. In the case of the Baudin expedition, it was François Péron and Louis de Freycinet who battled to obtain funding for the publication of the work of the voyage. The renewal of war with England was absorbing the attention of the Department of the Navy, which at first seemed little interested in the return of the great voyage of discovery.

On Péron's representations to the Navy Minister, M. Decrès, he was commissioned to write the narrative and Freycinet to prepare an atlas of the maps and charts. The Natural History Museum provided a grant for the production of an atlas of drawings. By 1806 the first volume of the narrative was ready for publication. Neither in the extended title of the *Voyage aux terres australes* nor in the text was Nicolas Baudin mentioned by name. On Péron's early death in 1810, the completion of his unfinished Volume Two of the narrative passed to Louis de Freycinet. The despised commander still received no recognition in the title of the volumes that appeared between the years 1807 and 1816 (with second editions in 1824). When referred to in the narrative he was called 'the commander' or 'our leader'. His competence as a navigator was frequently called into question and his management of the expedition disparaged. An ever present ill-will towards the scientific aims of the voyage was assumed throughout.

Authoritarianism in Conflict with Science

Complaints against commanding officers of voyages of exploration were not unusual, but this time Nicolas Baudin was not there to present his point of view. His incomplete *journal historique* and the lengthy reports despatched en route suggest that he was preparing material for publication. But his version of events was not published. Only in this century, in Australia, has his *journal de mer* appeared in print, translated into English by an Australian scholar Christine Cornell (1974). An Australian historian, Frank Horner (1987) has been able to present a more balanced picture of the expedition leader by consulting archival material which included the personal journals of the commander and of other expedition members. It is clear that the privations of the voyage, the sickness and loss of life, the several occasions when Baudin failed to meet a rendezvous or abandoned a search for lost crew members gave rise to considerable animosity towards him, not only from the impatient scientists, but also from some of his officers. It is clear also that he had the friendship and respect of others of both groups. The conflict between the demands of science and the demands of safe navigation along uncharted coastlines was inevitable. There was potential for conflict also between the revolutionary attitudes of an ardent young scientist like François Péron, who had fought in the republican army, and an older commander raised in a more authoritarian era, who had moreover once served in the service of Emperor Joseph II of Austria, brother of the deposed Queen of France, Marie Antoinette. There was still further potential for a personality clash between young officers of noble birth such as Henri and Louis de Freycinet and an *officier bleu* such as Nicolas Baudin.

At the first stop in November 1800 at Santa Cruz on the island of Tenerife, the comments of Baudin (1974 p.21) in his journal reveal that already he found his scientific contingent difficult to tolerate. He was, however, prepared to make excuses for their behaviour:

> *More anxious than the rest, they had pestered me from the moment we dropped anchor to allow them to go ashore and I had been obliged to give my permission in order to be rid of them. I must say here, in passing, that those captains who have scientists, or who may some day have them aboard their ships, must, upon departure, take a good supply of patience. I admit that although I have no lack of it, the scientists have frequently driven me to the end of my tether and forced me to retire testily to my room. However, since they are not familiar with our practices, their conduct must be excusable.*

When the expedition reached the western shores of New Holland and broached the dangers of the surf in longboat or dinghy to land shore parties, Baudin's patience was wearing thin. He was not only worried but irritated:

> *The large dinghy also set off, carrying the scientists, their knowledge and their baggage, for these gentlemen never move without pomp and magnificence. The cooks with their utensils, the pots, the pans and the saucepans, cluttered up the boat so much that not everyone could fit in, and part of the load had to be put in the longboat. All this apparatus so infuriated me that I went back to my cabin, extremely dissatisfied that the whole lot of them had not left on the* Naturaliste.

Friction between commander and civilian scientist, and, indeed, between commander and naval officer was not unique to the Baudin expedition and was, in fact, not easy to avoid on these long and arduous voyages of discovery. There were bitter clashes between Laperouse and the civilian scientist Lamanon on the *Boussole*. Significantly, on the next French scientific voyage to the Pacific, all the scientific work was performed by naval officers with special training in science.

Passports for Science

When the *Naturaliste* reached Port Jackson, a state of war existed between Britain and France, as indeed had existed for more than 40 of the preceding 140 years. It is interesting to note that the naval facilities of the British port were nevertheless made freely available to the *Naturaliste* and the *Géographe.* The arms of these French corvettes were intended for protection mainly against privateers, for, as was the custom, the French commander carried passports of safe-conduct furnished by all the governments of Europe. Scientific expeditions of the eighteenth and nineteenth centuries, though funded by governments, were promoted by the learned societies of European countries which had a long tradition of cooperation, whether their nations were at war or not. A letter to Sir Joseph Banks dated 16 May 1800 and reproduced in translation in De Beer (1960, p.238), *The Sciences were Never at War* illustrates the spirit of cooperation that existed between members of the Royal Society of London and the National Institute, the scientific society which had replaced the earlier Royal Academy of Sciences in Paris:

Sir Joseph Banks, President of the Royal Society of London.

The National Institute of France is desirous that several distant voyages useful to the progress of human knowledge should begin without delay. Its wishes have been endorsed by our Government which has just issued orders for the preparation as soon as possible of expeditions led by skilful navigators as well as enlightened men of science, and will approach the Government of your country for the necessary passports or safe-conducts for our vessels. The National Institute considers that it is precisely at the moment when war still burdens the world that the friends of humanity should work for it, by advancing the limits of science and of useful arts by means of enterprises similar to those which have immortalised the great navigators of our two nations and the illustrious men of science who have scoured sea and land to study nature, Sir, where they could do so with greatest success.

Then follows a request for Banks's assistance in procuring these passports and also the release of a French naturalist. The letter is signed by the distinguished names of Jussieu, Camus, Laplace, Bougainville, Fleurieu, Dutheil and Lacépède.

In May 1803, the *Naturaliste*, returning home from Ile de France was impounded for ten days when Hamelin's passport was queried by an intercepting English frigate. It was subsequently released by the British Admiralty when Sir Joseph Banks made representations on Hamelin's behalf. At Port Jackson Governor King had done much more than grant a safe-conduct for the French expedition. He had provided generous help from the limited resources of the young colony. In the same spirit, members of the French Institute made strenuous efforts to try to procure the release of Matthew Flinders when he was detained by Governor Decaen on Ile-de-France. In 1803, when war had again broken out between the two nations, Flinders had arrived there without a passport for the *Cumberland*. The passport he carried was for the *Investigator*, which had become unseaworthy and was unavailable for his return voyage. By an unlucky chance, the *Géographe,* which had been in port on its homeward course, and could have vouched for Flinders identity and purpose had sailed only the day before. Flinders was held on the island for six and a half years on suspicion as a spy. It may have helped if Governor King had given him a copy of the open letter of gratitude left with him by Baudin to record the hospitality shown him at the British settlement. On the other hand it may not have. Decaen had only recently taken charge of the island and was fired with the idea of thwarting British influence in the Indian and Pacific and re-establishing French influence in India. It made no difference when Governor King sent him a personal appeal with a copy of Baudin's letter in April 1805. In July 1807 Decaen received the order of the Council of State for Flinders' release. But still Decaen held him prisoner. The long detention was a tragic situation for Flinders, anxious to reach England, publish his Australian charts and procure a replacement for the *Investigator* to continue his interrupted survey of Australia.

Louis de Freycinet's Expedition in the *Uranie*, 1817-1820

After the conclusion of the Napoleonic wars, at a time when the British were more interested in seeking a northern passage between the Pacific and Atlantic oceans, the French again chose to concentrate on Oceania and the South Seas. Louis XVIII, on the restored Bourbon throne, gave his support to such an expedition. The French empire was now greatly diminished. They no longer owned Ile-de-France, which in 1814 had passed to the British, who also now occupied Cape Town, seized from the Dutch. Louis de Saulces de Freycinet, at 38 years of age, was given command of a Pacific expedition in the 20-gun, 350-ton corvette, *Uranie.* Freycinet had established a reputation as a surveyor, cartographer and navigator and was a correspondent of the restored Academy of Sciences within the National Institute.

What is the exact shape of the globe?

Freycinet’s expedition differed from that of Baudin's in that geographic discovery was not considered of such importance. The maps of the Pacific area were by now almost complete. Scientists, however, had many questions for which they sought information. They were interested in variations in magnetic intensity in different regions, for example, in comparisons between the temperature of the air and the atmosphere, and in the actual shape of the globe. It was known that the earth was not perfectly spherical and this had been one of the projects of the Spanish expedition under Malaspina before the end of the eighteenth century.

There was a theory that the southern hemisphere of the globe might be flatter than the northern hemisphere. Experiments with the oscillating pendulum were still sought to test this theory and were part of the instructions for this voyage. While the absolute determination of gravitational force requires much precision, it was possible to compare the difference in the number of swings of the pendulum in a given time at two places to obtain the difference in the gravitational field. The force of gravity increases slightly as the radius of the earth decreases.

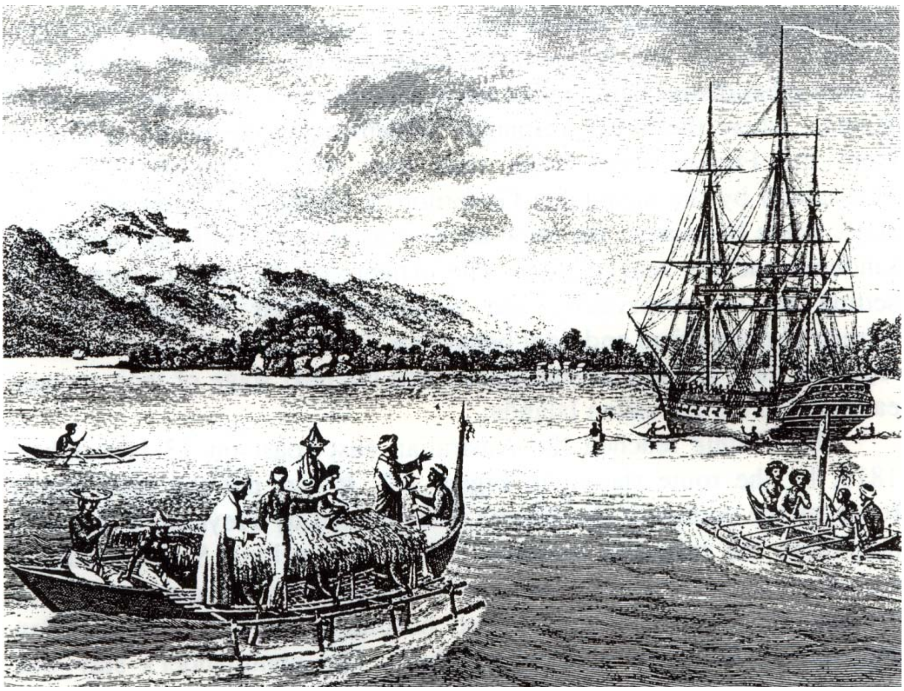
The French Naval Officer as Scientist at Sea

All the scientific work on Freycinet's expedition was done by naval officers. The *Uranie* carried no civilian scientists. Officers with an interest in science were specially selected and given an opportunity to study their specialty at the Paris Museum of Natural History for nine months before the voyage. Freycinet had vivid memories of the difficulty on the Baudin expedition of accommodating civilian scientists to the discipline of an inevitably rigorous sea voyage .A surgeon and a pharmacist were chosen who were capable of work in zoology and botany respectively. Except for the chaplain, the only civilian included in the ship's number was the artist, Jacques Arago. He was the brother of the astronomer François Arago, who played a prominent role in providing instructions for research into the physical sciences on this and subsequent nineteenth-century voyages from France.

As one of the aims of the expedition was research with the pendulum a variety of halting places was chosen in advance as most likely to supply information for this purpose, and for gathering specimens for museums. As well as established locations, such as Rio de Janeiro, the Cape of Good Hope, Mauritius (Ile-de-France) and Port Jackson, the *Uranie* was to spend some time at Waigeo and Rawak, islands off New Guinea which were only one and a half degrees south of the equator.

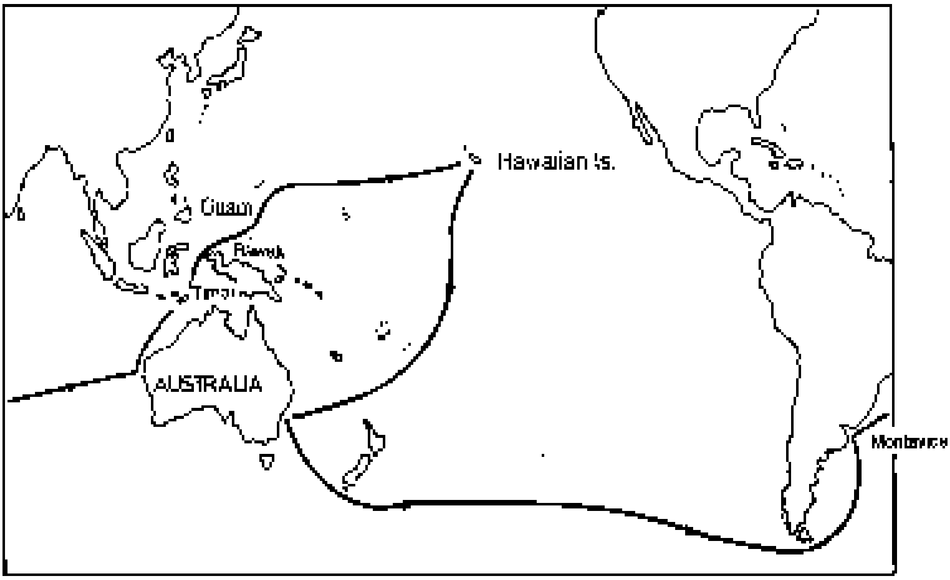
Freycinet's expedition reached Shark Bay on the West Australian coast on 12 September, 1818. Two scientific officers became lost and disorientated in the dry, featureless landscape, much as Francois Péron had done when the *Géographe* had stayed there.They suffered badly from heat and thirst. From Shark Bay the expedition sailed to Timor, visiting both the Dutch port of Kupang and the Portuguese port of Dili.

After time spent at Timor, Rawak and Waigeo, the onset of fever, dysentery and scurvy caused great distress among the crew. Help was sought further north in the Marianne Islands at the Spanish settlement on the island of Guam. Here the French spent more than two months, housed, fed and entertained by the hospitable Governor de Medinilla. 'Throughout our stay', wrote Freycinet, 'the crew never ceased to bless his inexhaustible kindness and his zeal to help'. The officers of the *Uranie* were busy setting up an observatory and conducting their measurements of terrestrial magnetism and tidal behaviour. In the prison hospital the sick regained their health and strength to face the next stage of their voyage eastward to the Hawaiian Islands.



2.6
The Uranie at anchor in a sheltered cove on Rawak Island, almost on the equator, with the mountains of Waigeo Island in the background. Canoes brought visitors anxious to trade. Most were fuzzy-haired Papuans from nearby New Guinea. In the foreground is a Muslim family group from the Moluccan Islands paying a social call. From Freycinet (1824-1844).

The *Uranie* reached the Australian east coast on 13 November 1819 by the route shown in Figure 2.7. It was not the most direct route, as the course of the *Uranie* was dictated by Freycinet's desire to determine the magnetic equator They were received hospitably by Governor Lachlan Macquarie and given housing on shore. The commander's stayat the convict settlement was marred, however, and the governor embarrassed, by the theft, the first night ashore, of the French household silver, table linen and servants' clothing. The thief was caught, but the silver had already been melted down. The *Uranie* sailed on Christmas Day, 1819, for a return voyage via Cape Horn, with, it was discovered later, ten convict stowaways. One was a runaway Frenchman, whose plight had aroused the sympathy and connivance of his compatriots.



2.7

The track into the South Seas of the French corvette,* Uranie*, commanded by Louis de Freycinet, 1817-1820. The* Uranie spent time at Waigeo and Rawak islands very close to the equator to conduct measurements of terrestrial magnetism. *They visited Shark Bay in September 1818 and Port Jackson in November 1819.

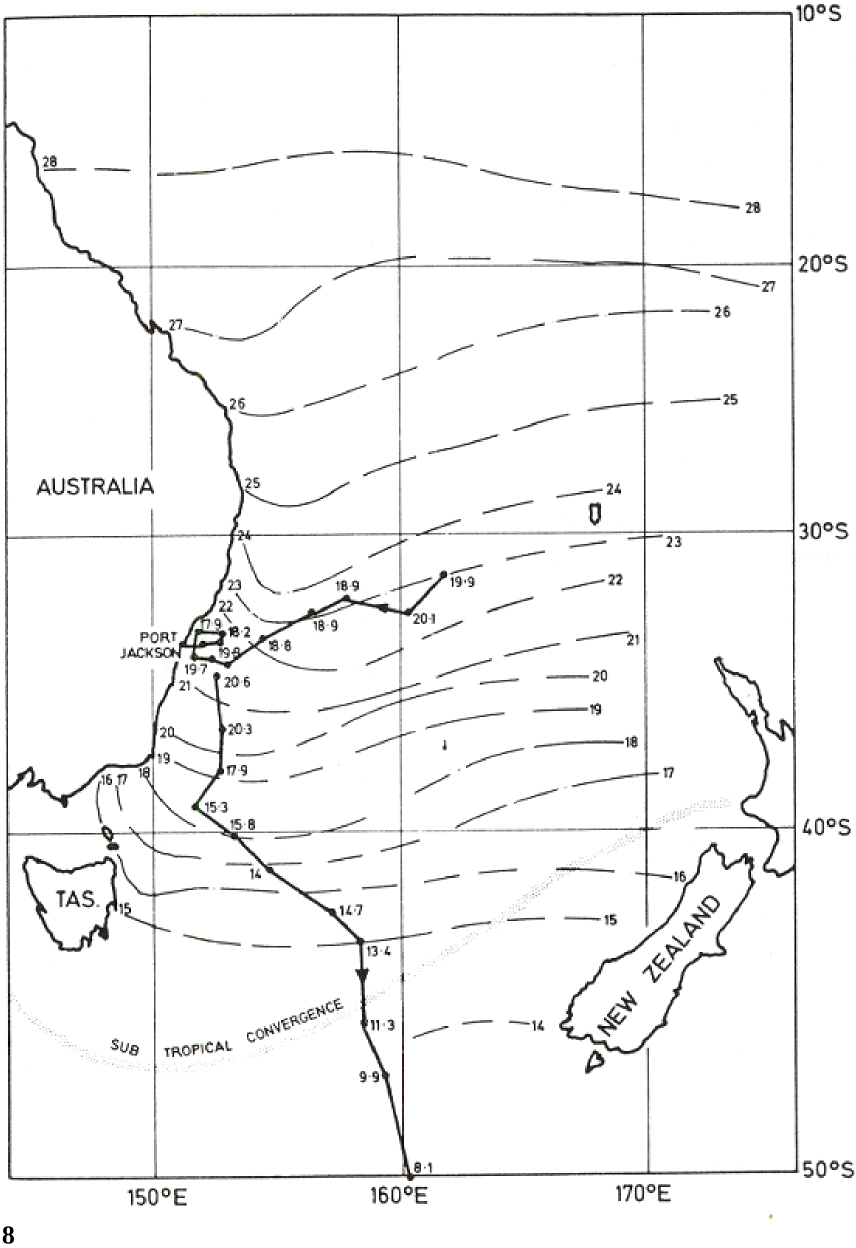
Two-hourly sea surface measurements

The collection of sea-surface temperatures was part of the routine procedure of the naval officers of the *Uranie*. Throughout the voyage measurements were made of atmospheric and ocean temperatures every two hours, 'an important acquisition', said the report to the Academy of Sciences of the astronomer, François Arago, 'as remarkable for its exactitude as its extent'. In addition fifty-five flagons of sea water from a variety of locations were collected for chemical analysis. It had been observed by the Swiss chemist, Alexander Marcet that the salinity of sea-water samples he had analysed was, on the average, greater in those collected to the south of the equator than those to the north. Could it be that the waters of the southern hemisphere were saltier than those of the northern? But, he noted, he had received more samples from the high latitudes of the northern Atlantic, where there had been several recent Arctic expeditions, than from similar latitudes of the southern hemisphere. Moreover the phenomenon he was considering had not been supported by a series of experiments conducted by John Davy on a voyage to India in 1816. It was just one of the many curiosities awaiting elucidation.

The water samples from the *Uranie* were designed to provide fresh material for this topic under discussion by French physicists.

A Resource of historical value

The extensive data-set of two-hourly sea-surface temperature readings obtained from the *Uranie* was published in the volume on meteorology (1844) of the official account of the voyage, prepared by Freycinet. This provides the earliest set available for Australian waters. Just as ice cores and tree rings can be studied to assess climate change over the centuries, so too are these recorded nineteenth century measurements of sea surface temperature available for study by scientists of a later era. An interesting set of sea-surface temperatures in the Tasman Sea for December 1819 has been plotted from these data and is compared in Figure 2.8 with a ten-year mean during the period 1967-76. In the year 1819 the surface temperature was significantly below the more recent mean temperature, except for a small region south of Sydney. It could be that the *Uranie* crossed. the Subtropical Convergence near 39° South.

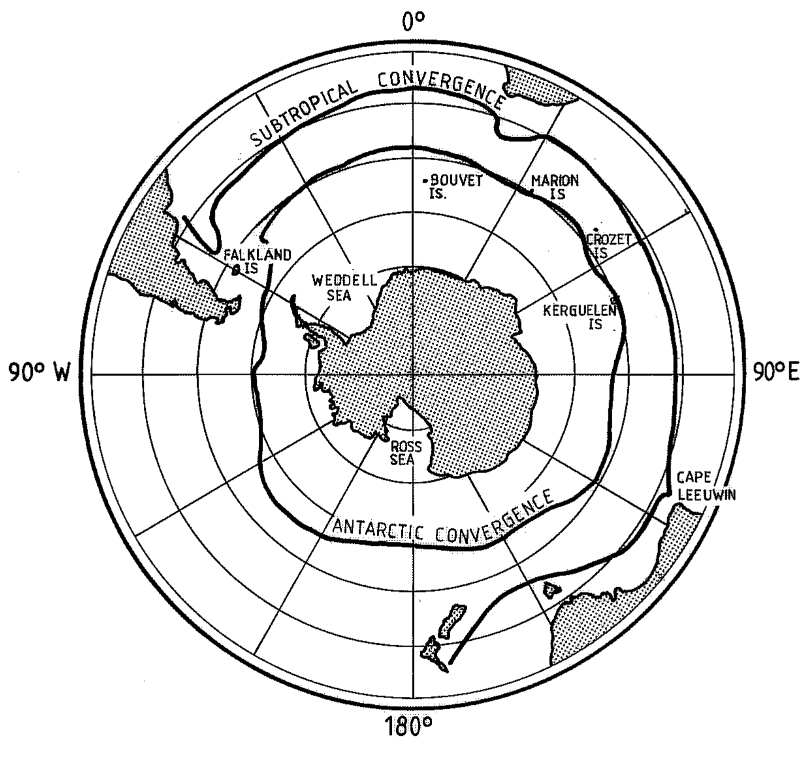


2. 8

The sea-surface temperatures plotted at midday for Freycinet's voyage in November-December 1819 along the track through the Tasman Sea shown as the dark line. Also shown as broken lines are the average temperatures to be expected for December and the position of the Subtropical Convergence as plotted by Deacon (1963). Reproduced from Jones and Jones (1980)

The Subtropical and Antarctic Convergences

The ocean boundary known as the Subtropical Convergence occurs around the earth where subantarctic surface waters meet warmer subtropical waters and, sinking below them, continue their movement towards the equator at a lower level. It is a more variable boundary than the Antarctic Convergence closer to the poles, of which mention will be made later (in chapter 4). To the south of the Subtropical Convergence there is cold, subantarctic surface water and this leads to a sharp drop in surface temperature along a north-south line. Such regions between waters of different properties are known as fronts. Sir George Deacon (1963) has plotted the likely position of this Subtropical Convergence and we have reproduced his position in Figure 2.9.



2.9

The Antarctic and Subtropical convergences as plotted by Sir George Deacon (1934) represent zones where cool surface water descend and move equatorwards, largely retaining their characteristic qualities of temperature and salinity.

At the Subtropical Convergence the surface water in summer, according to Deacon, exhibits a 4° C drop in surface temperature in the range of 14°C to 18°C. There was no appreciation of crossing the Subtropical Convergence by those on the *Uranie.* In the first quarter of the nineteenth century there was no understanding of the deep circulation of the oceans, although there were questions about the origin of cold water found deep below warm tropical seas. There had been, however, the suggestion from Benjamin Thompson, Count Rumford, at the turn of the century, that colder (and more dense) water in high latitudes, since its specific gravity is greater than water at the same depth in warmer latitudes, would flow under the surface towards the equator. The same proposition was espoused by Alexander von Humboldt.

Could the position of the Subtropical Convergence, often to be found around latitude 45°S in this region, have been as far north as 39°S, in the summer of 1819. According to Deacon’s placement of the convergence, the track of the *Uranie* should have intersected it at about 45°S. Yet at that latitude the surface temperatures recorded on the *Uranie* were much lower than the summer range suggested by Deacon and the 4°C front would seem to have been encountered further north at 39°South.

Conditions on Board the *Uranie*

Unlike commanders Lapérouse, d'Entrecasteaux and Baudin before him, Freycinet survived the perils of his three-year voyage. The expedition was not, however, without its human costs. After a stay in tropical regions, dysentery claimed the lives of four men, malaria another two, and many were ill with these diseases and scurvy as well, despite the use of iron water-casks and the improvements in diet. Freycinet carried supplies of preserved as well as salt meats, and at first had dispensed with the customary collection of farm animals on board, in an effort to improve hygiene. At Timor, however, he relaxed this last decision and took on board 300 fowls and several buffaloes, together with maize to feed them. One innovation on this voyage was the extensive use of an alembic for the distillation of fresh water from sea water. An alembic had been tried by Bougainville and Cook, and briefly by Baudin, but it was brought into use for nine days by Freycinet at the waterless stopping place of Shark Bay. So fruitless was their search for water in this arid terrain that the French were left with the conviction that the few Aboriginal people that they encountered must have drunk salt water. For a month afterwards the ship's company drank nothing but this distilled water. At the commander's table it was drunk for three consecutive months. Freycinet declared that he preferred it to the natural water supply of Timor. It certainly could have been more hygienic. The use of the alembic on a wooden vessel was not, however, without its risk of fire.

Shipwecked in the Falkland Islands

On the return voyage the *Uranie* was wrecked in the Falkland Islands on an uncharted reef, without loss of life, but with considerable damage to natural history specimens and to drawings. Most of the Australian possums, black swans, emus, parrots and cockatoos carried on board had already died with the cold. One of the pair of merino sheep presented by John Macarthur fared better. One wonders what the convict stowaways now thought of their chances of survival? After two months living in tents and eking out their food-supplies with penguins, sea elephants and wild horses, the French, after protracted negotiations, were able to purchase a replacement ship from a passing American trader. Good use was made of the *Uranie's* team of carpenters and artisans in the bargaining for what was in fact an unseaworthy vessel unable to withstand the strains of the heavy seas around Cape Horn. In this vessel, renamed *La Physicienne,* the expedition reached Le Havre on 13 November, 1820, after an absence of three years and 57 days. The toll of human life was less than previous voyages into the area. There had been only seven deaths. There were thirty-eight desertions; fifteen men had been disembarked at their own request and two left sick at stopovers (Brosse(1983)].

The publication of different aspects of the voyage of the *Uranie* was authorised by the government and appeared, with considerable gaps of time, between the years 1824-1844. There was critical comment from Francois Arago about the delays in the publication of the scientific investigations, but the quality of the charts and illustrations in the four atlases was outstanding. They served to bring the South Seas to the attention of their readers. In his volume on meteorology (1844) Freycinet analysed his atmospheric and sea-temperature readings and related his findings to those of Péron, most of which he was able to confirm. With measurements at two-hourly intervals he was able to confirm Péron's finding that at midnight the temperature of the sea surface is generally higher, in the open sea, than that of the atmosphere above it, and to state more precisely (p.201)

> *The temperature of the air is generally lower than the temperature of the water at 2 a.m., 4 a.m., 6 a.m., and 8 a.m., at 4 p.m., 6 p.m., 8 p.m., 10 p.m., and midnight. The daily mean temperature of the air is likewise lower than the daily mean temperature of the water.*
>
> *The temperature of the air is generally higher than that of the sea at 10 a.m., midday and 2 p.m. The maximum temperature of the air is likewise higher than that of the water.*

Such findings illustrate the role of the oceans in providing a stabilising effect on the climate of the globe.

Rose de Freycinet

An unusual feature of the voyage of the *Uranie* was the presence on board of the commander's wife, Rose de Freycinet. This was against the rules of the French Navy, and Freycinet risked official censure in permitting her to join the expedition. Rose displayed considerable determination in taking such a step: disguising herself as a youth and 'stowing away' on the *Uranie.* A gently bred and well-educated Parisienne, three years married and childless, it was not without many qualms that she determined to follow her husband on his dangerous mission:

> *I confess that I am agitated by a thousand fears. The thought of that sea frightens me; I greatly need to have my courage strenghtened by Him who commands the wind and the waves. I, who trembled in a boat in the middle of Marseille harbour - how shall I fare on the ocean, when I can see nothing but sky and water and the weather grows stormy!*

Rose did not need long to keep up the deception. Once away from France, her husband could take responsibility for her presence, and, reverting to her feminine dress, Rose, with her charming manners, was a popular presence on board and was enthusiastically received by the ladies at every port of call. One of those ports was Sydney, New South Wales, in 1819. From her letters to her mother and a personal journal, emerge some aspects of a long voyage of science and discovery, on which no comment might be made in an official account. She was distressed at the gift of four child slaves by the Governor of Portuguese Timor, and only out of politeness and the fear of giving offence did she agree to take one small boy. The improvement in a monotonous diet, provided by the Appert's preserves receives her frequent approval. The experimental use of the alembic on deck caused her concern when her husband, Louis, burnt his hand. The chimney of the alembic caught on fire; the *Uranie's* bridge became overheated, and Freycinet burnt the inside of his hand while demonstrating to the sailors how to correct the problem.

2.10
Louis and Rose de Freycinet, who sailed together on the world scientific cruise of the French corvette,* Uranie*, 1817-1820. Rose was smuggled on board in Toulon as it was against naval regulations for women to travel on board the King's ships.
From engravings of original portraits in the possession of Baron Claude de Freycinet.

Writing to her mother after a stay onshore at arid Shark Bay, Rose described her mixed feelings as she faced her first experience of running aground:

> *It had been without a single regret that I left that hell on earth, the coast of New Holland. But would you believe! Soon that land that I detested became almost the object of my desires! We were not yet out of Shark's Bay when, towards 6 o'clock in the evening, while sounding continuously, the water suddenly shoaled, though we were already far from land, and the ship touched upon a sandbank. I cannot describe to you one's sensations at the sudden immobility of a vessel that has run aground. Alas! my thoughts had dwelt only too often on the frightful predicament that would face voyagers wrecked in these parts of the world. I had envisaged the poor* Uranie *beyond repair and as for ourselves . . . the thought of that fate halts one's imagination.*

Rose returned to France, quite a heroine, having endured the reality of some of the dangers of shipwreck she so feared when the *Uranie* was wrecked in the bleak Falkland Islands. But although she had escaped death also from the virulent fevers of the tropics, she succumbed to a cholera epidemic in Paris in 1832 and died at the age of thirty-seven. Her husband, Louis, survived the epidemic. He worked on the publication of the reports of the voyage until his death in 1842. Rose's journal was not published in her lifetime. In 1927, however, it was edited by Charles Duplomb and published in Paris, illustrated with prints of scenes and incidents by the artists of the *Uranie.* For English readers, her story is vividly told by Marnie Basset, from whose book, *Realms and Islands*, the above quotations are taken.

Duperrey's Voyage in the *Coquille,* 1823-25

On the world voyage of the *Uranie,* the hydrographic work had been the responsibility of sub-lieutenant Louis Isidore Duperrey. On the return to France, he was employed on the publication of the atlas of charts which accompanied the narrative of the voyage. For his excellent work he received promotion and command of the next French expedition, in the *Coquille,* which was despatched this time by way of Cape Horn into much the same region of the Pacific as he had sailed with Freycinet. The primary aim of the voyage, again, was scientific rather than geographic discovery. One of its political objectives, however, was explicitly the locating of a site for a possible French penal settlement on the western half of Australia. Three suggested sites were King George's Sound, Flinders Bay, near Cape Leeuwin, and the Swan River.

Louis Isidore Duperrey, who was 35 years old, had held a variety of positions in the navy before his voyage in the *Uranie*. He had written several memoirs on aspects of the scientific work of that expedition. With him on the *Coquille* as lieutenant was Dumont d'Urville, who had been a junior officer with him on an 1821 East Indies cruise in the *Chevrette.* In the meantime, to further his interest in natural history, Dumont d'Urville had taken botanical courses of study at the Museum of Natural History in Paris. Of the ship's company of seventy, six officers and two surgeons were capable of scientific investigation. Once again there were no civilian scientists included in their number.

The vessel chosen for this expedition, the *Coquille*, was a 380-ton transport ship, which was converted to a corvette and specially fitted out for a research voyage. The expedition sailed from Toulon in August 1823. The itinerary of the voyage involved a circumnavigation of Australasia, with calls at New Ireland, Waigeo Island, and Amboina to the north, but the only landfall on the continent was at Sydney, where the expedition spent two months. They were warmly welcomed by the scientifically minded Governor Brisbane, who had set up an observatory at his official residence at Parramatta, some twenty kilometres inland from Port Jackson and had established a number of weather stations around New South Wales.

As he sailed southwards from Timor, Duperrey was prevented by adverse winds from approaching at all closely to the coastline of western Australia, where a French settlement was under consideration. D'Entrecasteaux, also, had wished to gain Shark Bay from Timor but he too was forced by adverse winds and currents to abandon this plan. If the political aim of the *Coquille* expedition to locate a suitable site for settlement was not achieved, the scientific work was hailed as 'exemplary' by Georges Cuvier in his report of 22 August, 1825, to the Academy of Sciences.

Experiments with the pendulum to measure gravitational changes were again part of the scientific program of the French voyage and, as part of their meteorological work, the officers of the *Coquille* kept a systematic record of the temperatures of the sea-surface and the atmosphere at four-hourly intervals daily, expressed in Centigrade. An examination of the published measurements as they sailed north towards Sydney in January 1824, shows the presence of the Subtropical Convergence, located where it could be expected near 46°S.

The East Australian Current

The measurements from the *Coquille*, which have been plotted in Jones and Jones (1980) illustrate another oceanographic feature which was not well understood in 1824. James Cook had noted the south-setting currents along the south east Australian coast and we now believe that this current leaves the coast a little north of Sydney and travels towards New Zealand. With the current comes warm water from the equatorial regions. The surface temperature section from the *Coquille* shows a front, about one hundred kilometres wide which caused a substantial north-east set to the ship. This is as we would expect for the vessel crossed the East Australian Current on its journey towards New Zealand. We now understand the balance of forces that causes such a current to flow at right angles to a density (temperature) gradient, just as winds may be expected to blow at right angles to the pressure gradients on a weather map. Thus we expect to find a current flowing to the east (in the southern hemisphere), whereby a ship, heading towards the equator and encountering increasing water temperature, can expect to be set to the east.

The statistical data, published in the volume on hydrography of the official account of the voyage of Duperrey (1829), contain systematic measurements, expressed in miles per hour, of ocean currents encountered. This was the first of the French Pacific expeditions to publish current measurements determined from the ship's set. In the years following his time at sea Duperrey took the analysis of records of surface water temperatures and surface current speeds from other ships as an area of special interest. His observations were incorporated into the first chart of the physical characteristics of the Pacific Ocean, compiled by Heinrich Berghaus at Potsdam in 1837 and were of continuing value in determining the slowly emerging picture of the surface circulation of that ocean.

Measurements of Light Penetration

Oceanographic work on the *Coquille* included tidal observations and also experiments to measure water clarity. When the weather was calm, a white-painted board, 0.66metres in diameter, was lowered into the water, carrying a weight so that it remained horizontal. The depth at which the board disappeared from sight was noted and experiments at different latitudes and times of day showed considerable variation in the degree of visibility. Similar experimentation had already been undertaken on Russian research expeditions (see chapter 3) and such observations were gradually standardised and pursued throughout the century. These early Secchi-disk measurements can be expected to yield a result accurate to 10%. At Port Jackson in February, Duperrey observed the disk to become invisible at a depth of twelve metres. In the Bay of Islands, New Zealand, in April, the mean of similar experiments was one metre less. It is now perceived that visibility can vary in the range of one to over sixty metres and is closely associated with the depth of the photic zone.

Duperrey's expedition, which returned on 24 March, 1825, after a circumnavigation of two years and seven months, was accomplished without serious damage and, an impressive achievement, without any loss of life. Duperrey was then, until 1830, engaged in the publication of the *Voyage*. He continued his scientific interests by contributions on topics in physical geography and terrestrial magnetism to the Academy of Sciences, of which he eventually became president in 1850.

Hyacinthe de Bougainville in the Pacific (1824-1826)

Another French expedition into the Pacific early in the nineteenth century was that led by Hyacinthe de Bougainville. It was sent by the French government clearly for political reasons, although the leadership of a voyage to this region had long been in the mind of Bougainville, anxious to follow in the footsteps of his illustrious father, Louis Comte de Bougainville who commanded the first French circumnavigation of the globe, and had laid the original claim to Tahiti for France in 1768.

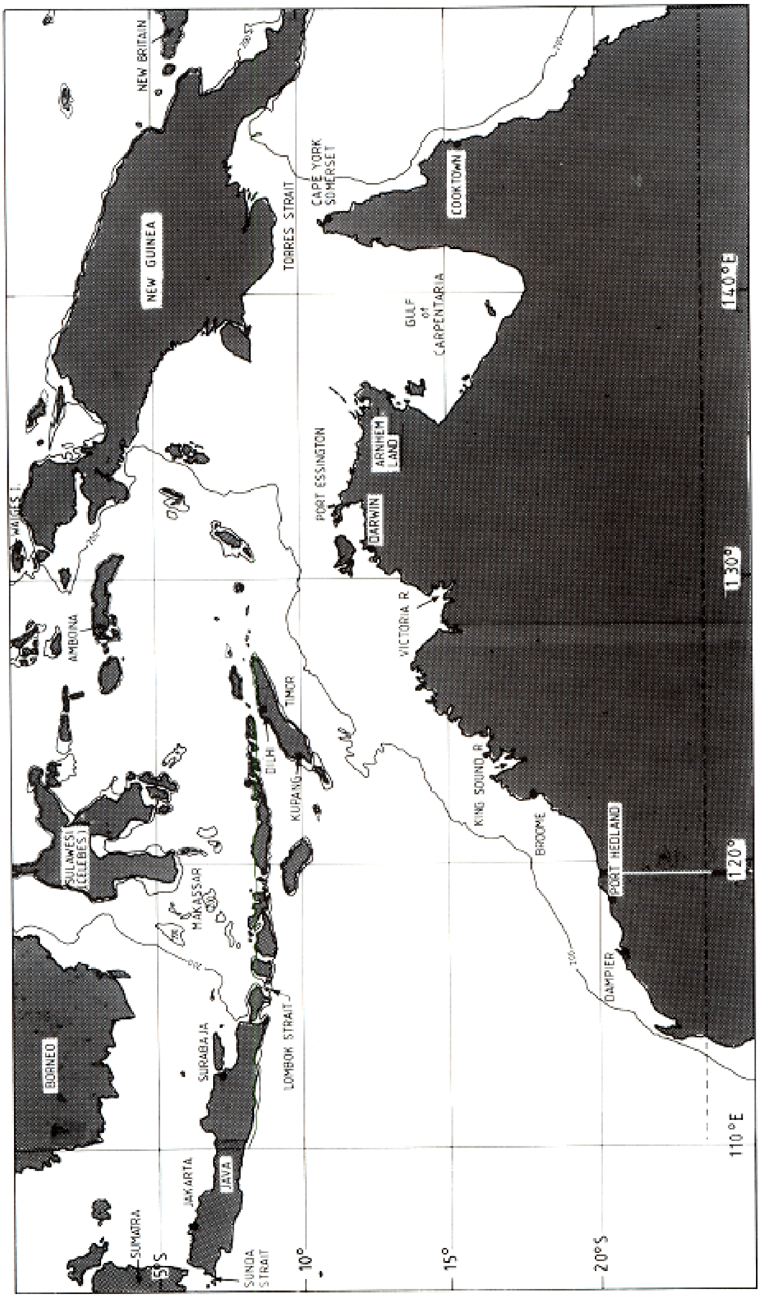
Hyacinthe de Bougainville, at the age of eighteen years, had joined the Baudin expedition as a midshipman. Twenty-five years later, after service in the Napoleonic wars, he had command of the frigate *Thétis* when he was directed to go to Cochin-China and attempt to re-establish diplomatic relations and obtain trade outlets lost there during the European wars. Carrying official letters, Bougainville had instructions to sail by way of the Cape of Good Hope, calling at Bourbon Island, Pondicherry, Manila and Macao. He was allowed a free choice of the return journey, apart from an obligatory visit to Java, and it is not surprising to find that he chose to make his voyage a circumnavigation like that of his father. The choice of route brought him to Port Jackson on 25 June, 1825. His three months' stay there he described as a very pleasant time for all, as if, perhaps, to contrast it with his previous visit under Baudin's command. It certainly gave Bougainville pleasure to obtain a concession of land and the services of an architect to erect a lasting stone memorial to Lapérouse at the entrance to Botany Bay, the last known anchorage of the ill-fated explorer before he disappeared in the Pacific.

Scientific Achievements

Although the *Thétis* and its accompanying corvette, the *Espérance*, were less well staffed for scientific work than the ships of Bougainville's predecessors, an important collection of natural history specimens was gathered, and at sea, the air and surface temperatures were systematically measured and the currents estimated. The temperatures were recorded at 6 a.m., midday, 6 p.m., and midnight, at the same interval and time, that is, as Péron's. The temperatures published by Bougainville (1837) were expressed in degrees Réaumur, as were Péron's. Despite Bougainville's comment that the sea-surface temperatures were measured by plunging the thermometer *immediatement* into the bucket in which the water had been drawn from the surface, large fluctuations in the temperatures of the sea about the daily means are revealed in the measurements recorded for the Tasman Sea south of Sydney. Such variations, which are not usual in these waters could have been the result of carelessness: perhaps by allowing the water to stand for some time in the sun before recording the temperature.

Two years and three months were spent on this voyage, which ended at Brest on 24 June, 1826. One result of the visits of Duperrey and Bougainville to Australia was the move made by the British government to establish a garrison in western Australia, just as its settlement at Hobart in Tasmania had been in response to Baudin's visit some twenty years earlier.

Almost forty years had passed since the *Boussole* and the *Astrolabe* had disappeared in the Pacific, but interest in the fate of Lapérouse and his companions continued. Could any survivors still be alive? Successive voyagers into the Pacific kept a watch for any clues. Finally it fell to the next French expedition to the South Seas, that led by Dumont d'Urville, to settle the mystery. But before returning to the story of the search for Lapérouse we shall follow the scientific voyages into the Pacific of another European power, Imperial Russia.



2.11

The Dutch settlements in the Spice Islands of the Indonesian Archipelago frequently provided hospitality, supplies and repairs for visiting European expeditions of discovery in the eighteenth and **nineteenth centuries**

3

The Curiosity of the Europeans

In eighteenth- and nineteenth- century Europe the institutions of learning were populated by an international collegiate of scholars, some of whom were interested in the marine sciences. Despite the constant warring of the hereditary princes and self-proclaimed emperors of European kingdoms, intellectual ideas and the savants who disseminated them travelled freely across Europe. The European academies, as we have seen, provided centres from which the curious could lobby governments to provide places on naval expeditions to learn about the sea. Scientists travelled willingly on the vessels of foreign governments. The Forsters, of German birth, sailed with Cook; Haenke from Bohemia travelled with Malaspina; and on the pioneer nineteenth-century Pacific voyage of the Russian navy, the astronomer, J. K. Horner from Zurich, and the naturalists, W. G. Tilesius von Tilenau from Leipzig and G. H. von Landsdorff from Gottingen, Germany, sailed with Krusenstern. One of the earliest physical oceanographers, the German physicist, Emil von Lenz, sailed, as a young man, on the 1823-26 Russian expedition led by Kotzebue.

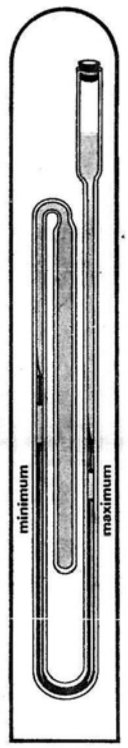
Science Finds a Platform on Russian Trading Vessels in the Pacific, 1803-1830

In the early years of the nineteenth century, while western Europe was feeling the impact of French expansionism, the Russians continued to develop their trading interests in the North Pacific. The overland route, by way of Okhotsk, to these distant trading posts in Kamchatka, the Aleutian Islands and the islands off the north-west coast of America was long and difficult. The merchants of the Russian-American Company, with the support of Tsar Alexander I, and the resources of the Russian Navy pioneered a sea-route to Kamchatka and the North Pacific. Although this involved a long voyage of circumnavigation of several years' duration, as a bonus a profitable trade with China was established in highly valued otter furs gathered at the North Pacific Aleutian trading forts.

This first Russian circumnavigation, led by I. F. Krusenstern and Y. F. Lisianskii in the 450-ton *Nadezhda* and the 370-ton *Neva*, took place in the years 1803 to 1806. On this voyage the naval precedent was established of combining exploration, transport and defence with the advancement of marine astronomy, hydrography and the natural sciences. Krusenstern, appointed captain of the expedition which he himself had proposed, consulted the German universities for the recruitment of scientists and naturalists. The Minister for Trade, Count Romanzof, was a great patron of the arts and sciences and gave his support. The Imperial court had considerable naval expertise available in Baltic German officers. Some, like Krusenstern and Lisianskii, and Hagemeister and Lazarev after them, had spent periods of secondment with the British Navy and were familiar with the achievements of James Cook in Pacific exploration and with the value of trade with the East Indies and China. Lieutant James Trevenen had sailed on Cook’s third voyage. A diplomatic mission was added to the objectives of the voyage. The *Nadezhda* carried a Russian ambassador and his staff for Nagasaki, the only Japanese port then open to Europeans. The visit was made, but the embassy was not received and returned independently to St Petersburg.

Six's Maximum and Minimum Thermometer

The Russian expedition of 1803-1806 sailed from Kronstadt in British-built ships and was equipped with the best charts and instruments, including chronometers, available in London. It was the first of the European scientific voyages to use the self-registering maximum and minimum thermometer invented in England by James Six in 1780 and adapted for marine use in 1794. Six's original self-registering thermometer (see Figure 3.1) consisted of a sealed U-shaped tube with mercury in the bend. Alcohol from an expanded reservoir filled one limb of the tube. The other limb was only partly filled with alcohol. Light steel needle-point markers, enclosed in glass, were positioned in the alcohol columns. As the alcohol in the reservoir expanded with rising temperature, one of the indices could be pushed upwards by the rising mercury column. The index was then prevented from falling, when the mercury column fell, by a glass 'tail' acting as a spring. It thus marked by its position in the tube the maximum temperature attained. In the other column, the index, pushed upwards as the mercury column retreated around the U-bend when the temperature fell, marked by its position the minimum temperature experienced. After use it was necessary to reset the indices at the ends of the mercury columns and this could be achieved with the aid of a magnet.



3.1
Diagram of the original maximum and minimum thermometer designed by James Six in 1782. It was adapted in the nineteenth century for measuring sub-surface temperatures and first used on the Krusenstern expedition 1803-1806. Reproduced from McConnell (1980)

The Six thermometer had proved very useful for meteorological use on land. Now for the first time, with strengthened glass and some modifications to the indices and their usage [McConnell (1980)], a maritime version was used for oceanographic purposes on a world-wide voyage of discovery. With many modifications over the years it was to be employed for some seventy years of the nineteenth century to record subsurface temperatures. Eventually it was rendered obsolete, for reasons which we shall discuss later, and was replaced by the 'reversing thermometer'.

On Krusenstern's expedition the Russians experimented both with the Six thermometer and with a version of the Hales bucket to investigate subsurface temperatures at various depths down to 125 fathoms. The results did not always correspond exactly. It was found that care was needed in the handling of the thermometers to prevent the jolting and dislodging of the indices. On the voyage observations were recorded also of currents and tides and measurements were made of the specific gravity of sea-water. In later years Krusenstern, as Director of the Naval Academy, a member of the St Petersburg Academy of Sciences and a member of the scientific committee of the Ministry of the Navy was in a favourable position to ensure continued scientific activity on the long voyages of Russian naval vessels. In 1824 and 1827 he published, in two parts, the first *Atlas of the Pacific Ocean.* In the accompanying text, we find an early reference to the East Australian Current and the Kuroshio.

The Russian Navy had demonstrated by Krusenstern's voyage around the world that it could successfully mount an expedition of scientific exploration, in the style of Britain and France. Moreover Krusenstern returned his crew in good health and without loss of life. Like Lapérouse before him, he had sent preliminary reports, charts and drawings back from Petropavlovsk by the overland route in case of shipwreck, but his ships returned to Kronstadt safely. Krusenstern wrote a description of the voyage of the *Nadezhda* and Lisianskii produced an account of the voyage of the *Neva,* which had differed in some respe cts from that of the *Nadezhda.* The two naturalists, Tilesius von Tilesius and Carl Heinrich von Langsdorff, each published accounts of their scientific work.

Russian Expeditions to the Pacific

On his famous voyage, Krusenstern rounded Cape Horn and proceeded to the North Pacific by way of the Marquesas and Hawaiian islands. On the return voyage from China, he passed through the Dutch East Indies, by way of the Sunda Strait, thence homewards by way of the Cape of Good Hope and the Atlantic. In November 1806 when the *Neva* was sent out again, with stores for the North Pacific settlements, a route by way of the Cape of Good Hope and New Holland was taken. It was a longer voyage, but the route was chosen mainly because of the lateness of the season and the dangers of a winter passage by Cape Horn. It was followed subsequently by some of the later Russian navigators for the same reasons. The commander of the *Neva*, Lieutenant Hagemeister, found a very convenient and hospitable port of call at the British colony at Sydney. The officers were entertained at a ball in their honour by Governor Bligh who had made voyages to the Pacific himself. There were good facilities for water, firewood, fresh food and repairs at this port.

During the latter part of the Napoleonic wars, when the North Atlantic sea routes were blockaded by the British, there were no more opportunities for Russian ships to leave Kronstadt and the North Pacific settlements had again to be supplied by overland routes. In October 1813, however, after Napoleon's retreat from Moscow, a Russian-built vessel, named the *Suvorov*, under the command of Mikhail Lazarev, once more sailed into the Pacific, taking the route by way of Cape Town and Sydney. The reception accorded the *Suvorov* in Sydney, August 1814, was all the warmer for the fact that it carried official news from the British ambassador at Rio de Janeiro of the defeat of Napoleon and the presence of Russian and Prussian forces in Paris. The *Suvorov* was anchored in Neutral Bay within Port Jackson where caulking and general repairs went ahead. Onshore at Bennelong Point an observatory was set up to check the chronometers and other instruments. We have not found any oceanographic measurements made by Lazarev on the *Suvorov* in its passage into the Pacific, although it is likely that they were part of the naval routine.

In the first half of the nineteenth century there were 36 Russian voyages around the world with the North Pacific settlements as their destination. The objectives of trading and transport were often combined with geographic and scientific investigation. Two of the most notable for their work for ocean sciences were those commanded by Otto von Kotzebue, firstly in the *Rurik* between 1815 and 1818 and secondly in the *Predpriyatye* between 1823.and 1826.

The circumnavigation in the *Rurik* was inspired by the enthusiasm of the powerful Russian Chancellor, Count Romanzoff, who from his personal wealth financed the construction of the 180-ton vessel . It was designed with movable keels specifically for exploration and equipped for scientific investigation. [Barratt (1981) p.33] The expressed geographic aim was the search for a navigable passage in the north between the Atlantic and Pacific oceans. The command was given to Lieutenant Kotzebue who had sailed with Krusenstern on the *Nadezhda* and Krusenstern was asked to plan the expedition. Two *savants* of international reputation were enlisted as naturalists for the voyage, Johann-Friedrich Eschscholtz, a young Estonian doctor and Adelbert von Chamisso, who had studied at the University of Berlin. From this small brig, carrying three naturalists, an artist and a crew of only thirty-two, Kotzebue obtained 116 subsurface temperature measurements at depths from 24 to 2448 feet (746 metres) using English made Six's thermometers. The thermometers were enclosed in a wooden case with a wire grating, presumably designed to prevent breakage, and they were fastened onto the sounding-line about six feet above the weight [Prestwich (1871)]. They were submerged for seven or eight minutes. In this pioneer work some difficulty was reported with the shifting of the indices, the positions of which indicated the maximum and minimum temperatures. The expedition had no success in finding a passage through the Arctic Ocean but the oceanographic measurements proved very valuable. As we will discuss later in the chapter, they were used to good effect thirty years later by the German physicict Emil von Lenz as data for a model of the movement of the deep water masses of the oceans.

The circumnavigation of the *Rurik* had been by way of Cape Horn and the Cape of Good Hope. In 1819, when Russia decided to send four ships on a two-pronged exploratory expedition into the Pacific, two into the Arctic and two into the Antarctic, the *Vostok* and the *Mirnyi* sailed around the Horn, but the *Otkrytie* and the *Blagonamerenniy* went eastward around the Cape. All four vessels visited Sydney as a port for refreshment and repairs. The *Vostok* and the *Miryni* needed considerable attention for damage after their penetration into ice-strewn waters south of Cape Horn.

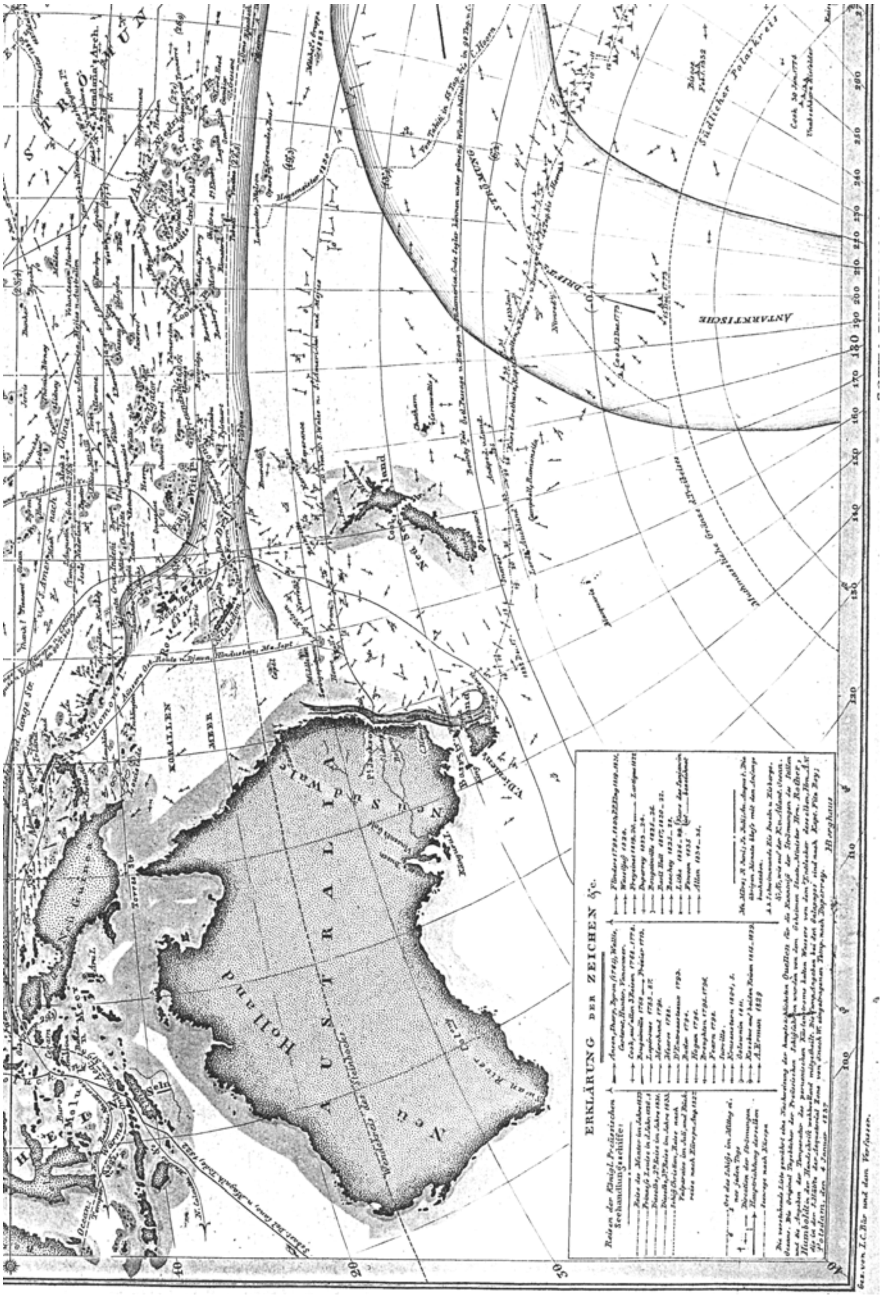
Each spent two periods of over a month in duration in 1820 and the officers and naturalists were received very hospitably at a time when relations between England and Russia were most cordial.

The Antarctic voyage of Fabian Bellingshausen and Mikhail Lazarev in the *Vostok* and the *Miryni* was of considerable geographic importance. They had traversed the Antarctic waters in considerable danger and discomfort in the opposite direction to Cook, crossing the Antarctic Circle on two occasions in January 1820 and again in December 1820. In January at a latitude of 67ºS, land was sighted through the fog. It must have been the Antarctic continent. In December of the same year, sailing south from Tasmania, they discovered an island beyond the Antarctic Circle which they named Alexander 1 Land, thinking it might be part of a continent but later it was shown to be an island.

Instructions for Bellinghausen's voyage required him to take observations of tides, wind directions, atmospheric conditions and currents as well as "measurements of the temperature of the sea . . . and of its salinity in different parts and depths, also measurements of temperature at known depths" Bellingshausen (Hakluyt 1945)]. This data is probably still available but we have not had the opportunity to sight it.

There were, as we have mentioned thirty six voyages into the Pacific in the first half of the nineteenth century. These voyages added considerably to the general knowledge of the Pacific and were most effective in the production of charts. Information about ocean features was used in the production of sailing directions and physical charts also by cartographers other than Russian – such as Berghaus in Germany (Figure 3.2) and Findlay in England.

The second Pacific voyage of Otto von Kotzebue in the *Predpriyatiye*, 1823-26, is worthy of special mention. On board was Emil von Lenz, a promising young student, who had been recommended by his physics professor, G.F. Parrot to participate in the voyage and who, with the commander's cooperation, conducted a series of temperature and salinity measurements at even greater depths than had been obtained on the *Rurik*. These became the basis for some important papers on the dynamics of the ocean which we will discuss later in the chapter.



3.2

Part of Berghaus's physical chart of the Pacific Ocean, 1837. This compilation, derived from the individual observations of many navigators was the first depiction of ocean currents in the Australian region.

In the second quarter of the nineteenth century, there was little prospect of significant geographic discovery in the Pacific, nevertheless the Admiralties of Britain and France also continued to show interest in sending expeditions to the South Seas. There were compelling reasons for outfitting these ambitious naval expeditions into distant waters. Improved geographic knowledge could bring great rewards in the form of strategically placed colonies or trading posts. Ensuing commercial activity brought increased need to 'show the flag' in support of whalers, traders and missionaries. In the interests of safer navigation, the study of ocean conditions and the charting of harbours and coastlines was necessary, and the navies of the great powers trained their officers for such work. The learned societies continued to provide advice or instruction on projects and technology. Naval astronomers, hydrographers and surgeons showed great versatility in their collection of scientific data and natural history specimens. In the period 1825-50 there was marked progress in the description of the surface currents of the Pacific, in the determination of temperature with depth and in the explanation of temperature variations in terms of the deep circulation. However it is now clear that progress would have been greater had there been more specialists in ocean physics such as Emil von Lenz amongst their numbers, for most naval officers were not familiar with the latest experimentation in the physical sciences.

Nevertheless we should today applaud the dedication, the courage and the spirit of inquiry in which data was collected with the limited technology then available. The feeling of the age may perhaps be observed in the words of Dumont d'Urville (1833, p.67-68):

> *Les révolutions passent, les opinions politiques peuvent varier à l'infini, mais les faits acquis à la science restent là pour honorer la mémoire de ceux qui ont contribué à leur conquête. Ce sont autant de jalons plantés par les générations pour attester le perfectionnement progressif de l'esprit humain.*
>
> *'Revolutions pass, political opinions can vary endlessly, but facts gained for science endure, to honour the memory of those who have contributed to their acquisition. They are all landmarks set up by the generations to attest the gradual improvement of the spirit of man.'*

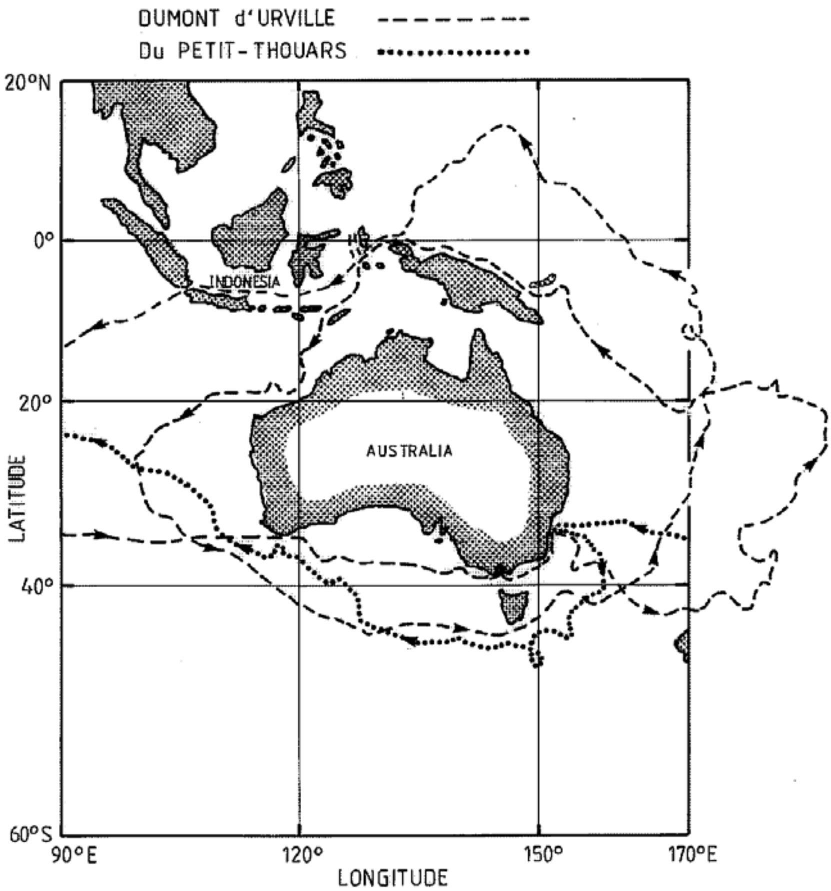
These are the sentiments of a French naval officer of broad scientific interests, who in the second quarter of the nineteenth century made three voyages to the South Seas, two of which he commanded. His portrait is seen in the Frontispiece.

Dumont d'Urville's Extensive Survey of Ocean Depths

The voyage had been suggested by its commander, who had proposed a detailed study of the Australasian region. This, he said, could better be achieved by visiting the same waters in more than one season, rather than by a circumnavigation of the globe. Visits to New Zealand, Tonga, Fiji and the Loyalty Islands were added to the itinerary. The expedition, comprising 79 officers and men, sailed from Toulon, April 1826, in the *Coquille,* renamed the *Astrolabe* for the occasion. Their departure was delayed a few days awaiting the arrival of replacements of the deep-sea thermometers, the first consignment of which had arrived broken.

The route of the voyage was by way of the Cape of Good Hope and the Indian Ocean and along the southern shores of the Australian continent. King George's Sound in Western Australia, Westernport Bay in Victoria and Jervis Bay in New South Wales were visited for replenishment of wood and water. There were at that time no British settlements in these harbours. The French expedition encountered only Aborigines, sealers, and a few runaway convicts. At Port Jackson, where they stayed seventeen days, Sydney newspapers reported that the French flag had been raised at King George's Sound, and, as on previous visits by French naval vessels, there was some disquiet about their intentions.

Crossing the Tasman Sea, Dumont d'Urville reached New Zealand where careful surveying filled out details of parts of the coastline unmapped by Cook. He found English missionaries established at the Bay of Islands. After New Zealand the expedition visited and surveyed many of the islands of Tonga, Fiji, the New Hebrides and New Britain and passed along the northern coast of New Guinea to the Dutch settlement at Amboina. The Dutch were most hospitable, but the tropical climate brought its usual toll of fever and dysentery for the crew. Dumont d'Urville had hoped to follow the western coastline of Australia closely when he turned southwards but, like Duperrey before him, he was forced by contrary winds to keep a more westerly course until he reached the latitude of Tasmania. Strong westerlies then brought him to Hobart in December 1827.



3.3
Dumont d'Urville's route encircled Australasia, on the 1826-1829 voyage of the* Astrolabe*. Abel Du Petit-Thouars' route, on the 1836-1839 world voyage of the* Vénus*, took him through the Tasman Sea and the Southern and Indian Oceans.

News of Lapérouse

At Hobart, Dumont d'Urville heard news of the claim that relics of Lapérouse had been found on a Pacific island to the north of the New Hebrides. D'Entrecasteaux, before him, had checked out a story of natives wearing European clothes in the Admiralty Islands, to no effect. The latest account concerned the claims of the captain of an English ship, Peter Dillon, whose word was not given much credence in Hobart. He had been involved in a law case there and sentenced to two months' imprisonment [Dixon (1935)]. Despite his strong desire to return to New Zealand and continue his surveys there, Dumont d'Urville nevertheless abandoned these plans and sailed for the Santa Cruz group. Here, in March 1828, on the island of Vanikoro, he substantiated Dillon's claims, recovered a few relics of the original *Astrolabe,* and erected a memorial to Lapérouse and his men (Figure 3.4). Dillon, whose evidence was accepted in France, received a reward for his discovery. An important stage had been reached in solving the 40-year-old mystery of the disappearance of Lapérouse. More than a century later, in 1964, the wreck of the *Boussole* was found on a coral reef on the other side of the island, victim at the same time, it seems, of hurricane conditions common to the region.

3.4
Inauguration of the memorial to Lapérouse erected at Vanikoro by members of the* Astrolabe *expedition, 1826-29. The* Boussole *and* Astrolabe *were wrecked 40 years earlier off the island of Vanikoro in the Santa Cruz Islands in 1788. From Dumont d'Urville (1830-1835).

Although all the crew of the *Astrolabe* were in good condition on their arrival at Vanikoro, the stay there was disastrous for their health. Fever began to spread rapidly among them. When the time came for departure, half the ship's company were unfit for duty. The commander, himself afflicted, wished to return to the healthier climate of Port Jackson, for rest and fresh supplies, but after a few days battling against contrary winds with an enfeebled crew, he turned northwards instead and on 2 May reached the Spanish settlement on Guam in the Marianas.

The Governor, Don Medinilla, offered generous hospitality, as he had for Freycinet. Forty fever-stricken men were hospitalised. By the end of the month they sailed again, for the Carolinas, Amboina, the Celebes, Batavia and then for the island of Mauritius. At the next port of call, the French island of Bourbon, fourteen men were left behind in hospital, mostly because of dysentery. The *Astrolabe* reached Marseilles in March 1829 after a difficult voyage of almost three years. Although there had been ten deaths on the voyage and twenty members of crew left at ports of call because of sickness, in the matter of natural history specimens for the museums and charts for the Navy the expedition had been very successful.

Throughout the voyage the officers of the *Astrolabe* had recorded four-hourly observations of the atmospheric and sea-surface conditions. In addition they had taken 54 measurements of deep-sea temperatures, of which 43 were in the southern hemisphere. The results were delivered to Arago of the Academy of Sciences. When, after two years, no paper had appeared analysing his data, Dumont d'Urville [(1833) p.52], with some bitterness, undertook a review of his own:

> *Without my desire to satisfy the expectations of the members of the Institute, I would never have taken upon myself to subject to this task men who had to experience so many misfortunes and cruel illnesses.*

He was referring to the heavy manual labour entailed in hauling in from great depths the sounding line with the *thermometrographe* attached. He often remarked that this exercise was no easy task for the ship's complement of less than eighty men. When their numbers were reduced by sickness the task was even more burdensome.

Dumont d'Urville's Generalisations and Hypotheses

In the face of what he saw as a lack of regard for his work by the Academy of Sciences, Dumont d'Urville undertook the compilation of a set of all the deep-sea temperatures recorded to that date. He found 421 such measurements, of which 138 were at depths below 200 brasses. (A *brasse* was a French fathom, 1.62 metres, and there were 138 meaurements below 320m) These he arranged by depth. Included was an extensive set of 97 single and serial measurements obtained by the British captain Frederick Beechey on the 1825-28 voyage of the *Blossom.* On this voyage around Cape Horn and through the Pacific Ocean to Bering Strait the range of Beechey's measurements covered both the North and South Atlantic and the North and South Pacific and depths from 30ft (9m) to 5124ft (1562m). An important set of deep-sea temperatures which was not included and which, since they were published in St Petersburg, we must suppose had not come to his attention, were those recorded on the voyage of the Russian ship, *Predpriyatiye,* 1823-26, to which we shall refer again later.

Dumont d'Urville's generalisations, *Sur La Température de la mer à Diverses Profondeurs,* may be found in the volume on *Physique* of the official account of the voyage. He considered and discussed the subsurface temperatures of the Mediterranean Sea, as well as those of open seas. After an historical review of the circumstances under which the marine data was obtained, he presented several generalisations:

> 1. *Throughout the open seas the temperature of the lower levels at a depth of 600 brasses* (974 metres) *and more is nearly constant and at a temperature of about 4.4°C.*
>
> 2. *This temperature is modified progressively towards the surface to reach the temperature of the surface waters relative to the season of observation.*

Here Dumont d'Urville was giving his support to the current but fallacious theory that the lower layers of the oceans (he suggested below about 1000 metres) were filled with water of a uniform temperature of about 4°C, extending down to the ocean bottom. This theory depended on the assumption that salt sea water behaved in the same way as fresh water and reached its point of maximum density at 4°C. Despite the fact that prior experimentation by Marcet (1819) in England and Erman in Germany seemed to indicate that, for salt water, an even lower temperature would be found at the point of maximum density, the 4°C theory came to be widely accepted and it persisted into the 1840s and even beyond. The concept found support in a number of recordings of this temperature at great depths by contemporary observers, particularly those taken by Beechey. These were consistent with Dumont d'Urville's own lowest reading of 4.4°C, which he had recorded at 1330 metres in tropical waters off the north-west coast of Australia. Although Dumont d`Urville had heard of Erman's laboratory experimentatiom with salt water, he queried the results [(1833) p.63]: 'If the experiments of M. Hermann [sic] are definitely confirmed, my theory collapses'.

3.5 Heinrich Friedrich Emil Lenz , 1804-1865, geophysicist.

The 4°C fallacy had been supported by the inaccuracy of the Six-type thermometer which gave too high a value of temperature at great depths because the relatively elastic glass bulb was squeezed and deformed by hydrostatic pressure at these depths. No information on this possibility had been provided for Dumont d'Urville by the physicists of the Academy of Sciences when he sailed with the *Astrolabe*. The Bunten thermometers used on the *Astrolabe* were protected from damage by a metal capsule, but, it seems, were insufficiently protected against the pressure of the water in the greater depths of the ocean. This was, in fact, the reason why the glass bulb of a thermometer just withdrawn from a considerable depth suddenly shattered on deck when accidentally touched. The incident was noted but its significance ignored.

After his voyage with Kotzebue in the *Predpriyatiye* Emil Lenz had pursued his interest in ocean physics and as a result of experiments with Professor Parrot, they drew attention to the vulnerability of the Six thermometers. They pointed out (Lenz and Parrot, 1832) the necessity of protecting deep-sea thermometers from distortion by hydrostatic pressure. The glass on the Six thermometer was inadequate under great pressure. At large depths the reading would appear higher than it should be. This paper published in St Petersburg must have gone largely unnoticed or its message was not conveyed to naval officers attempting the measurements. Dumont d'Urville did not take it into account. And on British scientific voyages unprotected thermometers were used for some twenty years after the warning had been published.

3. A further generalisation by Dumont d'Urville proved to have a sounder foundation. He noted that, in the zone closest to the equator, namely between 10°N and 10°S, an unexpectedly rapid cooling seemed to occur in the submarine layers of the sea up to 100 brasses (162m) depth. The reason was not immediately apparent, he said, but the phenomenon was consistent with the idea of equatorial waters, constantly diminished by considerable evaporation, being replaced from below by the transfer en masse from higher latitudes of deep, cold water, stabilised, he proposed, at 4.4°C.

4. The replenishment of equatorial waters, Dumont d'Urville suggested, probably originated from a movement of colder waters from the region between latitudes 40° and 60°. Time has shown this idea to have some validity, but not his attempted explanation of a large scale

seasonal movement of ocean water. In the 40° and 60° latitude zone, he wrote [(1833) p.64], there would be a point where cold waters start moving slowly at depth and:

> *that the lower waters of this zone are directed periodically in two imperceptible currents, the one towards the equator to check the warming effect of the successive transfer of heat from the upper waters, the other towards the poles to oppose the cooling down which results from the opposite effect. The first would prevail in winter, which corresponds to the dry season of the torrid zone, to replace the waters lost by evaporation and which are not restored by the rains; the current towards the poles would occur in summer to replace the volume of lighter waters coming from the melting of ice, which soon gets away at the surface towards the temperate regions*.

There were, he claimed, sufficient measurements from the southern hemisphere between latitudes 40°S and 60°S to show that 4°C temperature occurred very close to the surface there. The 4°C limit, he said, seemed already established for depths of 200 and 300 brasses (330-487 metres), and for greater depths, there were the 'three valuable measurements of Beechey at a latitude of 47°, which gave uniformly a temperature of 4.1° at depths of 678, 825 and 961 brasses' [(1833) p.61]. There would, he suggested, be a zone where, at a certain season, the entire mass of the water would be at the constant temperature of 4°C from the surface to the bottom. His hypothesis about the characteristics of the waters between latitudes 40 to 60 degrees, was to be taken further, as we shall see in chapter four, to develop another unsustainable concept in ocean science by James Clark Ross (1847), the renowned British investigator of the Southern and Antarctic oceans.

Publication of the Results of the Voyage of the Astrolabe

The published report on the results of the *Astrolabe* expedition, written by Dumont d'Urville and the naturalists, filled fourteen volumes and five atlases. They appeared over the years 1830 to 1835. The work of the naturalists, Dr. Jean Rene Contant Quoy, J. P. Gaimard and Pierre Lesson was highly commended. Dumont d'Urville presented himself for a place in the Academy of Sciences, when a vacancy occurred in 1829, and was bitterly disappointed when he was not elected. He saw his rejection as the work of François Arago, whose lack of interest in his scientific achievements he continued to resent, and whom henceforth he regarded as an enemy.

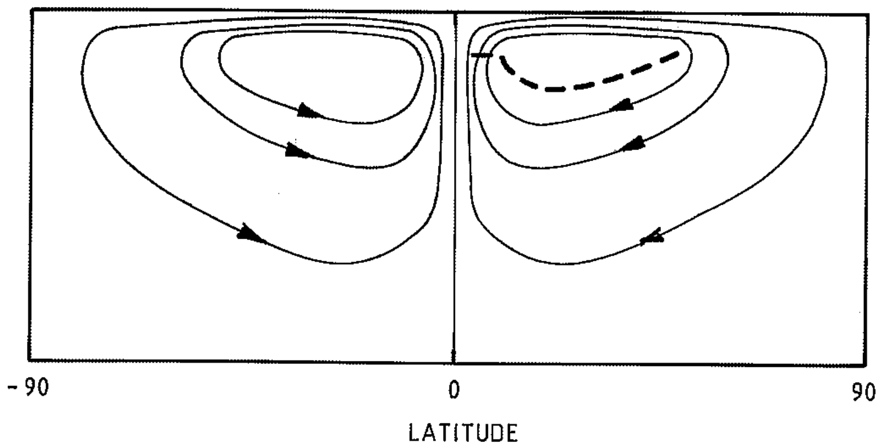
A Dispute about the Height of Ocean Waves

There was another point of disagreement between the eminent astronomer and the explorer-scientist. When the *Astrolabe* in 1826 was making its way across the southern stretches of the Indian Ocean, it encountered a gale with mountainous seas in which a man was lost overboard. Dumont d'Urville, in his narrative, expressed the opinion that the waves reached a height of 'at least 80 to 100 feet'. In an era when opinions were being expressed that no wave would exceed 30 feet, Dumont d'Urville's estimations were received, it seemed, with some scepticism. No one was more outspoken in his rejection than François Arago, who, calling for a more scientific approach to the estimation of wave height in his instructions for the physical research on the voyage of the *Bonité*, suggested that imagination played a part in estimations as high as '33 metres' (108 feet). Later, in his 1841 report on the results of the *Vénus* expedition, Arago made further reference to the 'truly prodigious waves with which the lively imagination of certain navigators delights in covering the seas'.

Dumont d'Urville, smarting at the ridicule, was provoked to make an indignant rebuttal of this charge. And indeed, twentieth-century wave observations of the Southern Ocean from satellites now suggest that, at least in a once-in-a-hundred-years context, Dumont d'Urville's estimation was not altogether implausible.

The First Model of Longitudinal Deep-Ocean Circulation

As we have noted there had long been speculation about the origin of the cool water found at depth in equatorial and tropical waters. Count Rumford in England and Alexander von Humboldt in Europe had advanced the theory that such water must derive longitudinally from the polar regions of the earth, since there was no way it could have originated from cooling of the surface waters warmed by the tropical sun. The theory was supported in the 1820s by Dumont d'Urville's observations and in the 1830's by the meteorologist, François Arago, but Emil von Lenz, in the 1840s, was the first to propose a model of the deep water circulation from polar to equatorial regions. Reviewing the series of temperature measurements made in 1815-18 by Kotzebue in the Rurik at nearly the same depths and only short distances apart over a great length of the North Atlantic, he observed a rapid rise of the isothermal planes in approaching the equator, in the manner shown schematically in Figure 3.6. The submarine isotherm of 14.5°C, plotted from 48°N to the equator



3.6
Lenz's view of the symmetrical circulation of the ocean in the meridional direction was based on the existing measurements, which showed the shoaling of the 14.5°C isotherm as one approached the equator. This picture of the deep-ocean circulation is no longer believed to be accurate. There is significant flow at depth around Antarctica, connecting the three ocean basins. Also there is not a source of sinking water in the North Pacific and Indian Oceans. Despite later embellishments to Lenz's concept, his model remains a useful generalisation.

was used as an illustration. At latitude 45°N to 48°N it lay at 350 feet. By latitude 23°N to 26°N it had sunk gradually to 640 feet, and then, rising more abruptly as it approached the equatorial regions, it lay at 390 feet below the surface at latitude 15°N. This he interpreted as an indication that a subsurface flow of cool Atlantic water from higher latitudes moved at depth towards the equator and there rose from below towards the surface to replace warmed surface water which must be moving outwards on the surface towards the northern pole. A corresponding flow, but in the opposite direction, he postulated, took place in the southern hemisphere

> *so that, in a zone surrounding the equator where both are united, the water flows almost in the direction from below up to the surface; and thus one meets with cold water in much shallower depths than in those two zones north and south which lie immediately adjoining, and which, in fact, is shown by the observations.* [Lenz (1847) trans. Prestwich (1875)]

Thus, from Kotzebue's 1815-18 data, Lenz proposed a model of polar-to-equator, deep-ocean circulation, which gave support to the thoretical notions on this topic which for several decades had awaited substantiation. By 1847, there was, as well, supplementary data from a French expedition in the *Vénus,* to which we shall refer later, and Lenz's understanding of the physics of the ocean had been increased by his own observations on Kotzebue's second voyage and by his experiments with the thermometers used for measuring subsurface temperatures. His model of polar-to-equator deep-water circulation influenced ocean physicists for seven decades. Improvements in technology then occasioned modifications of detail to his theoretical model.

The Salinity of the Sea

From over two hundred observations of specific gravity made during 1823-26 on his voyage, Lenz (1832) could conclude that to the depth of 1000 fathoms, over a wide range of latitudes, the water of the sea possessed the same degree of saltiness. The density of sea water depends on the amount of dissolved salt. For the sea surface, however, he was able to identify and explain the existence of salinity maximums within the tropics in the Atlantic Ocean a few degrees north and south of the equator. The same situation, he suggested, was possible for the Pacific Ocean. He pointed to the effect of the heat of the sun on the rate of evaporation and hence on the salinity of the ocean surface, but drew attention to the fact that evaporation at the equator is minimised by the calm air that usually prevails there. We now know that evaporation exceeds precipitation away from the equatorial band of the ocean.

Lenz won renown for his work in other fields at the St Petersburg Academy of Sciences. He is remembered particularly for the discovery of two fundamental laws of electro-magnetism.

What is the Lowest Temperature to Occur at the Bottom of the Oceans?

At the time that Lenz sailed on the *Predpriyatiye* in 1823 it was generally known that there was a progressive decrease in temperature with depth in the oceans, but it was believed that there was a limit to the temperature decrease. By analogy with the limit of about 4°C found in the deep fresh-water lakes of Europe, scientists generally believed that this was the temperature of sea water also at its point of greatest density and that the bottoms of the oceans were filled with a dark, lifeless layer of constant 4°C water. As we have noted, the measurements made by Dumon d'Urville seemed to support this theory. Using the maximum and minimum index thermometer devised by James Six, no one had measured at depth any temperatures lower than 4°C. On the *Predpriyatiye*, however, within the tropics, Lenz measured several deep temperatures as low as 2°C. He had used, not a Six-type thermometer, but a version of the Hales bucket, designed by the Russian academician, G. F. Parrot [Lenz (1830)]. To the insulated bucket, which had valves top and bottom was attached a strong mercurial thermometer and the apparatus, which Lenz termed a 'bathometer', was left submerged up to fifteen minutes. He applied a correction, calculated by experimentation, for the temperature increase which would occur as the bucket was retrieved. Corrections were also made for the angle of the sounding rope and for gain in the length of the rope by tension under water [Prestwich (1875) p.599]. In all he had recorded nine occasions when the temperature of the water at great depth was less than the 4°C which Dumont d'Urville had supported as the uniform bottom temperature of the oceans. His findings occasioned little comment at the time but were substantiated by others in the next decade.

The Voyages of Laplace

There were many French naval voyages into the South Seas in the 1830s. Most were primarily of a diplomatic and commercial nature. The former Spanish colonies in South America were the target of numerous trading vessels and there was great interest in the whaling industry. As matter of routine, the naval vessels included some observations in meteorology and ocean conditions.

Two such voyages were commanded by Cyrille Pierre-Théodore Laplace. The first, a voyage in the *Favorite*, 1831-1832, was intended to complement the earlier diplomatic mission of Hyacinthe de Bougainville. The aim was to re-establish French interests in Indo-China and to make charts and gain information of value to merchants. On the voyage to Indo-China in the 24-gun, 680-ton corvette, Laplace was instructed, incidental to his primary purpose of 'showing the flag', to make a careful study 'by means of numerous observations' of the direction and strength of the ocean currents encountered throughout the voyage. These were tabulated and included in the published account of the expedition, together with the systematic three-hourly meteorological observations carried out by the ship's officers [Laplace (1833-1839)]. There was no publication of any data on sea-surface temperatures.

The English settlement at Hobart provided not only refreshment but also vital hospitalisation for the crew of the French corvette, which arrived with sixty of their number out of action as a result of a 'frightful epidemic' of dysentery. Laplace spoke of the generosity and kindness shown to his crew at Hobart. An account of the penal system was included in the official account of this 28-month voyage, which, with handsome colour plates and an atlas of charts, appeared in parts over the six years after the return of the expedition.

Laplace commanded a second voyage to south-east Asia and the Pacific in the years 1837-40, which was a period of extensive French naval activity in that region for the protection and promotion of French commerce. In the same year, for instance, the corvette, *Héroine*, commander J.-B. Cécille, was despatched to the Pacific, with specific instructions to patrol the whaling regions where French vessels were in conflict with British and American operations. Although the gathering of information 'useful for hydrography and the physical sciences' was included in the official instructions for the voyage, no meteorological or oceanographic data has been sighted by the authors in the six-volume report of this voyage, published by the Paris *Imprimerie Royale* [Laplace (1841-53)]. There were, however, voluminous reports on the trade prospects, indicative of the increasingly commercial aims of the era. As so often before in the age of sail, there was a heavy cost in human life.

There were 36 deaths on the voyage, and eleven invalids were left in hospital or transferred to other vessels. At various ports of call twenty men deserted [Dunmore (1969) p.336].

The voyage of the *Bonité,* 1836-1837

The first expedition of the reign of Louis Philippe to take the 'King's flag and the noble colours of France' into the Pacific was that of the *Bonité*, captained by Auguste-Nicolas Vaillant. The *Bonité* was an armed naval storeship and troop carrier of 800 tons. She was despatched primarily on a diplomatic mission, conveying consular officials and their staff to the South American republics of Chile and Peru, and also to the Philippines. En route information of value to French traders and the Minister for Foreign Affairs was to be gathered. Instructions for the voyage included a series of observations on meteorology, physics and magnetism and although no lengthy stays were planned for any of the places to be visited, nevertheless it was expected that opportunities would arise for service to other sciences.

The French Academy of Sciences had drawn up special instructions for scientific work on the voyage of the *Bonité*, which became guidelines for other French expeditions of that era The expedition sailed from Toulon in February 1836, visiting Rio de Janeiro and Montevideo on the east coast of South America and Valparaiso, Callao, Payta and Guayaquil on the west coast, and then sailing north-west to Hawaii. A French naval presence in the Sandwich Islands was required mainly in support of Catholic missionary endeavours. From there Vaillant visited the Philippines, Macau, Vietnam, Singapore, and India, seeking commercial opportunities for France. The islands of Bourbon in the Indian Ocean and St Helena in the Atlantic were visited for supplies on the homeward sector and the *Bonité* reached Brest in November 1837. It was a circumnavigation of short duration and carried out without loss of life or serious misadventure.

Instructions for the Advancement of the Physical Sciences

The instructions for the physical sciences had been prepared by François Arago (1836), whose likeness is shown in Figure 3.7:

In meteorology, Arago wrote, *we must resign ourselves to making observations which, for the moment cannot lead to any brilliant result; we must, in effect, keep in mind that we are providing our successors with the terms of comparison which we ourselves lack; it is necessary to prepare for them the means of resolving a great number of important questions which we have not had the chance to broach, because antiquity possessed neither the thermometer nor the barometer*.

3.7
François Arago (1785-1853), the eminent French astronomer and Secretary of the Academy of Sciences, whose suggestions for research into oceanic physics were part of the instructions carried by French naval vessels on nineteenth-century Pacific exploration.

Along with the hourly meteorological and sea-surface observations required of them, the officers of the *Bonité* were asked to record the direction and speed of the ocean currents giving particular attention to the cold current along the coast of Chile and Peru, first pointed out by Humboldt. By their measurements of the sea-surface temperatures from Cape Horn to the equator, it was hoped, wrote Arago, that they would extend the information about this current which Duperrey had procured in the *Coquille.* The value of such information was borne out by a navigational problem experienced by Vaillant himself. After a stay in the port of Guayaquil he had intended to visit the Galapagos Islands, but in a period of four overcast days, when no astronomical checks could be made, he found that the ship was a degree further north and half a degree further west than their estimated position. It seemed they had overestimated the strength of the north-west current [Dunmore (1969) p.273] and were then north of the islands. Vaillant decided to forego the visit to the Galapagos he had hoped for and to continue on towards the Sandwich Islands.

As for the variance in reported wave heights encountered in strong seas, a range commonly from 5 metres to 33 metres Arago stated, he had some practical suggestions for improvement of the estimations. An observer should be assigned to climb the mast, and, when the ship was in the trough of a wave, determine the height at which he could see, in a straight line, the crests of the oncoming and the receding waves. This simple procedure, he proposed, would provide an informed estimation of the vertical height of the surrounding waves.

Arago recommended that the *Bonité* carry apparatus for sounding and for the measuring of depth temperatures:

> *There is little doubt today but that the cold lower waters of the equatorial regions are brought by submarine currents coming from*
>
> *the polar zones; but even the complete solution of this point of theory would not remove all interest from the observations which we are recommending here. Who does not see, for example, that the depth where one will find the maximum coldness . . . must depend, at each parallel, in quite a direct manner upon the total depth of the ocean, whereby it may be permitted to hope that this last quantity will be*

> *deduced sooner or later from the value of the thermometric soundings.*

The *Bonité* was provided with Six-type thermometers, made by Bunten, for subsurface measurements. For protection they were wrapped in wool, enclosed in a glass tube and then in a copper cylinder, but, even so, according to Prestwich (1875), the cylinder was often not strong enough to prevent the entry of water, and the effect of hydrostatic pressure. The most convenient opportunity for this work occurred when the ship was becalmed near the equator. Sixteen temperature measurements were made at a variety of depths down to 2695 metres [Arago (1838)].

Using apparatus devised by J.-B. Biot, the officers of the *Bonité* procured water samples from great depths and made investigations of the composition of sea water. Studies were made of terrestrial magnetism at all the ports of call. There is no mention by Arago in his report to the Academy of Sciences of any calculations from the *Bonité* of wave dimensions.

Valuable as were the observations in physical oceanography carried out throughout the voyage of the *Bonité*, they were overshadowed by the results brought back by a lengthier voyage covering the South Seas at the same period, the voyage of the *Vénus.*

Ocean Physics Advanced by the *Vénus* Expedition, 1836-1839

The understanding of the dynamics of the oceans was conspicuously advanced by observations on the voyage of the French frigate *Vénus,* 1836-39, commanded by Abel Du Petit-Thouars.

Du Petit-Thouars's main task on the *Vénus* revolved around the protection of increasing numbers of whalers, traders and missionaries as well as the charting of safe harbours for their activities. In the year 1838 as many as twenty French ships visited the Bay of Islands, in New Zealand [Dunmore (1969)]. In the summer of 1840 the visiting French corvettes, *Astrolabe* and *Zélée,* noted thirteen French whaling vessels in port at Hobart at the same time.

The *Vénus* entered the Pacific by way of Cape Horn, visited several South American ports, and traversed the North Pacific as far as Kamchatka. Returning southwards, Du Petit-Thouars examined the coasts of California and Mexico and the Easter Islands before visiting Valparaiso for repairs and supplies. Then in the summer of 1838 the expedition reached New Zealand and crossed the Tasman Sea to Australia. After almost a month in Sydney Harbour, where an observatory was set up on Pinchgut Island (now Fort Denison), the *Vénus* sailed southwards and eventually westwards around Tasmania, battling against violent winds and high seas and on to Cape Leeuwin (See Figure 3.3). Sailing conditions were so poor against the contrary winds of the Southern Ocean that the voyage from Sydney to Cape Leeuwin took 44 days. A circumnavigation of the globe was completed by a passage across the Indian Ocean and around the Cape of Good Hope into the Atlantic. The voyage of two and a half years ended at Brest in June 1839.

Oceanographic Contributions from Du Petit-Thouars and Dortet de Tessan

During the circumnavigation of the *Vénus* a regular intensive program of scientific observations was pursued. They included hourly meteorological and sea-surface temperatures, systematic observations of surface currents and a series of 59 temperature casts, amongst which were recorded some very low temperatures at great depth. These latter were conducted with considerable expertise by the *Ingénieur-hydrographe*, Dortet de Tessan.

The observations from the *Vénus* proved particularly valuable for an emerging picture of the surface circulation of the Pacific Ocean. In the course of several passages between the Pacific-coast ports of South America significant information was gathered about the extent of the Peruvian current. Several temperature casts revealed the great depth of the massive cold stream moving towards the equator. It was shown to be no less than 1780 metres deep by a sounding to the S.W of Chiloe, where the water measured 13°C at the surface, 4.1°C at 812 metres and as low as 2.3°C at 1786 metres. No bottom was reached in this last sounding.

During the passage of the Tasman Sea from New Zealand to Sydney, Tessan could observe the presence of the warm current moving southwards along the eastern margin of New South Wales. On the voyage southwards from Sydney, when, to the east of Tasmania, the vessel for two days passed through a band of water 4 to 5 degrees higher than each side of it, he commented that this could be an extension of this warm current, which by this date had been drawn on Berghaus's chart of the Pacific. In the light of present knowledge, it may have been an eddy shed from the East Australian Current which does not usually extend so far south. Such eddies can form or coalesce within a few days. For example, in 1984-85, this phenomenon, was observed by satellite imagery to be occurring on the continental shelf of Tasmania [Anon (1987)]. Such variation in water temperature is of considerable significance for the fishing industry.

As the *Vénus* rounded Cape Leeuwin in February 1839, the hydrographer was looking for evidence of a likely equatorwards cold current on the eastern margin of the Indian Ocean. His theory was supported by temperature measurements he obtained at depth in the region traversed. While this is the area where the warm coastal Leeuwin current is also to be found flowing southwards inside the cold West Australian current, Tessan's en-route observations were not detailed enough for this complexity [Jones and Jones (1989 B)].

At the conclusion of the voyage, Tessan, who prepared the volumes on *Physique*, could offer a strongly founded generalisation, now familiar to all geographers, about the pattern of

> *the cold currents directed from the poles towards the equator on the western coasts of the continents, the cold currents directed from the east to the west along the equator and the warm currents directed from the equator towards the poles on the eastern sides of the continents*. [Du Petit-Thouars (1841-45) Vol 10 p.381]

> *the Vénus observations were very useful in their day. Tessan's generalisations formed a major basis for the systematisation of the surface circulation of the Pacific proposed in Findlay's assessments of 1851 and 1853, which will be discussed later.*

As for the height of the largest wave encountered on the *Vénus*, it was reported to have been 7.5 metres, from the summit to the trough, a figure considerably less than that claimed by Dumont d'Urville for the 1826-29 voyage of the *Astrolabe*. The longest waves were said to have been encountered to the south of New Holland, estimated to have been three times the length of the *Vénus*, or about 150 metres [Arago (1841)]. Only with the collection of a much larger statistical base can the plausibility of d'Urville's large wave be assessed.

Attempts were also made to find the greatest depth of the ocean. On one occasion, near Cape Horn, no bottom was found in a sounding calculated to be at a depth of more than 4000 metres; on another, in mid-Pacific, close to the equator, the depth was calculated to be more than 3790 metres. Such investigations could involve more than two hours haulage by sixty or more sailors.

Du Petit-Thouars and Dortet de Tessan brought back from this voyage some significantly low subsurface temperature measurements of the ocean at great depths. Moreover, conscious of the problem of hydrostatic pressure on the readings of the thermometer, they experimented to calculate the possible extent of its influence. Tessan was using a self-registering maximum and minimum thermometer, made by Bunten, enclosed in a sealed metal container intended to be watertight and hence a protection against the pressure of water at great depths. On some occasions, nevertheless, water did enter the container. For these readings Tessan applied the pressure correction he had worked out by experimentation. Sometimes at depths below 2000 metres both container and thermometer were crushed. Nevertheless a number of readings were procured well below the 4.4°C recorded by Dumont d'Urville and Beechey. For instance, Tessan recorded 3.0°C and 2.7°C at locations 1610 metres deep near King George's Sound, Western Australia. The lowest reading of 1.4°C was obtained near the equator in the Pacific at a depth of 3740 metres.

These low temperatures were consistent with the similarly low measurements obtained a decade earlier by Lenz on his voyage with Kotzebue. Lenz's results, it will be remembered, had been obtained, not with the Six thermometer, but by submerging for up to fifteen minutes a mercurial thermometer in an insulated container fitted with valves, and recording the temperature of the water sample thus obtained.

As a result of the recording on the *Vénus* also temperatures at depth several degrees below 4°C, it was pointed out by François Arago (1841) in his report to the Academy of Sciences that the claim that the waters of the ocean would never descend below 4.4°C should now no longer be heard. It should have been the end of the fallacy of the ocean depths filled with water uniformly at that temperature, but in fact the idea continued to persist for another decade in many circles, along with the neglect of the pressure factor in measuring deep-sea temperatures.

The long-held belief, however, in a direct submarine connection between polar and equatorial water was reinforced by Tessan's measurements at depth in the intertropical regions of temperatures of 2° and 3°C. The only explanation, said Arago, that physicists could accept for such low temperatures was the existence of submarine currents carrying the lower waters of icy seas as far as the equator. This theory, as seen in Fig 3.6, was subsequently supported by Emil Lenz (1847) in his review of the data collected to 1845.

Another aspect of the circulation of the oceans' depths received thoughtful consideration from Tessan. From apparent anomalies in depth-temperatures recorded below similar surface temperatures and from observations of the angle taken by the sounding line he saw indications that it could be possible to have a current of a different direction and temperature below a surface current. This he said, could explain why the direction of the sounding line did not always agree with that indicated by the ships's set, calculated from dead reckoning [Du Petit-Thouars (1841-45) Vol 10 p.392]. A series of readings in a vertical line, he said, would have been useful for this hypothesis, but, except in a few instances, such a time-consuming exercise had not been found practical for a warship, too constrained by circumstance to devote the necessary time. His suggestion has proved valid. In the Pacific Ocean, for example, a strong subsurface countercurrent is now known to be flowing eastward beneath the westward-flowing South Equatorial Current at a depth of about 60 metres. Nowadays oceanographic research ships are often equipped with a device called an acoustic Doppler current profiler. This instrument can measure the currents, relative to the ship, at a number of depths simultaneously. What is more, there is no need to stop the vessel as the currents can be determined while the ship is underway.

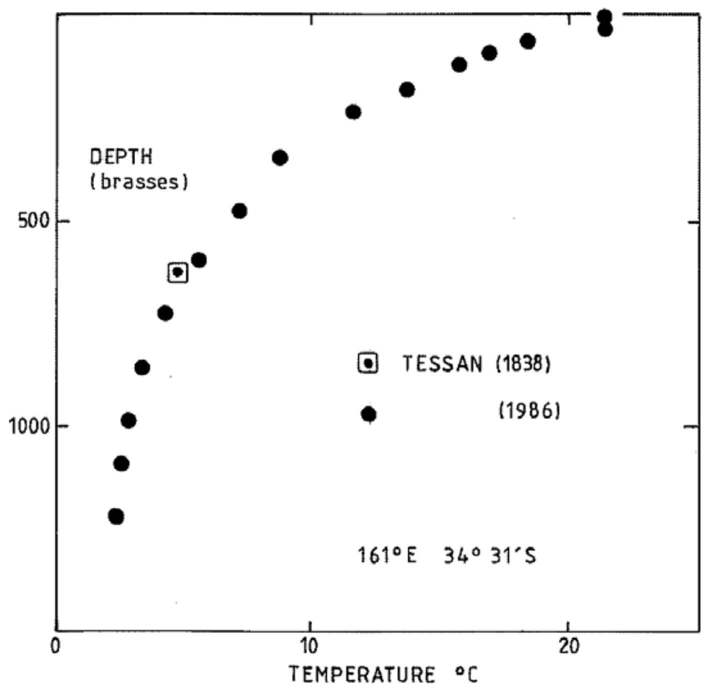
Temperature Records and Climatology

Since at depths below 1000 metres the seasonal temperature fluctuations in the oceans are small, global climatic changes over periods of centuries could be revealed by comparing temperatures in the mid-depths of the ocean taken by the nineteenth-century oceanographers and those measured later. We have chosen, as an example, a measurement taken in 1838 from the *Vénus* at a depth below 1000 metres in the Tasman Sea almost 150 years ago to compare with a temperature cast made from the oceanographic research vessel HMAS *Cook* in 1986 at the same coordinate.

The modern measurements are made with reversing thermometers, but Tessan's maximum and minimum thermometer in this cast was successfully protected against pressure effects and he made a correction to the depth to allow for the angle of the sounding line. Figure 3.7 shows the comparison. In this instance there is remarkable similarity with Tessan’s earlier measurements. It should be possible to re-examine other locations in the South Seas for which historical data survives from the great scientific voyages of the nineteenth century.

The Surface Currents of the Pacific Ocean

As already noted, the first atlas of the Pacific was that drawn by Krusenstern. The *Atlas of the South Seas* was published in two volumes at St Petersburg in 1824 and 1827. It contained large-scale charts of islands and coastlines and textual information for mariners on the currents reported by navigators to that date, but it did not depict the ocean currents. In 1837, however, Heinrich Berghaus made such a current chart. At the Potsdam *Geographische Kunstschule* he worked on the production of a companion atlas for Humboldt's *Kosmos*. For a physical chart of the Pacific Ocean he undertook an exhaustive review of the observations of many navigators, and produced a chart depicting the surface currents, as noted to that date, by arrows or streams. This chart was incorporated into his *Physikalischer Atlas* of 1845. It defined the extent of the cold Humboldt or Peruvian current, which because of the Spanish settlements on the west coast of South America was well known to navigators from Europe and was first described by Alexander von Humboldt in 1803. The existence of the North and South Equatorial currents was shown on Berghaus's chart, at least for part of their extent. A warm 'Japanese Current', and a warm stream off the coast of New South Wales and Van Diemen's Land were also indicated.



3.8
A single deep-sea temperature reading from the French frigate, la Vénus in the Tasman Sea in 1838, obtained with a pressure-protected thermometer, gives a result closely compatible with that observed in a serial cast from HMAS Cook 148 years later.

A section of Berghaus's 1837 Pacific chart is shown as Figure 3.2 Two interesting features are worth noting :

1. No clear idea is apparent of the closed circulation patterns of the surface currents of the ocean basins. A broad current is shown flowing northwards out of an area where Antarctica is now known to be. The charts of the Indian and Atlantic oceans show no corresponding inflow. At this time, 1837, the Antarctic continent, of course, was not yet mapped.

2. The current off the east coast of Australia is shown extending too far southwards and with arrows indicating a change of direction. This current which had been observed since the time of the settlement at Port Jackson and even earlier by Cook and Lapérouse is drawn from about latitude 28°S to the latitude of Hobart. The arrows indicate an incorrect seasonal reversal. This seasonal change of direction was based on a statement of Lieutenant Jeffreys who sailed a number of voyages between Sydney and Hobart between 1814 and 1817 on the British survey vessel HMS *Kangaroo* (see chapter four). The 1829 British Admiralty *General Chart of Terra Australis or Australia* included Jeffrey's description. We now know that the region off the Australian coast between Sydney and Hobart has a well-developed eddy structure. While it is not presently believed that there is a seasonal nature to these eddies, the large variability in current, speed and direction that results is likely to have led Jeffreys to attribute this to the seasons. The name, *New South Wales Alternating Current*, was used on the subsequent English version of Berghaus' Pacific chart, to be found in Johnston's *Physical Atlas* of 1848 and 1850.

In the 1850s, as a result of the accumulation of recorded observations of the now more widely traversed and studied Pacific Ocean, a more detailed and comprehensive generalisation of the surface movements of this ocean became possible and the earliest was achieved, by the British geographer and cartographer, Alexander George Findlay. In a review of the existing knowledge of the Pacific Ocean in 1851 in his *Directory for the navigation of the Pacific Ocean*, he mentioned his need to consult over one hundred books, in a variety of languages, in order to compile his up-to-date sailing directions. In 1853 in a report on the likely effect of the currents of the Atlantic and Pacific on the proposed Central American canal, Findlay (1853) was able to draw for the Pacific a two-cell system of surface currents, the essential features of which correspond largely with the picture today. By that date there was also sufficient evidence to define the full west-to-east extent of the Equatorial counter current. He did not assign seasonality to the East Australian Current. His information is drawn in large part from the observations of the numerous Pacific navigators we have mentioned. Contributions came also from the voyages of other British and American navigators, which we shall describe in the following chapters.

Dumont d'Urville in Oceania and the Antarctic, 1837-1840

Mention should be made of another French scientific expedition of this era - Dumont d'Urville's third voyage into the southern hemisphere. During the 1820s English and American sealers had penetrated the far southern waters of the great oceans to ever higher latitudes. The English sealer, James Weddell, who found the South Orkney Islands, reached the high southern latitude of 74° in January 1823 in the area which now bears his name – the Weddell Sea. In his *Voyage Towards the South Pole* (1825) he suggested that it should be possible to reach the South Pole by ship. In 1831 and 1832 Captains Biscoe and Avery charted Enderby Land and Graham Land which eventually were seen to be part of an Antarctic continent. When, in 1837, Dumont d'Urville, his work on the publications of the voyage of the *Astrolabe* now finished, proposed another expedition to further survey the islands of the South Seas, he found the idea of a voyage of exploration was very popular with King Louis-Philippe. To his proposal a further task was added. The British were known to be preparing an Antarctic expedition. It was time that France exhibited her interest in this as yet incompletely explored region. An attempt to penetrate the Antarctic regions in summer, it was planned, could be combined with winter surveys amidst the islands of the South Pacific.

Dumont d'Urville, now 46 years old, took command again of the *Astrolabe*, and of another 300-ton storeship converted to a corvette, the *Zélée*. His friend, Charles Hector Jacquinot, who had sailed with him in the *Coquille*, and as his second in command on the previous voyage of the *Astrolabe*, was captain of the *Zélée*. Extra-heavy clothing was issued for the ships' complements of 165 officers and seamen, but neither ship was in any way strengthened for work amidst ice. The naval surgeons were chosen for their capacity to act also as naturalists. In addition, a physiologist and phrenologist, P.-M. A. Dumoutier was appointed assistant naturalist. Before the voyage Dumont d'Urville spent ten days in London gathering charts and reference books.

The expedition sailed from Toulon in September 1837. The main objectives were scientific and exploratory rather than diplomatic, although for French warships of the time the role of watchdog was implicit in their armoury. An extensive program of meteorological, magnetic and oceanographic observations was part of the expedition's scientific schedule. Whilst still in the Mediterranean, Dumont d'Urville, made use of the deep-sea thermometer to make comparisons with measurements he had made there in 1829. At 220 brasses (369 m) and 550 brasses (922m) he found the temperature to be 13.2°C and 12.8°C respectively. This was added evidence for the theory, which he had supported in his earlier work on subsurface temperatures, that in the enclosed waters of the Mediterranean the levels below about 200 brasses were uniformly at a temperature of about 13°C, Yet in the open sea, it appeared, a progressive and continuing decrease was to be expected at the same latitude. To test this notion, he sent down the sounding line when the *Astrolabe* had passed through the Straits of Gibraltar. In the Atlantic Ocean, he found that the temperature had decreased to 8°C at a depth of 600 brasses (1006m). Instances of similar striking differences in temperature profiles each side of the enclosing ridge of a semi-enclosed sea were to be found later on the expeditions of the *Challenger* and the *Gazelle* (see chapter six) amongst the islands of the Indonesian Archipelago.

Experimentation with the *thermometrographe* was carried out in other locations when the opportunity arose, often, this time, with several instruments attached to the lead line at intervals to enable a serial reading. There is a reference to the cylinder in which the thermometrographe was enclosed but no mention of its effectiveness. Observations were also made of the degree of transparency of the water in different locations and also of the effect of water pressure on different substances, such as wood, fabric and metals.

By December the expedition had set up a camp at Port Famine in the Strait of Magellan. From here they followed Weddell's route south, but, blocked by impenetrable ice-floes, failed to reach the latitude he had attained. On three occasions the ships were caught in an ice pack, and only escaped by the crew breaking up the ice and hauling the ships free with towing lines. This was exhausting work. Soon scurvy broke out on both ships, rendering 40 men too ill to work. Leaving the area in March, the expedition sought rest and recuperation in Chilean ports, before sailing north-west to survey and naturalise in the Marquesas, Society, Samoan and Friendly islands. At the Fijian islands, the French commander demonstrated his country's might by exacting vengeance on the inhabitants of the village of Piva, who four years earlier had killed the commander of a French ship, the *Amiable Joséphine*. Their village was burned to the ground. The safety of French navigators and traders was at issue. Authority established, the expedition completed the exploration of the islands.

By January of 1839 Dumont d'Urville was again in Guam, where ten years before, in the *Astrolabe*, he had so gratefully accepted the hospitalisation of his crew. In March he visited the settlement at Port Essington, the northern outpost of the British presence in Australia. He had entertained ideas of a passage eastward through Torres Strait, but abandoned the idea because of unfavourable winds. In the following six months the party naturalised and surveyed amongst the islands of the East Indies and were delighted with the zoological specimens they were able to collect. Eventually, however, the humid tropics took their toll on the health of the crew. In October they sailed south by way of the Sunda Strait into the Indian Ocean heading for Tasmania. Within a few days of leaving Lampung Bay in Sumatra, where they had taken on board food and water for the voyage to Hobart, both ships had seamen on the sick list with dysentery. It was hoped cooler weather would restore them to health, but within a month the deaths began to occur:

> *November 1st ushered in the most catastrophic period of our expedition. That day the wind again settled steadily on the SSE. So we had to give up hope of soon meeting the westerlies that our two corvettes were so impatiently awaiting. Their orlop decks were crowded with the sick. From that date until our arrival at Hobart Town our voyage was, so to speak, nothing but a scene of death and mourning, when each day I had to record the names of new victims lost either from* Astrolabe *or* Zélée. [Dumont d'Urville, trans. Rosenman (1987) Vol 2, p.439]

The surgeon on the *Zélée* begged the Commander to sail for Swan River on the Australian west coast or for the island of Mauritius, but he would not be diverted from his plan to make another probe into Antarctic waters from a base at Hobart. The expedition had failed to equal Weddell's geographic achievements and the knowledge that both the Americans and the British were on their way to the Antarctic was a strong incentive to make a second attempt.

Three young officers and thirteen petty officers and seamen had died before they reached Hobart on 11 December and six died soon after. The crew were so decimated by illness that Dumont d'Urville proposed that he should take only the *Astrolabe* southwards, combining those seamen of the two ships who were fit enough to sail. Jacquinot, however, insisted on accompanying him in the *Zélée* and procured enough seamen from the Hobart wharves to do so. Some of these were deserters from French whaling vessels which were frequenting the port in considerable numbers.

Whilst the corvettes were under repair and the sick hospitalised on shore, the visitors were received with solicitude and great interest by Lieutenant-Governor, Sir John Franklin, and the citizens of Hobart. John Franklin later became famous as a result of perishing in the Artic. On board the *Astrolabe,* the commander received a visit from a Captain Biscoe, who spoke of the belief amongst sailors that land existed south of Macquarie Island. He also spoke of a recent meeting in Sydney with Charles Wilkes, the commander of an American expedition exploring the high southern latitudes (see chapter 5).

The *Astrolabe* and *Zélée* sailed due south on New Year's Day. In the early stages of their exploration they were blessed with favourable weather, although they encountered ice fields much sooner than they had hoped for. If it did not succeed in his aim to sail beyond the 70th parallel, Dumont d'Urville's expedition was crowned by the sighting, behind the ice ramparts stretching east and west, of high snow-covered land, which he took possession of in the name of France and named, in honour of his wife, *Terre Adélie*. Fragments of granite chipped triumphantly from an ice-free rocky island were borne away as souvenirs and trophies. Some time was spent searching for an accessible ice island on which experiments with the magnetic instruments could be conducted. It was believed, erroneously, that they were very close to the magnetic pole, but there was no possibility of penetrating the ice barrier to approach it. Then for several days, in deteriorating weather, at great risk amongst the abundant icebergs, the ships coasted what proved to be the Antarctic continent. On 30 January there was an opportunity for a measurement with the deep-sea thermometer, the result of which occasioned some surprise:

> *In the evening we reached a headland projecting from this extraordinary coast.It was there that we ended this reconnaissance. Being in the shelter of the ice, at 6 p.m., before changing the course to westward, we availed ourselves of a short period when our ships*

> *could communicate with one another. While a boat from* Astrolabe *went across to* Zélée *we sent down a lead attached to a 200-fathom line without finding bottom. A thermometrograph had been tied to the lead; at this depth it registered only one degree less than on the surface. M. Dumoulin was expecting an increase in temperature rather than a decrease, the water temperature at the surface being zero. He attributed this result to the too-close proximity of the ice. For my part I concur quite happily with this opinion, which consists in thinking that when the water on the sea surface is at zero, one must expect an increase in temperature at great depths.* [Dumont d'Urville, trans. Rosenman (1987) Vol 2, p.488]

The expedition returned to Hobart briefly to pick up the sick crew members, then sailed for New Zealand by way of the Auckland Islands to survey the eastern coastline of the South Island. At the Bay of Islands they found that Captain Hobson had taken possession of the North Island for Britain. The French commander refused to acknowledge his authority. From here the two ships turned for home, exploring the islands of the Louisiade archipelago before attempting a passage of Torres Strait.

At the entrance to the Strait both the *Astrolabe* and the *Zélée* were caught on the face of a coral reef. Some anxious days were spent hoping for a tide high enough to allow them to warp the vessels free. The *Astrolabe*, which had already lost its protective false-keel, jolting over the coral, began to list dangerously at an angle of 38° and, as the water level fell, threatened to capsize. It was a desperate predicament. Plans were made to take to the boats, but, by a lucky chance, before the sea reached its expected lowest level, the water began to rise again and reached a level that enabled the vessel to right itself, finding at the same time some support under the hull. The commander attributed their escape to the strength of the prevailing winds that, he said, must have been forcing the water back to the west. On the next high tide, thirty men from the *Zélée*, which was now free, joined the crew of the *Astrolabe* to heave on the capstan and shift the vessel from its bed of coral. Torres Strait is a shallow passage, studded with islands and reefs. Although it provided a shorter route to Asia, great care was needed to negotiate its waters into the Arafura Sea. The expedition stayed only three days in Kupang Bay, Timor, to avoid the risk of dysentery. Then, with no plans for further surveying, they headed for France.

When the expedition finally reached Toulon on 7 November, 1840, it bore an outstanding collection of zoological and botanical specimens to impress the members of the Museum of Natural History. Their work on magnetism, meteorology and hydrography received high praise. The presence of the two corvettes in the Pacific had also played an important part in 'showing the flag' in support of French missionaries, traders and whalers.

A handsome publication of the results of the voyage appeared over the years 1842 to 1854 in twenty-three volumes with seven folio atlases of high quality. Dumont d'Urville, however, did not survive to see their completion. He had written only the first three volumes, when he, his wife and son were killed in a railway accident in May 1842. The remainder of the narrative of the voyage and the volumes on physics and hydrography were completed by the hydrographer, Vincendon Dumoulin. The volume on *Physique* contained tables of meteorological and sea-surface data but did not include the data on deep-sea thermometry. It was explained that the death of Dumont d'Urville had cut short the work on the physical sciences. The surgeon of the *Zélée*, Elie Leguillou, produced his own account (1842), in which he criticised his leader's inhumanity in the face of the many illnesses and the deaths - twenty aboard ship, others in hospitals en route. The human costs had indeed been high.

On Dumont d'Urville's Oceanic and Antarctic cruises, like those of the American exploring expedition led by Charles Wilkes and the British expedition led by James Clark Ross in the same period, more attention was given to serial temperature casts than had been attempted in earlier decades. The results of these subsurface measurements, like those procured by Ross and Wilkes were not well presented. One must search the narrative to extricate the data. Joseph Prestwich in his otherwise comprehensive appraisal (1875) of deep-sea temperatures failed to include those of Dumont d'Urville's last voyage. The proud navigator, despite his promotion to Rear-Admiral and his assured place in history for the solution of the mystery of the fate of Lapérouse and his share in the discovery of Antarctica would surely have resented this final disregard for his hard-won oceanographic data.

4

Pax Britannica

After peace was restored to Europe in 1815, the British Navy played an ever-increasing role world-wide in securing the safety of the ocean lines of communication so important for trade. By the end of the Napoleonic wars Britain had secured a widespread empire. During the ensuing 'Pax Britannica', the hydrographic department of the British Admiralty pursued the surveying of coastlines as far afield as, for example, the Caribbean, West Africa, South America and Australasia. Improved charts came on sale for the shipping of all nations from 1823 onwards. The science of oceanography benefited directly from the activities of the British Royal Navy. There was little other government support for marine science in the first half of the nineteenth century, but through the scientific interests of succeeding Hydrographers, most of whom were Fellows of the Royal Society, the study of oceanic phenomena and the natural sciences became a regular aspect of the work of naval surveyors.

The Hydrographic Department had been established at the British Admiralty in 1795 with Alexander Dalrymple, a man of science, as the Hydrographer. Successors to Dalrymple were naval officers, Captain Thomas Hurd 1808-1823 and Rear-Admiral William Edward Parry 1823-1829, under whose direction the Admiralty charts came on sale for merchant fleets. Parry had considerable experience in Arctic exploration in search of a north-west passage around America. On each of his three voyages, some scientific probes of the deep sea were made. He typified the type of officer chosen for the position of Hydrographer. They were usually men with an interest in the progress of scientific knowledge and members of the Royal Society of London. This is particularly well exemplified in Rear-Admiral Francis Beaufort. During his twenty-five-year term as Hydrographer,1829-1854, the British Admiralty organised activity in all the oceans of the world, not only in surveying, but also in gathering meteorological and oceanographic data and providing a platform for the work of natural historians.

Matthew Flinders Circumnavigates the Australian Continent 1801-1803

The first circumnavigation and survey of the entire Australian continent was initiated by the British Admiralty soon after the turn of the nineteenth century at a time when there was still only the one British settlement at Port Jackson, with a sub-colony on Norfolk Island. This was undertaken very competently by Matthew Flinders in the *Investigator* 1801-03. Assisting Flinders was Lieutenant John Murray in the 60-ton brig, *Lady Nelson*, which, with its three sliding keels, and shallow six-foot draught had been sent out to the settlement for coastal survey work.

Matthew Flinders had sailed to New South Wales in 1795 as a junior officer on HMS *Reliance* which was bringing the second governor Captain Hunter to the colony. On the voyage he made friends with the ship's surgeon, George Bass. The two young men were excited at the prospect of adventure in the new settlement. At Sydney, with the support of Governor Hunter, they joined forces to pursue their passion for exploration. Together in a small boat they charted the bays and inlets of the immediate coastline to the north and south of Port Jackson. In December 1797 in an open whaleboat manned by six men, Bass followed the coastline further southward as far as his six weeks food supplies permitted and reached Westernport Bay (in present day Victoria). He saw signs that he may have reached the entrance of a strait extending westwards. The next year, to investigate this possibility, the two explorers were provided with the 25-ton sloop *Norfolk*, in which they demonstrated the existence of the strait and sailed around the island of Tasmania. This discovery offered the opportunity of shortening the passage out to Port Jackson by a week or more and had considerable strategic importance for the British. A settlement was promptly set up in Tasmania to forestall any French plans for the area.

In 1800 Flinders was back in England with the *Reliance*. He had published his coastal charts and now wished to undertake the charting of the entire southern landmass. For this ambitious aim he enlisted the help of the influential Sir Joseph Banks, President of the Royal Society, who proposed to the Lords of the Admiralty a complete exploration of the coastline of both New Holland and New South Wales. The Admiralty knew that Napoleon had already dispatched a scientific and surveying expedition to the area, led by Nicolas Baudin and wasted no time in organising the proposed survey. 'My leading object', wrote Flinders in his *Voyage to Terra Australis* (1814): 'was to make so accurate an investigation of the shores of Terra Australis, that no further voyage to that country should be necessary for that purpose'. When Flinders learned of his appointment to conduct the survey in command of the lightly armed, 334-ton sloop, HMS *Investigator,* he married his childhood sweetheart, Ann Chappell, intending to take her out to Sydney with him. The *Investigator,* lying at anchor at the naval dockyards, provided a home for the newlyweds, but, so goes the family legend [Ingleton (1986)], a visit from the First Lord of the Admiralty, Earl St. Vincent, a strict disciplinarian, put an end to their plans. Scandalised, the story goes, to discover Ann ensconsed in the cabin, 'without her bonnet', he invoked a regulation forbidding the presence of navy wives on board His Majesty's ships, a regulation which had often been ignored before. The *Investigator* sailed without Ann. They would never have foreseen that their separation was to extend to ten long years.

The weathy Joseph Banks, always very interested in the southern continent since his visit to Botany Bay with James Cook, took up the opportunity offered by the proposed survey of the Australian coastline to investigate the resources of the area for colonial expansion. He employed a botanist, Robert Brown, a gardener, Peter Good, and a botanical illustrator of Austrian birth, Ferdinand Bauer, to sail on the *Investigator*. It was a chance to extend the study of natural history and add to the collections for the Kew Gardens, for which Banks was the royal adviser. A special cabin was reserved for the preservation of specimens and a hothouse was constructed on deck. William Westall was included in the party as a landscape artist and John Allen as a mineralogist. The astronomer, John Crosley sailed with the *Investigator* as far as Cape Town. Among the young officers were Samuel Flinders, the captain’s younger brother and the young John Franklin, destined himself to become a famous Arctic explorer and the governor of Tasmania. The East India Company supplied £600 for the table of the captain, the officers and the men of science. The library of reference books included the latest edition of the *Encyclopaedia Britannica*, a gift from Banks. The French government provided a passport for the scientific voyage of the *Investigator*.

Oceanographic Observations by Matthew Flinders

As the *Investigator* sailed for Australia, sea-surface temperatures were recorded daily in the Atlantic. This activity, however, was terminated before the southern hemisphere was reached, for by that time all the thermometers were broken [Flinders (1802)]. A few salinity measurements were made on the outward voyage and whilst surveying the coastline. On some occasions, as the *Investigator* was coasting the Great Australian Bight, salinity measurements were used to test whether fresh water was disgorging from a river system. One location was at Smoky Bay in South Australia where, seeing some evidence of a possible river entrance in the floating vegetation, he tested the specific gravity of the sea water [Flinders (1814, Vol 1, p.113)]. It was found it to be 1.034, which was .008 greater than in the South Indian Ocean. (Fresh water has a specific gravity of 1.0.) A river entrance was thus shown to be unlikely in the vicinity. An important aspect of the exploration of the coastline was the search for river entrances by which the interior could be accessed.

At points with well-established positions, tidal measurements were recorded, if possible. Observation of the tides was considered useful in exploration. As Flinders reached the islands of St Peter and St Francis, beyond which the southern coastline had never previously been followed, he commented [(1814) Vol 1 p.109]:

> *That there was no entrance to a strait, nor any large inlet, near these islands, was almost demonstrated by the insignificance of the tides; for neither in Fowlers bay, nor at this isle of St Francis could any set be perceived, nor was there any rise by the shore worthy of notice.*

It was the observation of tidal phenomena among the Furneaux Islands on the eastern edge of Bass Strait in 1798 which had strengthened Flinders' belief in the existence of that strait. He had sailed to these islands from Sydney in the *Francis* which was rescuing men and cargo from the wreck of a merchant ship, the *Sydney Cove*. Discussions with his friend George Bass, who had already followed the coastline as far as Westernport Bay, led to their voyage in the *Norfolk* through the strait and around the island of Tasmania. Even earlier, of course, there had been speculation about an opening between New South Wales and Van Diemen's land, because of the easterly current flow.

> *Although the eastwardly currrent be not commonly found at the surface in Bass Strait, it is not lost. Navigators find it running with considerable strength when passing the strait two or three degrees east of the Furneaux Islands; and it was this current so found, which led Admiral Hunter to the first opinion of the existence of an opening between New South Wales and Van Diemen's Land.*[Flinders, *Voyage to Terra Australis* (1814, Vol 1, p.244)]:

Flinders published a monograph in 1801 on some tidal information for the southern shores of Bass Strait, but this was based, rather inadequately, on only a few days' observation.

The accuracy of magnetic compasses was a matter of vital concern for navigators of the era, who had observed some puzzling errors that could not be explained by magnetic variation. Matthew Flinders undertook a systematic investigation of the possibility that such errors might be caused by the local attraction of iron ballast in the hold or iron objects on the deck of a ship. As a result of the distribution of his observations, he was asked by the Admiralty to suggest experiments for other naval captains to test the possible effect of local attraction. In an appendix to his *Voyage to Terra Australis* Flinders describes his practice of “swinging the ship” that is placing the ships head at each point of the compass and noting the amount of deviation to the east or west of the magnetic north, a practise which came into general use. It was Flinders’s further suggestion that such errors might be corrected by the use of “counter-attractors” in the form of vertical bars each side of the compass. Eventually large masses of unmagnetised iron became standard for this purpose on ships in the second half of the century and became known as *Flinders Bars.*

Surveying the Australian coastline in the *Investigator*

The *Investigator* left England July 18, 1801, and reached the West Australian coastline at Cape Leeuwin by December and then proceeded to anchor in King George's Sound for several weeks. Here the naturalists were enthralled by the unusual fauna and flora. They soon had on board a collection of strange lizards, snakes and birds as well as kangaroos and emus. Flinders was now charting the southern coastline never previously surveyed for, as we have noted in chapter two, the French expedition led by Baudin, which reached the continent before him, had diverted northwards to Timor and from there sailed directly for anchorage in Van Diemen's land.

The rival British and French expeditions met at Encounter Bay near Kangaroo Island, as Baudin in the *Geographe* was surveying westwards along the unexplored southern coastline (see chapter two). There was a polite exchange between their captains. Flinders was able to point out the extent of the southern coastline that he had surveyed. He mentioned also that he had already investigated two nearby gulfs (he named them Spencer's Gulf and the Gulf of St Vincent) and ascertained that they did not represent a passageway dividing the known land mass into two (or more) large islands. This possibility had been the subject of speculation by both the French and the English. There was always the prospect of France acquiring the western portion if the area known as New Holland should prove to be, in fact, a large island or even an archipelago. The next year Baudin was in a position to send Louis Freycinet in the *Casuarina* also to chart these shallow gulfs, which appeared subsequently on his 1811 map as *Golfe Bonaparte* and *Golfe Josephine*. There was at the time much dismay and bitterness amongst the English over the French nomenclature on the areas for which Flinders could claim priority of discovery. [Horner (1987) *The French Reconnaissance*]

When the *Investigator* reached Port Jackson, the *Lady Nelson*, a small vessel with a shallow draught and retractable keels, was assigned to assist in the surveying northwards. All went well until the party reached the perilous area of the Great Barrier Reef along the Queensland coast. The *Lady Nelson* was damaged on a submerged reef and could not continue. The *Investigator* received some damage also but continued to round the Cape York Peninsula and with considerable difficulty negotiated the shoals, reefs and islands of Torres Strait to enter the Gulf of Carpentaria. This area was charted in meticulous detail in the hope that it might prove to provide an entrance to the interior of the continent, but the coastlines grew shallower and the gulf proved to be landlocked. The careful surveying of the northern coastline continued until a diversion was made to the Dutch settlement on Timor at Kupang. Since the *Investigator* had sustained considerable damage in its passage through reef-strewn waters the charting of the north western coastline of New Holland was now of necessity deferred and the decision was made to effect urgent repairs, take on fresh food supplies and then sail directly through the Indian Ocean, heading for Port Jackson. It took another two months to return. They had completed the first circumnavigation of the continent. There was sickness on board and three men died at sea. Four more died at Port Jackson. Whilst engaged in these surveys tragedy struck at a group of islands named for the *Investigator*, where a whole boat load of men were lost .There is a Cape Catastrophe to commemorate the loss.

Whilst on the coastline of Arnhem Land in northern Australia in February 1803, Flinders was interested to encounter a fleet of fishing boats ('prows') from Macassar in the south of the Celebes Islands (Sulawesi). The Macassans, he learned, visited the area regularly to collect trepang, the edible sea-slug, highly valued by the Chinese, with whom a regular trade in the dried product existed. It was their knowledge of the monsoonal wind pattern which enabled these islanders to make their way annually to and from the Australian coastline at the appropriate season, and this was accomplished, Flinders noted [Vol 2, p.232], “without the aid of any chart or astronomical observations”. They did, however, possess a small pocket compass, apparently of Dutch manufacture. In April of the same year, on some islands off the northwest coast of the continent, the Baudin party had a similar meeting with a Macassan flotilla, towards what, they gathered, was the end of their seasonal summer visit to gather and dry the trepang.

Back at Sydney, the *Investigator* was condemned as 'unfit to proceed to sea' and 'requiring greater repairs than can be given in this country'. Flinders was forced to postpone his survey of the northwest coast of the continent. With the intention of returning to England for a replacement vessel, he sailed northwards again in August, this time as a passenger, in HMAV *Porpoise,* which was intended to make a passage through Torres Strait, and then to proceed by way of the Cape of Good Hope to England. Such a route would have avoided both a westward passage against the prevailing Roaring Forties in the Southern Ocean and the equally difficult route eastward around stormy Cape Horn. The *Porpoise*, however, was wrecked on the Barrier Reef, and Flinders, with a small party, returned again to Sydney in an open boat. In desperation he sailed again in command of the only vessel available, the 29-ton, colonial-built *Cumberland.*

This was not the end of his run of misfortune for on the Ile-de France (Mauritius) he was detained by the Governor of the French island. War had again broken out between France and England. It was claimed that the passport Flinders carried for the scientific voyage of the *Investigator* was invalid for his present arrival in the *Cumberland*. He was detained as a spy and held on the island for six and a half long years. He did not reach England again until October 1810. In the next four years he worked on the publication of his Australian charts and the narrative of his *Voyage to Terra Australis.* He died in July 1814, as his book was coming from the publishers. The quality of Flinders's chartmaking has long been recognised and his *Atlas* of charts was welcomed by mariners plying Australian coastal waters. The first volume of *The Australia Directory* included Flinders's sailing directions. His 'General Chart of Terra Australis or Australia' was instrumental in naming the new continent 'Australia'. The full story of his achievements can best be read in marine historian G. Ingleton's handsome publication (1986), *Matthew Flinders: Navigator and Chartmaker.*

Flinders's Observations of Coastal Currents

Cook's observations of a southward 'set' of a current along the coast of New South Wales were corroborated by Flinders, who commented [(1814) Vol 2, p.283]:

> *It is a fact difficult to be reconciled, that whilst the most prevailing winds blow from the S.E. in summer, and S.W. in winter, upon this extra-tropical part of the East Coast, the current should almost constantly set to the south; at a rate which sometimes reaches two miles an hour. Its greatest strength is exerted near to the points which project most beyond the general line of the coast; but the usual limits of its force may be reckoned at from four, to twenty leagues from the land. Further out, there seems to be no constancy in the current; and close in with the shore, especially in the bights, there is commonly an eddy setting to the northward, from a quarter, to one mile an hour. It is in the southern parts that the current runs strongest.*

Flinders's recorded observations of the surface currents off the south-west coasts of Western Australia, [(1814) Vol 1 p.241] are also of historical interest. In December 1801, after the outward passage from the Cape of Good Hope, the *Investigator* approached New Holland at Cape Leeuwin and followed the southern coastline to the anchorage at King George's Sound, which had been visited by Captain George Vancouver in 1791. He made mention there 'that when the ship got in with the South Coast, I found the current setting N.70°E. at the average rate of twenty-seven miles per day'. And, during his circumnavigation of the continent Flinders, rounding Cape Leeuwin from the north in May 1803, commented further that;

> *From the meridian of the cape* [Leeuwin] *to past King George's Sound, the current set east, twenty-seven miles per day, nearly as it had before done in December. Captain Vancouver and Admiral D'Entrecasteaux do not speak very explicitly as to the currents; but it may be gathered from both, that they also experienced a set to the eastward along this part of the South Coast.*

It seems that the *Investigator* had encountered the eastward extension of the warm Leeuwin current. Only in this century has much been discovered about this current, which flows southwards, close to the coastline of southern Western Australia, and inside the cooler northerly current which makes up the South Indian Ocean gyre. Such a poleward flow on the eastern perimeter of an ocean basin is not typical. It is thought it may be a result of the forcing of equatorial water through the Indonesian archipelago, and a consequent elevation of the sea surface at the North-West Shelf. The warm, low-salinity water which it brings allows the development of tropical marine fauna in extratropical locations along the coast of south-western Australia. At Cape Leeuwin the current pivots eastward and follows the coastline towards the Great Australian Bight, beyond King George Sound and, in some seasons, at least as far as Esperance. This information has been gathered by using twentieth-century technology, which includes satellite remote-sensing and the tracking of freely floating buoys [see Jones and Jones (1989b)].

The Survey of the Australian Continent Completed by Phillip Parker King

Flinders's survey was followed up in more detail, chiefly in the northern and western areas, by five voyages in the years 1818-22 by Phillip Parker King, the Australian-born son of Governor Phillip Gidley King. Phillip P. King, one of Australia's earliest native-born (Norfolk Island, 1791), had been educated in England from the age of five, under the superintendance of Samuel Enderby of the famous whaling firm, and received a training in mathematics, astronomy and surveying at the Royal Naval Academy at Portsmouth. When selected to explore and chart the part of the coast of New Holland which Flinders had been unable to complete, King, unlike his predecessor, was able to bring his bride, Harriet (Lethbridge) with him to Sydney in 1817. The officers for this survey were supplied by the Admiralty, but the funds were provided by the Colonial Department. The 83-ton cutter *Mermaid*, built in India, was purchased for the project by Governor Macquarie. The sloop *Bathurst* served to assist. King's *Atlas*, published in 1825, contained eight coastal sheets and ten plans of harbours. Although not numerous, these charts, in the opinion of Ingleton (1944), were 'of a quality not attained by any previous navigator in the Pacific'. The next year appeared King's *Narrative of a Survey of the Intertropical and Western coasts of Australia, performed between the years 1818 and 1822*, which established his reputation as a keen observer of the natural sciences of the Antipodes. He had already been elected a member of the Royal Society and the Linnean Society of London.

Subsequently, four years of King's career were spent as commander of the *Adventure* and the *Beagle* in hydrographic exploration of South American waters, while his wife, Harriet, maintained the properties he had acquired in New South Wales, after which he retired from life at sea and, in 1832, turned to pastoral pursuits. His interest in matters scientific led him into friendships with other colonists with interests in the natural sciences, such as Alexander and William Sharp Macleay, of whom we shall speak later, the geologist Reverend W. B. Clarke, Surveyor-General, Thomas Mitchell, and James Dunlop, who was in charge of the Parramatta Observatory 1831-47. To pursue his scientific interests, King established a private observatory firstly at his estates west of Sydney and later at his posting at Tahlee, Port Stephens, when he became Commissioner there for the Australian Agricultural Company. He served as a trustee of the Australian Museum for many years. Visiting scientists of the exploring expeditions from the northern hemisphere often carried letters of introduction to this Australian 'anchor man' of colonial science [Branagan (1985)].

Accompanying King on the surveys of the Australian coastline was the naturalist, Alan Cunningham, who had been commissioned as a professional collector for Kew Gardens, in London. The emphasis on botany again reflected the interest of Sir Joseph Banks. Hydrographic work was the main aim of the cruises, but as might be expected, the officers of the *Mermaid* were most interested to observe and record the strange flora and fauna of the Antipodes and the lifestyle of the native inhabitants. King maintained a collection of meteorological and magnetic data, but not a great deal in the way of physical oceanography was included in the busy schedule of cartographers King or Flinders. One of the major aims of both coastal surveys was to locate harbours and waterways which might provide access to the interior of the continent, and for this purpose, as we have seen, salinity measurements were sometimes employed as a clue to the presence of a major river.

Both King and Flinders commented on aspects of the East Australian Current, the most significant oceanographic feature of the waters off New South Wales, but some years were to pass before its extent was to be clearly established. Between the comments of Flinders and King, those of a Lieutenant Jeffreys received some attention.

Charles Jeffreys and the *Kangaroo*

Prior to King's work in the *Mermaid*, a naval survey vessel, the *Kangaroo,* was sent at Governor Macquarie's request to the colony in 1813, under the command of Lieutenant Charles Jeffreys. In the course of the various services requiredof the *Kangaroo*, such as the conveying of settlers or convicts and provisions for the settlements, Lieutenant Jeffreys made the voyage from Sydney to Tasmania several times between 1814 and 1817. These voyages to and from Hobart were at times rather protracted.

R. C. Wright (1983) describes the leisurely nature of Jeffreys's voyages and the great annoyance his long absences occasioned for Governor Macquarie, who on one occasion specifically forbade him to take his wife with him on the *Kangaroo.* Eventually Macquarie requested the return of the vessel to England with some cutting comments about the usefulness of naval officers who considered themselves 'as Commanding Vessels of War, and are much too proud to Submit patiently to going to Newcastle for Coals, Lime and Timber, or to the Hawkesbury for Grain'. Either the colony was so short of vessels for everyday tasks, that the *Kangaroo* could not be spared for surveying or the Governor at this time did not see an urgent need for such work.

However, Jeffreys' observations on the coastal currents encountered off the south-east coast of New South Wales and particularly the variability of their direction were noted in published sailing directions. They are included in the text accompanying Krusenstern's 1824 *Atlas of the Pacific Ocean*. In A. K. Johnston's *Physical Atlas* of 1848, which was based on the *Physikalischer Atlas* of Heinrich Berghaus (1845), the coastal current was depicted and named, on the authority of Jeffreys, as the 'New South Wales Alternating Current'. Arrows indicated a flow southwards in winter and northwards in summer. It is now clear that Jeffreys may have encountered, at different times, the different parts of eddies known to characterise the East Australian Current, or alternatively, the weaker coastal counter-current, which moves northwards inside the major southward-flowing boundary current.

In the early decades of the century, and until 1855, most vessels of the British Navy which assisted the governors of New South Wales in their duties were supplied from the East India Station. Some small sketch-surveys were made from these vessels incidental to their escort duties and to the establishment of further settlements. After the surveys of Phillip Parker King, no British surveying vessel was employed continuously in the Australian region for fourteen years, that is, between the years 1823 and 1837.

Oceanographic Contributions of Robert Fitzroy of the *Beagle*

Australian waters were visited, however, in 1836 by Captain Robert Fitzroy in the 235-ton brig *Beagle* on the homeward section of the five-year voyage, so well known now for its impact upon the theories of evolution by natural selection proposed by Charles Darwin. The main focus of this British surveying cruise was the South American coastline, in the interests of trade with the American republics, but there was also the important mission of completing a longitude traverse of twenty-four hours westwards right around the world. The traverse was to include such stations in the Australasian area as the Bay of Islands,in New Zealand, Port Jackson, Hobart Town and King George's Sound, the locations of which were now well established.

The *Beagle* crossed the Pacific by way of Tahiti and New Zealand and reached Port Jackson in January 1836. In the light of our present understanding of the movement of eddies within the East Australian Current, it is interesting to note some early comments by Fitzroy on the alternating direction of currents encountered across the Tasman Sea:

> *Afterwards, in our passage to Port Jackson, we had alternately northerly and south-easterly currents of about ten miles a day, and it was easy to tell which current we were in, by the temperature of the sea- while the stream set from the north, the water thermometer showed about 72°; but when the current was running from the southward, the temperature of the ocean, a foot below as well as at the surface was only 67° I ought to have remarked elsewhere, if I have not already done so, that the thermometer may be used at sea to detect and trace currents, but little, if any, confidence may be placed in its indication of the approach of land.* [Fitzroy and King (1839) Vol 2 p. 620]

The confidence expressed in the value of the observation of sea-surface temperatures by the 1830s is worthy of note. On the voyage of the *Beagle* such measurements were taken frequently, some days at 9am or 10am, others at noon or 4pm, though not as systematically as on the French Pacific expeditions of this era.

In the passage of the Indian Ocean, Fitzroy called in April at the Cocos (Keeling) Islands to survey them and incidentally to examine by sounding the coralline structure of a deep-sea atoll. The formation of the coral atoll, it will be recalled, was a geological question, in which Darwin displayed great interest. Here, also, evincing the contemporary interest in the science of the ocean depths, a measurement was made of subsurface temperatures. A single temperature cast at 2178 feet (664 metres) showed a temperature reading of 45°F (7.2°C) at latitude 12°12' S. The sea-surface temperature at that time is not recorded.

A Comment on Wave Heights

The narrative of the ten years' surveying in South American waters by HMS *Adventure* and of HMS *Beagle* from 1826 to 1836 was published in 1839. Phillip Parker King was responsible for Volume 1, but since he had now retired to his pastoral pursuits in Australia, he left the publication arrangements to Fitzroy. Charles Darwin's scientific diary was the basis of Volume 3, which has proved to be perennially popular. Volume 2 was written by Fitzroy, covering the 1831-36 voyage of the *Beagle*, and included an appendix with a miscellany of extracts from ship's logs and his own remarks on a wide variety of topics. One of these was a comment on likely wave heights:

> *The height of waves may be here mentioned with reference to rollers or other undulations of water however caused. Large waves are seldom seen except where the sea is deep and extensive. The highest I have ever witnessed myself were not less than sixty feet in height reckoning from the hollow between, perpendicularly to the level of two adjacent waves; but from twenty to thirty feet is a common height in the open ocean during a storm. I am quite aware of, and have long been amused by the assertions of some persons, whose good fortune it has been not to witness really big waves--that the sea never rises above twelve or fifteen feet - or that no wave exceeds thirty feet in height, reckoning in a vertical line from the hollow to that of the crest.*

Then, as now, the height of waves likely to be encountered on voyages across the great oceans was of considerable interest. Dumont d'Urville had claimed to have encountered waves of 80-100 feet; Fitzroy estimated the highest wave he had witnessed to have been at least 60 feet; both claims were surely awesome for the readers of narratives of exploration.

Fitzroy did no more surveying after his years in the *Beagle*. After a distinguished career as a Member of Parliament and as Governor of New Zealand, in 1854 he accepted the position as Head of the Meteorological Department which was that year established within the Board of Trade. In 1851 he had been elected to Fellowship of the Royal Society of London. The enthusiasm which Fitzroy displayed for this new turn in his career and his pioneer work for marine meteorology has been fully covered by his biographer H. E. L. Mellersh (1968).

This voyage of the *Beagle*, 1831-36, is also noteworthy as the first on which the Beaufort scale for assessing wind force by eye was employed. Beaufort had devised this numerical wind-force scale and the lettered weather notation for entries in his own meteorological log and used it in his years at sea with the Royal Navy. As Hydrographer of the British Admiralty (1829-1854) he directed Captain Fitzroy to employ it in the reports from the *Beagle*. Fitzroy was provided with printed sheets for this purpose. By 1838 the Beaufort scale was in general use in the British Navy, and ultimately, at the international meteorological conference at Brussels in 1853 it was approved for international use. It is still in use today.

An International Conference at Brussels 1853

Meteorological observations at sea had already been collected for several decades and systematised at the Hydrographic Departments of European nations. The British Royal Society, notes Charnock (1972), recommended 'the collection of observations at sea, notably of pressure, temperature and humidity, sea temperature and currents, gales, thunderstorms, aurorae, falling stars and magnetic variation'. The establishment of the British Meteorological Department in 1854 was indicative of a new emphasis on marine meteorology, arising from the recommendations of the International Conference at Brussels in 1853. At this conference Lieutenant Matthew Fontaine Maury, head of the United States Naval Observatory, was able to convince the maritime nations represented there of the practical value of the standardisation and cooperative observation of winds and currents. This would extend the range and accuracy of the *Wind and Current Charts*, which he had been producing from the United States Navy's Depot of Charts and Instruments since 1847.

It was an era of new beginnings in international cooperation for the benefit of marine science.

Sir Francis Beaufort, Hydrographer, 1829-1854

Robert Fitzroy's election to the Royal Society and his appointment as Meteorological Statist had been supported by the Hydrographer, Francis Beaufort, who was then approaching the end of his remarkable term of the office.

4.1
A daguerrotype taken in 1848 of Sir Francis Beaufort, Hydrographer of the British Admiralty, 1829-1854. During his term of office surveyors of the Royal Navy were deployed world-wide and were encouraged to serve the advancement of science in every way possible. He is remembered for the system of estimating sea conditions known as the Beaufort scale.

By the second quarter of the century when the Hydrographic Department of the British Admiralty was under the command of Sir Francis Beaufort (Figure 4.2), officers of the Naval Surveying Service were operating in every ocean world-wide. Beaufort, who presided over the publication of the Admiralty Tide Tables, gave strong support to the extension of marine science. The first Tide Tables appeared in 1833. These gave the times of high water at selected English ports. Beaufort promoted the investigation of tidal theory by Dr William Whewell by instigating the collection of further data, in the first place by British Coastguard officers, and ultimately by European and American authorities. Consequently, the scope of the Admiralty Tide Tables and knowledge of tidal theory grew. We note that, in the surveying of the Australian coastline, Beaufort's officers were urged to record tidal information at points where geographic position was well established, The recording of the lowest water levels at Spring Low Tide was seen as particularly useful for shipping in harbours and bays.

Under Beaufort's auspices appeared various regular nautical publications as well as improved Admiralty charts: in 1832 the *Nautical Magazine*; in 1835 the *Notices for Mariners,* which provide corrections for Admiralty charts and timely warnings of newly noted marine hazards; and in 1849, a few years before Beaufort's retirement at the age of eighty, the *Manual of Scientific Enquiry*, edited by Sir John F. W. Herschel, to which leading scientists contributed chapters suggesting means by which seafarers, mercantile as well as naval, could add to the body of scientific knowledge.

As a Fellow of the Geological Society, of the Royal Society, and of the Astronomical Society, and as one of the founders of the Royal Geographic Society, Beaufort was in touch with the leading scientists of the day. A standard for the marine surveyor had been set by the advice he proferred in 1850 in the *General Instructions to Hydrographic Surveyors:*

> *The Hydrographic Surveyor should be alert to take advantage of his opportunities of adding to the general scientific knowledge of the world, when working in the lesser known quarters of the globe* . [quoted by Ritchie (1967)]

Towards the end of Beaufort's term of office, economies imposed upon his department meant the need to curtail some surveys in distant waters.

Fig 4.2 The Beauford Wind Scale

Beaufort Force	Windspeed Knots	Description	Sea Condition
0	0	Calm	Sea like a mirror
1	1 – 3	Light Air	Ripples but without foam crests
2	4 – 6	Light Breeze	Small wavelets. Crests do not break
3	7 – 10	Gentle Breeze	Large wavelets. Perhaps scattered white horses
4	11 – 16	Moderate Breeze	Small waves. Fairly frequent white horses.
5	17 – 21	Fresh Breeze	Moderate waves, many white horses
6	22 – 27	Strong Breeze	Large waves begin to form; white foam crests, probably spray
7	28 – 33	Near Gale	Sea heaps up and white foam blown in streaks along the direction of the wind
8	34 – 40	Gale	Moderately high waves, crests begin to break into spindrift
9	41 – 47	Strong Gale	High waves. Dense foam along the direction of the wind. Crests of waves begin to roll over. Spray may affect visibility
10	48 – 55	Storm	Very high waves with long overhanging crests. The surface of the sea takes a white appearance. The

			tumbling of the sea becomes heavy and shock like. Visibility affected
11	**56 – 63**	**Violent Storm**	**Exceptionally high waves. The sea is completely covered with long white patches of foam lying in the direction of the wind. Visibility affected**
12	**64+**	**Hurricane**	**The air is filled with foam and spray. Sea completely white with driving spray. Visibility very seriously affected.**

Marine Science in the Beaufort Era

As the British settlements around the coast of Australia increased in number, so did the need for coastal shipping. The danger of shipwreck was ever present in waters that had to date received only running surveys by Flinders and King. With settlements on both sides of Bass Strait at Port Phillip and Port Dalrymple and with the establishment of Port Essington near the western entrance to Torres Strait, more detailed surveys of these approach lanes seemed timely. Accordingly, on its return from South American waters in 1837, the *Beagle* was sent to Australia under the command of John Clements Wickham with instructions to make an exact survey of Torres Strait and Bass Strait, both of a hazardous nature and the scene of many shipwrecks. The *Beagle* carried, as well as Commander Wickham, other officers who had served previously under Captain Fitzroy, namely Lieutenant John Lort Stokes and surgeon Benjamin Bynoe. The surgeon was well equipped to make natural history collections, having learned so much from his association with Charles Darwin during his many years on the *Beagle*.

In Australia the *Beagle* was first deployed for five months, surveying 300 miles of the north-west coast, checking Dampier's theory of a possible inlet in the vicinity of Broome. Commander Wickham took with him a Swan River native, in the vain hope that he might be able to communicate with the Aboriginal inhabitants. In 1839 the *Beagle* cruised to the new settlement of Port Essington, near the present site of Darwin, on the northern coast of the continent. While exploring the Victoria River, Lieutenant Stokes was severely wounded by a native's spear. These surveys involved exploration into numerous inlets in search of sizeable rivers which, it was hoped, might allow penetration of the interior of the region. The surgeons, Benjamin Bynoe and Thomas Tait, in the tradition of naval surgeons of the time, collected a wide variety of natural history specimens, especially of birds and marsupials.

The Admiralty instructions for the *Beagle* survey of the Australian region reveal Beaufort's recommendation of such activities:

> *In such an extensive and distant survey, numerous subjects of inquiry, though not strictly nautical, will suggest themselves to your active mind; and though, from your transient stay at any one place, you will often experience the mortification of leaving them incomplete, yet that should not discourage you in the collection of every useful fact within your reach. Your example in this respect will stimulate the efforts of the younger officers under your command, and through them may even have a beneficial influence on the future character of the navy.* [Stokes (1846) p.21]

Beaufort drew specific attention to the likelihood of throwing light upon the formation of coral reefs by observation amongst the coral cays which abounded in the northern waters. He indicated, however, that the collections of atmospheric and sea-surface temperatures, which were made on most naval survey vessels, could in this case be dispensed with, as too demanding in respect of time and personnel:

> *Hitherto it has been made a part of the duty of all surveying vessels to keep an exact register of the height of the barometer, at its two maxima of 9, and its two minima of 3 o'clock, as well as that of the thermometer at the above periods, and at its own day and night maximum and minimum, as well as the continual comparative temperature of the sea and air. This was done with the view of assisting to provide authentic data, collected from all parts of the world, and ready for the use of future labourers, whenever some accidental discovery, or the direction of some powerful mind, should happily rescue that science from its present neglected state. But*

> *those hours of entry greatly interfere with the employments of such officers as are capable of registering those instruments with the precision and delicacy which alone can register meteorological data useful, and their future utility is at present so uncertain, that it does not appear necessary that you should do more than record, twice a day, the height of the former, as well as the extremes of the thermometer, unless, from some unforeseen cause, you should be long detained in any one port, when a system of these observations might then be advantageously undertaken.* [Stokes (1846) p.22]

The recording of the 'continual comparative temperature of the sea and air', then, was not to be a part of the duties of these hydrographic surveyors in the Australian region. It would seem perhaps that, after several decades of sea-surface observations, interest had now moved more towards the investigation of subsurface conditions in the open ocean. Other topics of contemporary interest are apparent in Beaufort's instructions, from which we select:

> *There are, however some occasional observations, which cannot fail of being extensively useful in future investigations :*
>
> 2) *The mean temperature of the sea at the equator, or, perhaps, under a vertical sun. These observations should be repeated whenever the ship is in either of those situations, as well in the Atlantic as in the Pacific; they should be made far away from the influence of the land, and at certain constant depths - suppose fifty and ten fathoms - and at the surface also; and this last ought to be again observed at the corresponding hour of the night.*
>
> 3) *A collection of good observations systematically continued, for the purpose of connecting the isothermal lines of the globe, and made, as above, at certain uniform depths. . .*
>
> *9) Large collections of natural history cannot be expected nor any connected account of the structure or geological arrangements of the great islands which you are to coast; nor, indeed, would minute inquiries on these subjects be at all consistent with the true objects of the survey. But, to an observant eye, some facts will unavoidably present themselves, which will be well worth recording, and the medical officers will, no doubt, be anxious to contribute their share*

to the scientific character of the survey. . .

Given, &c. this 8th day of June, 1837.

F. BEAUFORT,
Hydrographer.

[Stokes (1846) p.23]

The *Beagle* spent six years surveying in Australian waters. Command passed in 1841 from Lieutenant Wickham, who was invalided home, to Lieutenant Stokes. In 1842 the work in Bass Strait was advanced by the cooperation of John Franklin, Lieutenant-Governor of Tasmania, who provided the services of the *Vansittart*. The Admiralty chart of Bass Strait published in 1843 under Stokes's name was of inestimable value for shipping approaching Melbourne in the boom years ahead.

In the 1840s some civilian scientists cruised the outer Barrier Reef with the surveying party of the *Fly* and the *Bramble:* a geologist, Beete Jukes, and a zoologist, John Macgillivray, employed by the Earl of Derby. An artist, Mr Melville, was appointed to the expedition. Thousands of natural history specimens were collected by MacGillivray and Jukes over the four-year period to enrich the holdings of the British Museum. Jukes showed considerable ingenuity in befriending the natives, who were often hostile. Despite the surveyors' best efforts to ensure friendly relations, however, one seaman died of a spear wound on the Australian mainland. Jukes's (1847) narrative of the cruise of the *Fly* is distinguished by his perceptive observations of the native populations of both the mainland and the islands off the New Guinea coast.

We must turn to another expedition sent out by the British Admiralty in this period to see the efforts being made to understand the circulation of the water masses of the world's great oceans. This was the expedition into Antarctic waters led by James Clark Ross.

James Clark Ross and the 'Circle of Mean Temperature'

Between the years 1839 and 1843 a major British scientific expedition was sent into Antarctic waters to investigate the ocean deep. A major aim of the cruise was the investigation of terrestrial magnetism and the determination of the location of the South Magnetic Pole. A knowledge of the position of the magnetic poles is valuable both for hydrography and navigation. Research into geomagnetism was well advanced in the 1830s, especially in Germany, where Friedrich Gauss, working from the Gottingen Observatory, had initiated simultaneous observations of magnetic phenomena from stations in Germany, Sweden and Italy. An enthusiastic participant was Alexander von Humboldt, who in 1836 wrote to the then President of the Royal Society, the Duke of Sussex, urging England's participation in global investigation by establishing permanent observatories in appropriate locations in her world-wide possessions. A joint physical and meteorological committee of the Society recommended this action to the government and also the equipment of a naval expedition into the waters of the southern oceans [Humboldt (1849) Vol 1 p.186]. Further stimulus was provided by the British Association for the Advancement of Science, which in 1838 was addressed by the French physicist, François Arago, on the desirability of establishing a series of magnetic observatories in colonial outposts to complement those which France was building in her overseas territories [Savours and McConnell (1982)]. A knowledge of the lines of the magnetic variation was of practical importance, especially in the high latitudes frequented by whalers, where the skies were often obscured and the correction to the compass was large. The earth's magnetic poles move with time (a few kilometers a year) and these variations were being monitored by the leading European observatories.

The British Admiralty in 1839 agreed to support the establishment of four observatories: at St Helena in the Atlantic, at Cape Town in South Africa, Hobart in Tasmania and Toronto in Canada, and to participate in a regular international program of observations. To arrange for the establishment of the new southern observatories and to make magnetic observations in a wide range of island locations, a naval expedition was despatched in September 1839 in the 370-ton *Erebus* and the 349-ton *Terror*. The two vessels were what were known as 'bombs', sturdily built of double planking to withstand the shock of firing great 10-inch mortars, and as such were chosen to work amid the icefields of the Antarctic. They had watertight bulkheads with the capacity to prevent flooding if damaged by icebergs.

The leader of the expedition was Captain (later Admiral Sir) James Clark Ross, who had had considerable experience in Arctic cruises. He had accompanied his uncle, Captain John Ross, and Lieutenant W. E. Parry on several expeditions to search for a northern passage around America and held the distinction of having established the position of the North Magnetic Pole in the Boothia Peninsula in 1831, some one thousand miles away from the geographic North Pole. He was also a skilled zoologist. Commanding the *Terror* was Francis R. M. Crozier, who had been with James Ross on one of the Arctic cruises. The surgeons and their assistants served also as naturalists. They had received training for their role as naturalists as part of their course at the Naval Hospital at Haslar. One of the young naturalists, J. D. Hooker, produced an outstanding six-volume botanical work on the expedition and eventually succeeded his father as Director of the famous Kew gardens.

Exploration and Measurement of the Deep Sea

Throughout the voyage, Ross made a most determined effort to examine subsurface ocean temperatures in serial detail. Unhampered by the demands of commerce or diplomacy, as were most of the French and Russian expeditions to this date, on this purely scientific voyage he recorded subsurface temperatures at regular depths in serial casts in over 30 locations between latitudes 33°S and 77°S. Except for one serial cast in the South Atlantic and three in the Tasman Sea, the area explored was the Southern Ocean. To build up a profile, the measurements were made for the most part at four regular levels and to a depth of over 1000 metres, but sometimes at five or six levels and, on one occasion (in the Tasman Sea) at eight levels. In the highest latitudes the profiles confirmed the slight increase in temperature with depth that had been noted in these waters at 100 fathoms on Cook's second voyage.

Between latitudes 40°S and 60°S the recorded temperature of the deepest points of Ross's serial casts was very consistently between 39.5° and 40°F (4.2° and 4.4°C), even at a depth of over 2000 metres. This accorded neatly with the widely held belief that sea water, like fresh water, would have a temperature of around 4°C at its point of greatest density and that the deepest layers of the oceans would therefore be found to have such a temperature. In all his soundings Ross measured no temperatures lower than that figure. The consistency of his recording of a minimum of 39.5°- 40°F for the temperature at great depth was received with some scepticism by scientists on the continent. Jean-Baptiste Biot, of the French Academy of Science, queried their incompatibility with observations obtained from the *Vénus* and from some Arctic voyages. Many years later it was considered, notably by Joseph Prestwich (1875), that Ross's data required a pressure correction, for he had been supplied with maximum and minimum thermometers lacking adequate protection against distortion by hydrostatic pressure. The British expedition, it is now possible to see, had not received adequate advice from the physicists of the day [Deacon (1968)]. Experimentation on the continent by Lenz and Parrot had already demonstrated the effect of pressure on the accuracy of thermometers, but their work published in St Petersburg in 1833 did not seem to have been noticed in Britain and America (see chapter 3).

In some high-southern latitude locations where the surface temperature of the sea was around 4°C, Ross's serial casts revealed less than 1°C difference in temperature between successive depths. It seemed likely, he suggested, that there existed a zone in these colder latitudes where the ocean waters possessed a uniform temperature of about 4°C from surface to ocean floor. Ross sought actively to locate and define this zone, or circle of uniform temperature:

> *As we were now getting near the latitude in which, from our former observations, we might expect to cross the circle of uniform temperature of the ocean, our experiments for the determination of this interesting point in physical geography were made at every opportunity: and, according to our expectation, we reached it on the 13th* [Dec. 1841]*, in latitude* 55°18'S*, longitude* 149°20'W. [Ross (1847) Vol 2, p.140]

Ross identified six points at about 56°S, where the *Erebus* and *Terror* crossed what he defined as the Circle of Mean Temperature:

> *It is, therefore, evident that about this parallel of latitude there is a belt or circle round the earth, where the mean temperature of the sea obtains throughout its entire depth, forming a boundary or kind of neutral ground, between the two great thermic basins of the ocean.* [(1847) Vol 2 p.375]

The zone in the Southern Ocean that Ross was investigating, and which he erroneously claimed to consist of uniform 4°C water throughout its depth, is now seen to correspond closely with what is now termed the Antarctic Convergence (see Figure 4.2). At this convergence, plotted by Deacon (1934, 1963), cold polar water is observed to sink below the warmer water which occurs to the north of it and the latitude where it occurs has been identified also by changes in level of the deep and bottom currents. The position of this zone encircling the Antarctic continent varies between north of 50°S in the Atlantic Ocean to south of 60°S in the eastern Pacific and does correspond to a boundary both in climate and in the distribution of the bird life and marine fauna of the southern seas. A remarkable feature is that it is practically stationary. If the temperatures recorded by Ross are reduced 1°C for each 1000m of depth, to compensate for the effect of pressure on his unprotected thermometers, then, states Deacon [(1963) p.289)], much the same temperature structure is produced as we find today close to the convergence and, moreover, '*the agreement suggests that the convergence has not shifted in the past 100 years*'.

On the expedition of the *Erebus* and *Terror* a great deal of the work in physical science devolved upon the expedition leader himself, for he had no assistance from experts in physics. 'As far as oceanographical work was concerned', comments M. Deacon (1971)p.283, 'Ross was poorly advised, and can scarcely be blamed himself for not having kept up with research which was so widely neglected by others'. At about the same time as the British expedition to the Antarctic, expeditions to this area were also mounted by France and the United States. The United States expedition, led by Lieutenant Charles Wilkes (see chapter five), also used unprotected maximum and minimum thermometers for subsurface measurements. He made no observations which conflicted with Ross's theory of the circle of uniform 39.5°F water around latitude 56°S, which went unchallenged. Wilkes (1848) also gave his support to the figure of 39.5°F (4.16°C) as the mean temperature of the ocean at its point of greatest density, mentioning only to reject as in error the lower figure proposed by Lenz.

Climate Change

One of the questions exercising the minds of nineteenth-century scientists was whether the climate of the world was likely to change. Ross's thoughts were turning towards this question when he wrote

[(1847) Vol 2 p.376] :

> *This circle of mean temperature of the southern ocean is a standard point in nature, which, if determined with great accuracy, would afford to philosophers of future ages the means of ascertaining if the globe we inhabit shall have undergone any change of temperature, and to what amount, during the interval.*

In view of the urgent renewal of the question of global climate change and the current discussion of the possible impact of the 'Greenhouse Effect', Ross's 'Circle of Mean Temperature', could have had the utility he suggested, had it not proved to be, like the theory of a lifeless 'azoic Zone', just one of the several hypotheses formed in the pioneering stage of oceanography which had later to be abandoned.

The Azoic Zone

There was a widely accepted belief in the nineteenth century that it would be impossible for any kind of marine life to exist in the great depths of the oceans, where there was neither light nor warmth. Nor was it thought possible that any living organism could withstand the great water pressure in these depths. The lifeless or 'azoic' zone was generally thought to extend downwards from about a 300-fathom line. The naturalist Edward Forbes in the 1840s [Deacon (1971) p.381] had delineated zones of different marine species down to that depth in the Mediterranean Sea.. Corroborative evidence for this belief soon also came from other naturalists. It is interesting to note, however, that evidence to the contrary was provided in the same era by Ross's investigations. His 'deep-sea clamm' brought up examples of marine life from much greater depths in sea-floor deposits. Recalling that some of the creatures resembled those taken in the deep water of high latitudes of the northern hemisphere on the earlier expedition of his uncle, Sir John Ross, he expressed the opinion:

> *That, although contrary to the general belief of naturalists, I have no doubt that from however great a depth we may be enabled to bring up the mud and stones of the bed of the ocean, we shall find them teeming with animal life; the extreme pressure at the greatest depth does not seem to affect these creatures; hitherto we have not been*

> *able to determine this point beyond a thousand fathoms, but from that depth several shellfish have been brought up with the mud.* [Ross (1847) Vol 1, p.203]

The general belief in an extensive strata of dark, lifeless, 4°C water filling the ocean depths was slow to disappear. The experiments to test the extent of light penetration, which we have already noted, were partly to investigate the possible extent of marine life. The whole picture of the nature of the sea bottom was to be made clearer, later in the century, by the work of the British *Challenger* expedition, which is described in chapter six.

A Tidal Benchmark in Tasmania

In his account of the expedition of the *Erebus* and *Terror* Ross draws attention to a benchmark to indicate mean sea level which was inscribed in July 1841 on a rockface on the northern side of the Isle of the Dead near the penal settlement at Port Arthur in Tasmania. In company with Governor Franklin, Ross travelled to Port Arthur to confer with Mr T. J. Lemprière, the Deputy Assistant Commissary General at the convict establishment, who had been keeping tidal records there for some time. Ross mentions (Vol 2, p.23) that the fixing of marks to show the mean level of the sea in a variety of locations had been suggested by Humboldt in a letter to Lord Minto. He points out that the letter was received ' subsequent to the sailing of the expedition ' and that he did not receive any information about the suggestion until his return from the Antarctic, otherwise he would have established similar marks 'on the rocks of Kerguelen Land or some parts of Victoria Land'. The mark at Port Arthur, with its surmounting broad arrow, is still visible. Recently its value for establishing sea level changes over time has been demonstrated by the installation in 1998 of a modern acoustic tide guage in the same vicinity. This guage provided a continuous sea level record every 6 minutes over a period of three years which could be compared with those recorded manually by Lempriere more than 150 years earlier. Attention had been drawn to the historic value of the Tasmanian records in an article by Bruce Hamon (1985) and they were subsequently located in the archives of the Royal Society of London.

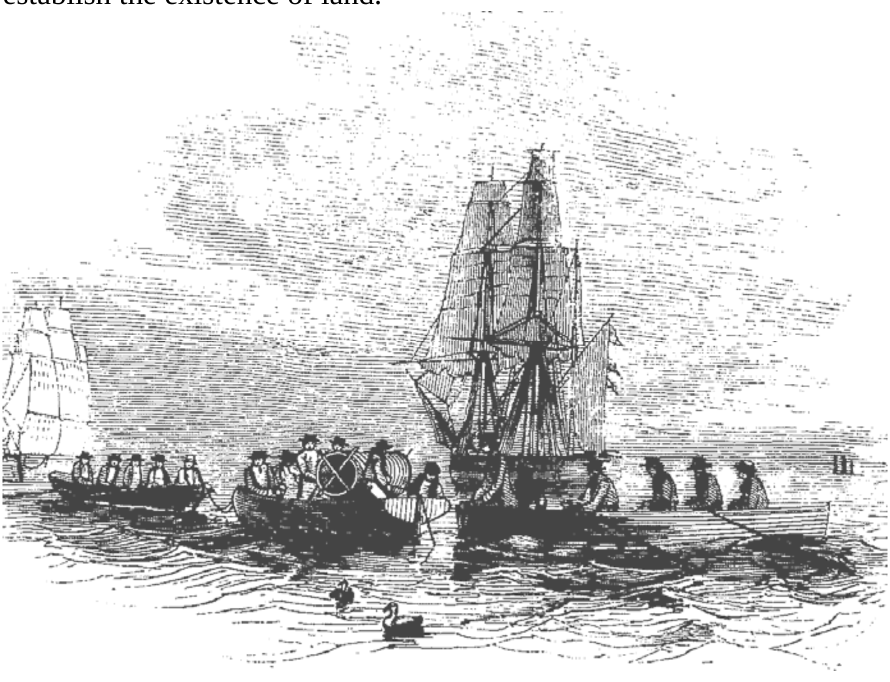
Of course tide guages measure sea level relative to the land which may itself be subject to change in height over time. Taking this and other factors into account, modern scientists have estimated that at this Tasmanian location over this period of time there has been an average rise in sea level due to an increase in the volume of the oceans of 1.0mm plus or minus 0.3mm per year. This accords with estimates that the global average sea level has risen at a rate of 1 to 2mm per year over the 20th century, based on the records from a variety of tide guages distributed over the earth.It was placed above the reach of high water to preserve it. The present value of the mark has been discussed by Hunter et al. (2003). Tidal observations also enabled two further benchmarks to be made on this expedition near Port Stanley in the Falkland Islands, where they too were placed at a prescribed distance above the mean level of the ocean.

How Deep is the Ocean?

James Clark Ross was enthusiastic about the prospect of deep-sea sounding and dredging. He initially had a sounding line of 3600 fathoms, fitted with swivels, prepared on board for this exercise. The reel containing this line was transferred to the ship's boat when the conditions were favourable. With a heavy lead weight of 76 pounds attached, the hempen sounding-line was allowed to run out freely (see Figure 4.3). Sounding in this way was a time-consuming operation, especially when pursued at depths of 2000 fathoms or more and required a calm sea. In January 1840 in the Atlantic Ocean, Ross measured a depth of 2,425 fathoms (4435m), a measurement now considered to be reasonably close to a twentieth-century measurement of 2100 fathoms in the location he recorded. In March 1843 in the Weddell Sea, Ross put out 4000 fathoms (7316m) of line, without apparently touching bottom but this location, shown on maps as the Ross Deep, was early this century shown to have a depth of only 2660 fathoms. The reason for the discrepancy has since been pointed out from a study of Admiralty records. The observation of the time-interval between successive 100-fathom marks on the line was crucial to the decision as to when bottom had been reached. This was a valuable technique Ross had developed, but it was not infallible. If a change in time-interval went unnoticed, as it did on this occasion, then the line could be drawn out over the seabed by bottom currents and give a false reading. Similar experiences befell other marine investigators of the era besides James Clark Ross. Soundings greater than 7000 and 8000 fathoms were reported in the 1850s when in actuality it is only in deep-ocean trenches that depths in any way approaching this magnitude exist. The greatest recorded depth, which is in the Marianas Trench, is given as slightly over 6000 fathoms. Such uncertainties could only be removed by improved technology, and the incentive to achieve this was to be provided later in the century by the development of under-sea cable telegraphy.

Determination of the Position of the South Magnetic Pole

In January 1841 the *Erebus* and *Terror* broke into the Ross Sea at 69°15'S. In pursuit of his aim to locate the South Magnetic Pole, James Clark Ross was the first to break through the Antarctic pack ice and establish the existence of land.



4.3
Deep-sea sounding from the boats of* HMS Erebus *and* Terror *on the British Antarctic Expedition, 1839-1842, commanded by James Clark Ross. This was a laborious task involving the paying out of kilometres of hempen line from large reels. To assist this operation, Ross had a sounding line constructed on board fitted with swivels. From Ross(1847) vol.2 p.355

The expedition reached the record southern latitude of 78°04'S, establishing the existence of land, which was named Victoria Land. Two high volcanic peaks were named Mount Erebus and Mount Terror. Their way was blocked by a perpendicular cliff of ice over 150 feet above the level of the sea, which they coasted for 450 miles. It was impossible to reach the South Magnetic Pole by sea, but, Ross [(1847) Vol 1 p.247] could claim that its position was determined 'with nearly as much accuracy as if we had reached the spot itself' by 'the multitude of observations that were made in so many directions from it'. The 1841 position assigned to the South Magnetic Pole by Ross was latitude 75°05'S and longitude 154°08'E. (It was reached only by sledge in January 1909 during Ernest Shackleton's *Nimrod* expedition, by Edgeworth David and Douglas Mawson, at which time its position had moved some 300 kilometres to the north and east. Since that time the South Magnetic Pole has migrated offshore about 13 kilometres a year to the northwest.

In the two ensuing summer seasons of the southern hemisphere the *Erebus* and *Terror* were taken again into the high latitudes of the Antarctic. In December 1841 they sailed southwards from the Bay of Islands in New Zealand and into the Ross Sea, but the cruise had to be curtailed because conditions were not so favourable as the year before. The next summer they probed the Weddell Sea from a base camp on the Falkland Islands. They met the ice further north than they had hoped and were actually held in the pack-ice for a week in January. In March they sailed for home, by way of Cape Town and St Helena, reaching Folkestone on 14 September, 1843. The voyage of almost four years' duration brought back a wealth of information for natural history, meteorology, terrestrial magnetism and oceanography. Government resources financed the publication of the narrative and the scientific reports.

Conditions in the British Navy

The *Erebus* and *Terror* had been amply provided with suitable stores, according to contemporary reports, but nevertheless living conditions on board would have been harsh by modern standards. The incidence of sickness had declined in the nineteenth century with greater attention to hygiene and diet but the life of the ordinary seaman was very hard; The pay was poor, as was the food, and there were few prospects of advancement. There was an enormous difference between the lives of the officers and scientists on naval cruises and those of the sailors who lived and ate 'below-decks'.

In the early part of the nineteenth century, when France and England were mostly at war, the demand for men in the navies was critical. In England press gangs were often used to provide crew. It was said that James Watt, the inventor, when he was living in London, was so afraid of the press gang that he did not dare set foot on the pavement alone for three years. In this era and subsequently, when the British Navy was engaged in the effort to rid the seas of slave traders, the ordinary British tar did not enjoy many of the benefits of free men. They could be lashed for minor offences, sometimes to death, even for attempting to leave their employment, and for more serious offences they could be hanged from the yard-arm. While 'official punishment' on board could hardly be called a 'fair trial', they were also apparently beaten and struck by petty officers to make them work more energetically. In port they were denied shore leave in case they should attempt to desert. From 1853 some improvements in living conditions were effected in the British navy to attract more men without the need of the 'press gang'. A uniform was introduced in 1857; hanging was abolished in 1860, but flogging was permitted until 1880.

Throughout the reign of Queen Victoria, the British Navy was deployed world-wide to maintain the 'Pax Britannica'. The Hydrographic Department continued its work in remote seas for the production of Admiralty charts enabling safer navigation for the ships of all nations. The incidence of sickness declined but there was always plenty of work for the ship's surgeon, who on hydrographic vessels, often served also as a naturalist. Such was the combined role which attracted the young Thomas Huxley, when he graduated from the Naval training establishment at Haslar, to join HMS *Rattlesnake* in 1847 for a surveying cruise in Australian waters. He looked forward enthusias-tically to the prospect of exploring uncharted tropical coastlines where he would encounter 'savage and semi-civilised people'. In later life he was to reflect upon the rough life on board her Majesty's ships, describing how, in the tropical heat, 'one woke up from a night's rest on a soft plank, with the sky for a canopy, and cocoa and weevilly biscuit the sole prospect for breakfast'. He described this life as 'down on the realities of existence by living on bare necessities' but conceded in retrospect that the experience had been for himself, personally, 'extremely valuable'.

Owen Stanley's Experiments on the Dimensions of Waves

When the survey vessel *Rattlesnake*, a 500-ton frigate shown in Figure 4.4, arrived in Australian waters in mid-1847, it was with instructions to improve the survey of the inner passage between the Barrier Reef and the mainland for the seaway to the East Indies and Asia through Torres Strait. For this exercise the former man-of-war, had been refitted for survey and science and carried only two of its previous 28 guns.

4.4
HM surveying ship* Rattlesnake*, during 1849, in the waters of the Great Barrier Reef, painted by O.W. Brierley, a talented marine artist who joined the ship in Sydney as Owen Stanley's guest.The young T.H. Huxley was assistant surgeon and naturalist on board.

[National Maritime Museum , Greenwich]

The commander of the *Rattlesnake* was Captain Owen Stanley, an experienced officer and a Fellow of the Royal Society. As a young man he had served under Phillip Parker King surveying the Straits of Magellan and had sailed with John Franklin in Arctic waters. In 1840, in command of the *Britomart,* he had assisted in the founding of Auckland.

On the voyage out to Australia, Stanley conducted some pioneer experiments on the determination of the height, length and velocity of waves, the results of which were communicated to Dr Whewell and appeared in a report of the British Association for the Advancement ofScience in 1849:

> *The method I adopted for the determination of the length and speed of the sea, was to veer a spar astern by the marked lead-line, when the ship was going dead before the wind and sea, until the spar was on the crest of one wave, while the ship's stern was on the crest of the preceding one. After a few trials, I found that when the sea was at all regular I could obtain the distance within two or three fathoms when the length of the wave was fifty. In order to ascertain the speed of the sea, the time was noted when the crest of the advancing wave passed the spar astern, and also the time when it reached the ship; and by taking a number of observations, I have reason to believe we have obtained a result not very far from the truth. The officer noting the time in all these observations having only to register the indications of the watch when the observer called stop, had no bias to induce him to make the differences more regular.*

To measure the height of the waves Stanley adopted a plan which, he said, he had tried for ten years 'with great success'. The method had been recommended to him by the scientific writer, Mary Somerville, and, we note, was along the lines suggested to French mariners by François Arago:

> *When the ship is in the trough of the sea, the person observing ascends the rigging until he can just see the crest of the coming wave on the horizon, and the height of his eye above the ship's water-line will give a very fair measure of the difference of level between the crest and the hollow of a sea. Of course in all these observations the mean of a great many have been taken, for even when the sea is most*

regular apparently there is a change in the height of the individual waves. I regret that we have had so few opportunities of making these observations, but it is only under very favourable circumstances, when the ship is going directly before both wind and sea, that they can be made with any chance of success; but I mean to lose no opportunity of obtaining more.

The following is Stanley's summary of the observations:

Date 1847	Number of observ- -ations	Wind force	Ship speed knots	Wave height feet	Wave length fathoms	Time of wave spar to stern seconds	Speed of sea knots	Remarks
Apr.21	**...**	**5**	**7.2**	**22**	**55**	**10.0**	**27**	**ship before wind heavy follow. sea**
Apr.23	**8**	**5**	**6.0**	**20**	**43**	**8.0**	**24.5**	**ditto**
Apr.24	**6**	**4**	**6.0**	**20**	**50**	**10.0**	**24.0**	**ditto**
Apr.25	**9**	**4**	**5.0**	**...**	**35-40**	**7.8**	**22.1**	**sea irregular**
Apr.26	**...**	**4**	**6.0**	**...**	**33**	**7.4**	**22.1**	**heavyfollowing sea**
May 2	**6**	**(4-5)**	**7.0**	**22**	**57**	**10.4**	**26.2**	**sea irregular obs.not v. good**
May 3	**7**	**5**	**7-8**	**17**	**35**	**8.9**	**22**	**wind and sea a little on Port Quarter.**

The numbers denoting the strength of the wind are those used by Beaufort.

The Beaufort number '4' denotes 'a moderate breeze' and '5' 'a fresh breeze'. The data above was obtained in the Indian Ocean during the passage of the *Rattlesnake* from the Cape of Good Hope to the island of Mauritius. The recorded heights for 'a heavy following sea' were within the lower range of twenty to thirty feet, described by Fitzroy as 'a common height in the open ocean during a storm'. The methods described by Stanley for determining the height, length and velocity of waves were incorporated in the British Admiralty's *Manual of Scientific Enquiry* [Herschel (1851)].

Deep-Sea Investigations from the *Rattlesnake*

Consistent with the general interest in determining the depth of the sea in the fourth decade of the nineteenth century, several such attempts were made from the *Rattlesnake* in the Atlantic Ocean, but bottom was not reached with 2400 fathoms of line. Another attempt in the Indian Ocean failed because the line parted at 3500 fathoms. The time taken to lower the sounding line was almost two hours. Investigation of subsurface temperatures was part of the regular schedule of the *Rattlesnake*:

> *Moreover at 1p.m. each day when the weather was favourable the ship was hove to for the purpose of obtaining observations on the temperature of the water at considerable depths under the superintendence of Lieutenant Dayman*. [MacGillivray (1852)]

Such soundings for temperature were achieved on 69 occasions en route to Tasmania, in the Atlantic, Indian and Southern oceans. For recording temperature, the Six-type maximum and minimum thermometer was still in use. Observations were usually obtained at two depths by attaching one thermometer to the end of a line of 370 fathoms and the other 150 fathoms higher up. The regularity of the temperature casts is evidence of the support and interest of Captain Stanley, as well as the diligence of Lieutenant Joseph Dayman, whose later career, it is worth noting, was directed towards sounding and sampling the sea-bed for the laying of submarine cables. In this era, before the availability of steam power, deep-sea sounding with the hempen rope and attached lead was always both labour-intensive and time-consuming. Experiments were also conducted on the *Rattlesnake* with a sounding machine, manufactured by the Massey family, which used the revolutions of a propellor to assess the depth attained. Sometimes, it was found that there were significant discrepancies between the two methods:

> *The depth recorded is that by Massey's patent sounding machine. As the same quantity of line was always used, the difference of depth each day should be trifling, varying only in proportion to the ship's drift; yet on several occasions the depth recorded for the machine gives as much as 100 fathoms short of the quantity of line let out.* [MacGillivray (1852) p.25]

More than one nation was collecting deep-sea temperature data in the first half of the nineteenth century. Besides the efforts of the British, we have noted those of France and Russia. There were also other nations, such as Austria and the United States, mounting scientific voyages. In

1875 there appeared an important and comprehensive compilation and analysis of this data, made by Joseph Prestwich for the years 1749 to 1868 and published in the *Philosophical Transactions* of the Royal Society. Prestwich [(1875) p.631] paid tribute to the value of Lieutenant Dayman's regularly recorded submarine temperatures on the *Rattlesnake:*

> *In laying down the lines of Section of the Bathymetrical Isotherms on the Admiralty 'Track Chart' of the world, I have selected those observations which appear the most reliable, and which at the same time offer the most continuous series over the greatest number of parallels of latitude, such as the observations of Kotzebue in the North and South Atlantic, and those of Dayman in the South Atlantic and Indian Oceans, subject to, as a correction for pressure, the deduction of 1°FAHR. for every 1700 feet of depth .*

The correction for pressure, referred to here, is, of course, that deemed necessary for the unprotected, Six-type thermometers. Prestwich suggested that 'the correction for Dayman's observations should probably be rather higher than that for the others', because they seemed uniformly too high by 1° or 2°F, but that they had 'a certain independent value as furnishing comparative temperatures at corresponding depths'. None of Dayman's readings on this voyage were, we note, at very great depths, being generally between 1000 and 2000 feet, and on no occasion did he record a temperature lower than 43°F (6.1°C). This was at a depth of 345 fathoms [2070 feet]. They did, however, provide material for the drawing of bathymetrical isotherms taken, as suggested by the Hydrographer, as a series at uniform depths. This was an improvement on the random temperature probes which had been achieved on earlier investigative cruises. In chapter five we shall draw attention to a similar plan of observation pursued on the American Exploring Expedition led by Charles Wilkes.

The experiences of the participants in the four Australian cruises of the *Rattlesnake*, 1846-50, have been brought to life in Bassett's (1966) account. They had considerable impact upon the life and career of the distinguished biologist, Thomas Huxley, who was the young assistant-surgeon on board. Huxley's observations of floating marine organisms on the outward voyage formed the subject of a paper on the *Anatomy of the Medusae* which Owen Stanley sent to his father, the Bishop of Norwich, to be submitted to the Royal Society. It earned

Huxley a place in that society, of which he was ultimately to become Secretary and then President. His diaries, published this century (1935), reveal his fascination also with the native peoples of the area. They seemed to interest him even more than the biological and zoological curiosities which abounded. When the survey party rescued a white woman who had lived for several years with an Aboriginal tribe near Evans Bay, Cape York, the young scientist hoped the encounter would prove enlightening but was disappointed at the limited mental resources of their informant. He chafed at the few opportunities which occurred to make contact with the native people of New Guinea.

For Owen Stanley the cruise proved very stressful in the face of the dangerous reefs and the ever-present menace of the consistently hostile native inhabitants of the New Guinea area. MacGillivray (1852) says only three landings were made on the New Guinea coast and that both surgeons Thompson and Huxley were very impatient of their commander's refusal to risk a landing. It must be remembered, however, that previous explorers in the area, Bougainville and Dumont D'Urville, for instance, had made no landings. When the *Rattlesnake* returned to Sydney in 1850, the captain died suddenly. The suggestion has been made [Ingleton (1944)] that he took his own life in a spell of depression. He was 38 years old.

The possibility of surveying with steam-assisted vessels was now offering. Increased manoeuvrability and safety would result, but coaling stations for remote areas would be needed. These were few and far between in the southern hemisphere. One of the aims of the *Rattlesnake* cruise was to choose a site for such a station near Cape York. Evans Bay, later called Somerset, was chosen.

During the nineteenth-century 'Pax Britannica', the British Admiralty expended great resources globally to maintain the freedom and improve the safety of the seas. We are here considering mainly the surveying missions to the Australasian coastlines, which were but a part of this activity. The most significant work in the field of physical oceanography accomplished on the Australian surveys we have reviewed was that attempted on the voyage of the *Rattlesnake*, namely the experiments on measuring the length and velocity of waves by Captain Owen Stanley and the deep-sea temperature measurements by Lieutenant Dayman. Except for the epoch-marking cruise of HMS *Challenger*, which is discussed in chapter six, for the scientific achievements of other Royal Navy cruises we refer the reader to M. Deacon's *Scientists and the Sea.*

Before the 'Greenhouse Effect'

Increased consumption of fossil fuel is leading to an increase in carbon dioxide in the world's atmosphere. Until the middle of the nineteenth century the industrial revolution had affected but few of the peoples of the earth. Extensive equatorial forests remained and the need for coal and hydrocarbons for energy was small by present standards. Ships were still powered by sail.

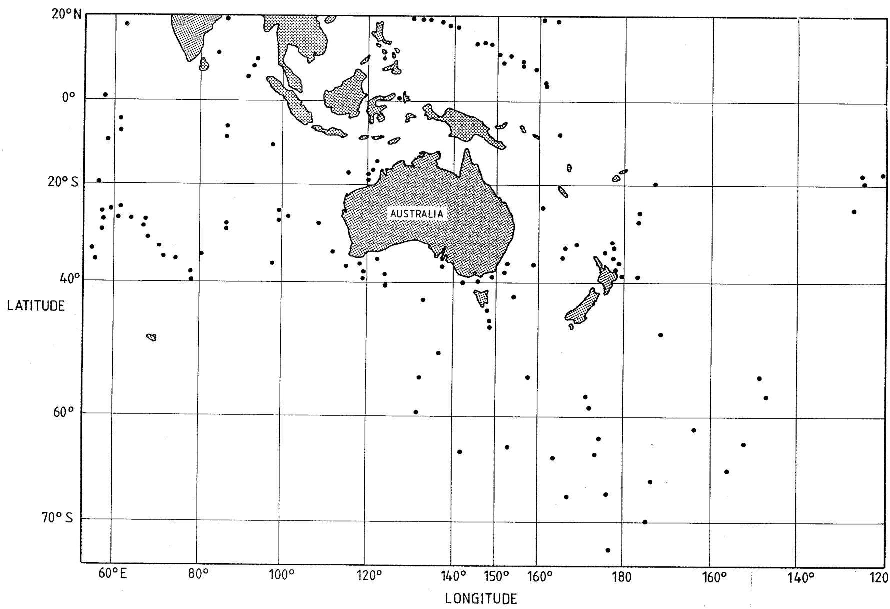


Fig 4.5
Location of deep-sea temperature casts around Australia prior to 1868, as presented in the compilation of J. Prestwich (1875). These, together with those from Wilkes in Figure 5.4 and those from Dumont d'Urville's expedition of 1837-40, represent a valuable record of the climate of last century.

Now there is a belief that the carbon dioxide released into the atmosphere over the last century may be leading to a global warming. There are more than 150 subsurface temperature casts in the Indian, South Pacific and

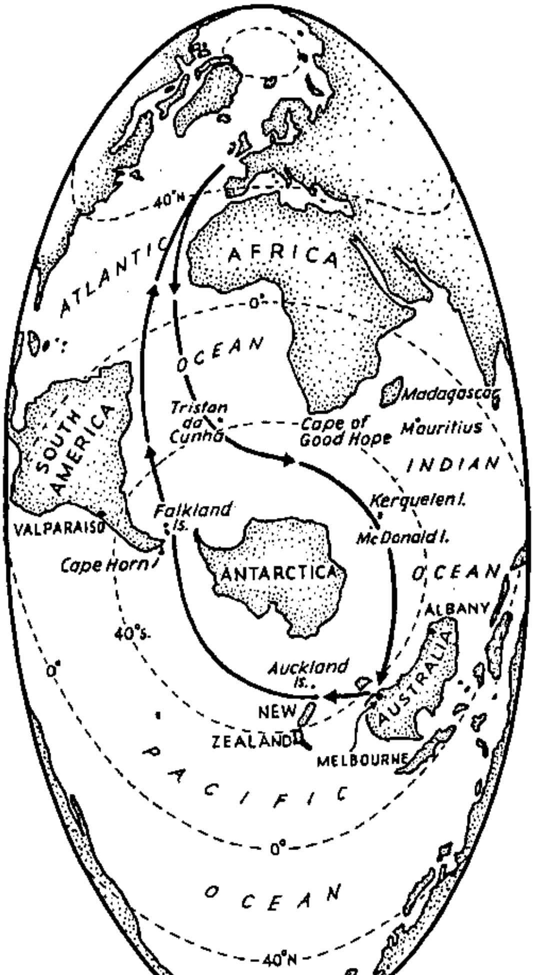
Southern Ocean alone, made before 1850, that we have identified. As these were all taken before the significant use of fossil fuels they represent a resource that can be used to compare with recent, more extensive, temperature soundings. From the many early measurements tabulated by Prestwich (1875) the positions of those in the Australasian area, taken from his distribution map, are shown in Figure 4.5. Some others not readily available to him at the time are also included.

The Great Circle Routes to Australia

The British colonies were developed to support the economy of the British Isles. Transport was no small part of the economy. To secure the greatest possible share of the transport of food, raw materials and manufactured goods, a series of restrictive laws were enacted allowing transport of goods between the colonies and the motherland only in British flag carriers, built and owned by British citizens. At first the tonnage to and from Australia was small. The restriction, nevertheless, could prove irksome. Entrepreneurial foreign merchants reaching Australian ports, found only illicit trade open to them. Australian wool and whale oil could only be exported in accordance with the Navigation-Acts, which favoured the East India Company. In the earliest days of the colony the masters of five whaling vessels took up contracts to transport convicts to Sydney as part of the Third Fleet with the idea of whaling in the eastern Pacific after disembarking their human freight [Hodgkinson (1975)]. There was an embargo on their taking whales to the west of the 180th meridian, but for this occasion, the owners had secured the permission of the East India Company to engage in whaling in Australian waters [Bateson (1974) p.139].

In 1849 the restrictive British Navigation acts were repealed. In 1851 and 1852 gold was discovered in New South Wales and Victoria. There followed an amazing growth in immigration to Australia. Tens of thousands of migrants reached Port Melbourne in the 1850s. They were mostly paying passengers, interested in a fast trip from Europe to try their luck before the gold ran out. Sailing ships were now reaching the peak of their development, which culminated in the fast American-built clippers, now free to sail into the Australian ports. Improvement in transport times helped lower costs and opened European markets to Australian produce.

Despite the development of steam power, the sailing ship still had advantages on the Great-Circle route which was used from Europe to Australia. Sailing with the maximum of canvas, ships' masters were interested in the winds, the currents and the disposition of icebergs. The need for knowledge of conditions at sea was as great as ever.



The Great Circle Route, 1850's

4.6
The Great circle routes of the Southern Ocean.

5

America's Bid for Status and Enlightenment

Behold! Now a nation, which, but a short time ago, was a discovery itself . . . is taking its place among the enlightened of the world, and endeavouring to contribute its mite, in the cause of knowledge.

William Reynolds's private journal [quoted by Stanton (1975) p.83]

The sentiments of national pride apparent in midshipman William Reynolds's journal entry on the occasion of his departure on the first United States Exploring Expedition in August 1838 were justifiable. The youngest of the world's nations, whilst making its bid to share in the economic rewards which could accrue from exploration of the island-world of the Pacific and the Southern Ocean, was at the same time joining the circle of enlightened nations which were adding to the world's scientific knowledge for the benefit of mankind.

It was natural that people in the newly independent American settlements should wish to demonstrate their prowess in science to emulate that of Britain, France and Russia. They were eager to show that the republic which they had set up was capable of the achievements of the monarchical Old World of Europe. At last their plans to send an exploring expedition into the Pacific and Southern Ocean had come to fruition. The path to that achievement had not been without difficulties, delay and dissension, for both the U.S. Navy and the scientific and professional societies were without experience in mounting a marine scientific expedition of the type that might now be considered routine for the great European powers.

In the next decade there came from the United States another significant landmark in science: the publication of Lieutenant Matthew F. Maury's textbook about the physical geography of the sea. Though sprinkled with contradictory and unfounded generalisations it was for many years and through many editions the only book specifically on the science of the ocean.

America Prepares a Scientific Exploring Expedition

The American colonies were established by sea and, clinging at first to the coastline, developed their skills as fishermen, shipbuilders and traders. After independence from Britain was achieved in 1776, American sailing ships were to be found in great numbers, not only trading in the Atlantic and Mediterranean ports, but also exploiting the distant whaling and sealing resources of the Falkland and South Shetland islands, of New Zealand waters, Bass Strait islands and the waters off Japan. In 1794 the United States Congress voted funds for the construction of six, later reduced to three, naval frigates to protect their merchant shipping from the ravages of piracy. As American sealers and merchants sailed further and further into remote waters, enthusiasm grew for the mounting of a United States exploring expedition that could make the seas safer for American seamen by charting the areas which they frequented. A strong advocate of this idea in the 1820s was Jeremiah N. Reynolds, a newspaper editor from Ohio. In lecture tours throughout the country, he pointed out the economic advantages which could accrue from the discovery of new sealing and whaling grounds, appealing also to the national pride of the young republic. Another enthusiastic supporter of a scientific voyage was a young naval officer of scientific bent, Charles Wilkes, whose great interest and expertise lay in hydrography and geomagnetism.

In May 1828 the House of Representatives requested President John Adams to send an exploring vessel into the Pacific. The Secretary of the Navy, Samuel Southard, arranged for the sloop-of-war *Peacock* to be rebuilt at the New York navy dockyard for this purpose. Jeremiah Reynolds was enjoined to obtain information about the extent of American enterprise in the Pacific and Southern seas. It was clear that the captains of New England sealing fleets had already penetrated the Antarctic Circle, but were inclined to guard jealously their geographical knowledge. He found that the New York Lyceum of Natural History was ready to recommend scientists of established reputation to join the expedition and to provide instructions. Lieutenant Charles Wilkes, who was eager to obtain the position of astronomer, was detailed to purchase the astronomical instruments needed. There were plenty of enthusiastic offers to fill the positions on the *Peacock,* which was ready for sea by September of that year. Command was offered to Thomas Catesby Jones and the principal naturalist and several assistants were appointed. Lieutenant Wilkes, although eager to join, was resisting the plan that he should serve as an assistant to the principal astronomer, who like the other scientists was to be a civilian. Jeremiah Reynolds was appointed to write the narrative of the voyage. The House of Representatives in December 1828 passed an appropriation bill of $50,000 and all seemed to be going well for the venture.

Then, as controversy developed over the employment of civilian scientists on a naval enterprise, the whole project was vetoed by a vote of the Senate. William Stanton (1975) from whom this account is mainly drawn, gives us the details (p.25): A Senator from South Carolina, Chairman of the Committee on Naval Affairs, objected to the expedition, on the grounds that “the civilian scientists, who ought to be the mere agents and instruments of the officers, would reap the glory of the enterprise, if any glory was to be acquired in it”. His additional argument, that it would be “altogether superfluous to attempt the discovery of unknown lands, while there remained unexplored regions at home”, won over the senators and the plans for the expedition were abruptly terminated.

The protagonists for the expedition however persisted with the idea. In the next decade agitation for the project was renewed. Jeremiah Reynolds, who had in the interval joined a private exploring venture into southern waters and then spent two years in Chile, returned to the United States in 1834 and to the eloquent pursuit of his former dream. John Adams still favoured the expedition. He had been succeeded as President by Andrew Jackson, but now held a seat in the Senate. There was a new Secretary of the Navy, Mahlon Dickerson. The maritime community was generally in favour of exploration. Petitions reaching the Congress from groups such as the East India Marine Society of Salem, Massachusetts, and the Boston Society of Natural History finally led the House in 1835 to vote an even larger amount, $300,000, for a maritime exploring and surveying expedition.

This time, after much dissension and delay and several false starts, the Exploring Expedition did eventuate and was to be of a scope larger than anything attempted to date by the great powers of Europe. The American scientific circles, although small, were enthusiastic. The appointment of a corps of ten civilian scientists and six artists was announced in January 1837. Jeremiah Reynolds became the champion of the scientific specialist, urging the government to support their scholarship by providing employment.

It became clear, however, that the Secretary of the Navy, had no real desire to see the expedition eventuate. He raised objections to the number of vessels (five) now proposed for the venture and also to the inclusion of civilian scientists. He agreed with Lieutenant Wilkes, who was again taking a prominent position in the planning, that the scientific tasks should be left to the naval officers. He was unwilling to allow a place for Jeremiah Reynolds as the historian of the voyage. His disinterest and his obstructive tactics frustrated Commodore Jones, who had again been appointed to lead the expedition.

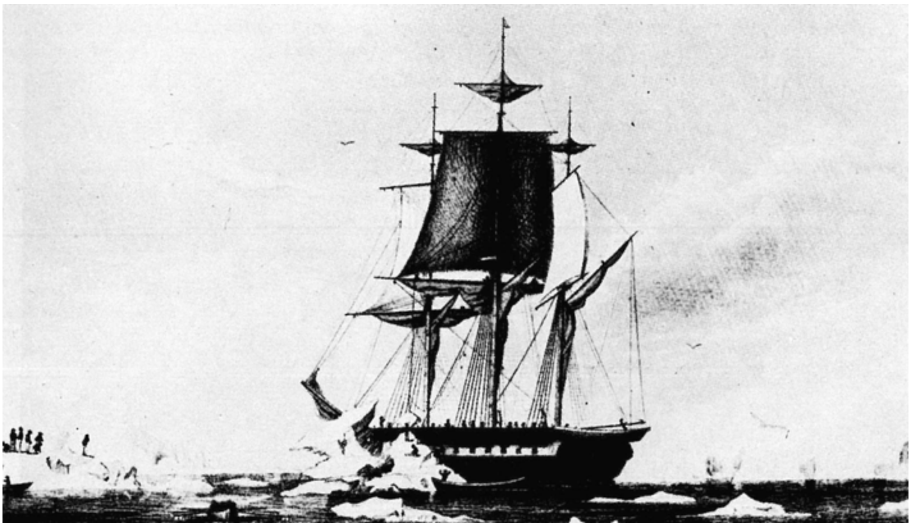
Charles Wilkes was sent to Europe to procure equipment and returned with an extensive range of books and astronomical instruments worth $20,000 but, to the dismay of the naturalists without the special equipment, such as microscopes, which they needed. To this stage the selected naturalists had not been placed on duty and lacked the resources to equip themselves. President Jackson stepped in and ordered the Secretary to have the scientific corps enrolled and allocated their duties. In the meantime news arrived that America would not have the field to itself. France was sending an expedition led by Dumont d'Urville in the *Astrolabe* and *Zélée* to explore Pacific and Antarctic waters. It was reported that King Louis-Philippe had promised a reward of 100 francs to the French sailors if they should reach latitude 75° South, and a bonus for each latitude further south. Dumont d'Urville was asked by the King to lead the expedition in February 1837 and seven months later, in September of that year he sailed from Toulon, only three weeks behind schedule.

In the United States, late in 1837, Commodore Jones resigned from the command. A Board of Survey appointed to assess the situation called for a reduction in ship strength and personnel. It proved difficult to find a new commander and President Van Buren requested the Secretary of

War, Joel Poinsett to assist. After two further attempts to find a commander, Poinsett solved the situation by recommending the appointment of Lieutenant Wilkes who had been waiting in the wings all these years for an opportunity to be part of the expedition.

Now that he had been raised to command over officers senior to him in service, and, what is more, was allowed a degree of autonomy greater than Commodore Jones had enjoyed, Wilkes became a decisive organiser. He announced a fresh choice of ships without delay and proceeded to dismantle the civilian scientific corps that had been preparing to sail. He outlined his ideas to Poinsett: "All the duties appertaining to Astronomy, Surveying, Hydrography, Geognosy, Geodesy, Magnetism, Meteorology, and Physics generally to be exclusively confined to the Navy Officer". The naval medical officers were, if possible, to be chosen for their knowledge of zoology, geology, mineralogy and conchology so that they could collect and record in those sciences. Wilkes's terms were accepted and it was proposed that the number of civilian scientists be kept as low as possible. The search for naval officers to fill the medical corps who were also knowledgeable in the natural sciences, was, however, unsuccessful. Wilkes decided that after all he would take five of the original scientific personnel appointed: Titian Ramsay Peale, as naturalist and painter, Charles Pickering as zoologist, James Dwight Dana as geologist, Asa Gray as botanist and James Pitty Couthouy as conchologist. He would, he said, have no need for Jeremiah Reynolds as historian. Asa Gray resigned from the expedition and was replaced by William Rich. William Dunlop Brackenridge was appointed gardener. The physical sciences, hydrology, meteorology and oceanography were to be carried out by naval officers and by Wilkes himself.

Finally an impressive squadron of six ships, with a complement of 627 officers and men, sailed from Norfolk, Virginia, in August 1838. It consisted of: the *Vincennes*, a 780-ton sloop-of-war, (Figure 5.1) the *Peacock*, a 650-ton sloop-of-war (Figure 5.2); the *Porpoise*, a 232-ton brig; the *Sea Gull*, a 110-ton schooner; the *Flying Fish*, a 96-ton schooner; and the *Relief*, a transport ship to service the squadron. The number of ships was unprecedented for a voyage of science and exploration. At one stage when Dickerson was objecting to the number of vessels planned, he had shown President Jackson the newly published seven volumes of the work of Dumont D'Urville's 1826-29 expedition to Australasia in the *Astrolabe* to demonstrate how much could be achieved with just one vessel, but Jackson had retorted that proportionately more could be achieved by the six ships proposed and so the strength of the squadron should remain. With a complement of six scientists, a taxidermist, two draftsmen, a scientific-instrument maker, a philologist and an interpreter, the number of civilian specialists had been exceeded only on the Baudin expedition, despatched by Napoleon Bonaparte at the turn of the century.

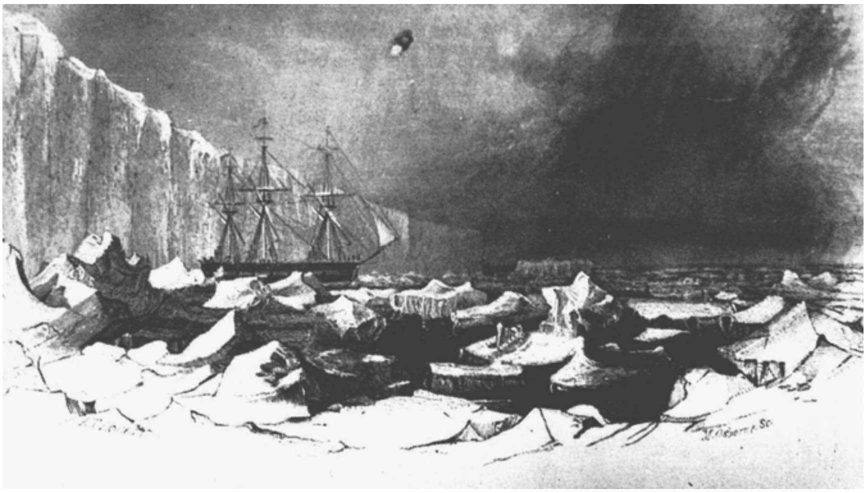


5.1
The* Vincennes*, flagship of the United States Exploring Expedition 1838-42, depicted inside the Antarctic Circle, watering the ship from a small iceberg. From a sketch by Charles Wilkes (1845).

In accordance with his long-stated preference, Wilkes had chosen his officers from young men, who had newly passed their examinations. There had been much jealous muttering about his choice. His second in command was Lieutenant William Hudson who was two years Wilkes's senior, but who had accepted the position on the clear understanding that normal rules of naval seniority did not apply on what was declared to be a purely scientific, not a military expedition.

Scientific Procedures of the Squadron

The equipment of the squadron was impressive. The French scientist, Jean-Baptiste Biot [(1848) p.675] drew the attention of the Academy of Sciences in Paris to the American enterprise. The ships carried, he said, all the precision instruments necessary for astronomical and physical observations. There were barometers, hygrometers and thermometers of every kind, not less than 29 chronometers, magnetic apparatus and a portable pendulum to determine variations in gravity. The instruments had been made by the finest English, French and German artisans.



5.2
The* Peacock*, a ship of the United States Exploring Expedition 1838-42, depicted amidst icebergs in the Antarctic Ocean. From the* Peacock *was taken the extensive temperature cast in the Tasman Sea, shown in figure 5.4. A sketch by A. T. Agate, [Wilkes (1845)].

After calling at Madeira, the Cape Verde Islands and Rio de Janeiro in the Atlantic, the American naval squadron sailed to Tierra del Fuego where they established a winter base at Orange Harbour on the south western coast in January 1839.

Leaving the *Vincennes* to survey the area around Orange Harbour and the *Relief* to examine Magellan Strait, Wilkes divided the rest of the party for exploration southwards towards Palmer Land or what is now known as the Antarctic Peninsula. Sailing amongst numerous icebergs, in danger of sudden mists and fogs, the *Peacock* penetrated as far as latitude 68°S and the *Flying Fish* as far as 70°S, before being forced by gales and freezing seas to retreat. Only one naturalist had sailed on this exercise**.** Observations were recorded of the weather and the currents and the Aurora Borealis. Four opportunities were found in these high latitudes to lower a maximum and minimum thermometer to depths of 183 metres and 548 metres. At these depths temperatures as low as minus 1.6°C were recorded.

When the squadron reassembled at Valparaiso in Chile, its numbers were reduced by the loss of the *Sea Gull* and its fifty men. They had not survived the dangers of Cape Horn in their passage from Orange Harbour. The store ship, *Relief*, which was a slow sailer, was ordered to proceed directly to Hawaii and to Sydney to leave supplies and then to return to New York. The four remaining ships took different routes on different assignments surveying among the Pacific islands, with the next rendezvous at Sydney, in preparation for another venture into Antarctic waters.

En route the ships' officers made regular oceanographic and eteorological observations. The determination of surface currents was a part of their regular duties. For this purpose they used, as a 'log', a device which consisted of 'two kegs joined with a five fathom line'. One was sufficiently weighted to sink 'its air-tight companion to just below the surface'. Thus, 'with the log-line fastened to the connecting line', Wilkes [(1844) Appendix, Vol 2] pointed out, 'it was possible to get a reading uninfluenced by wind and wave'. Instructions drawn up for the expedition by the American Philosophical Society required them to look for evidence for or against James Espy's theory of the origin of storms. This proposed that heated air, in rising, created a vacuum into which surrounding heavier air would rush.

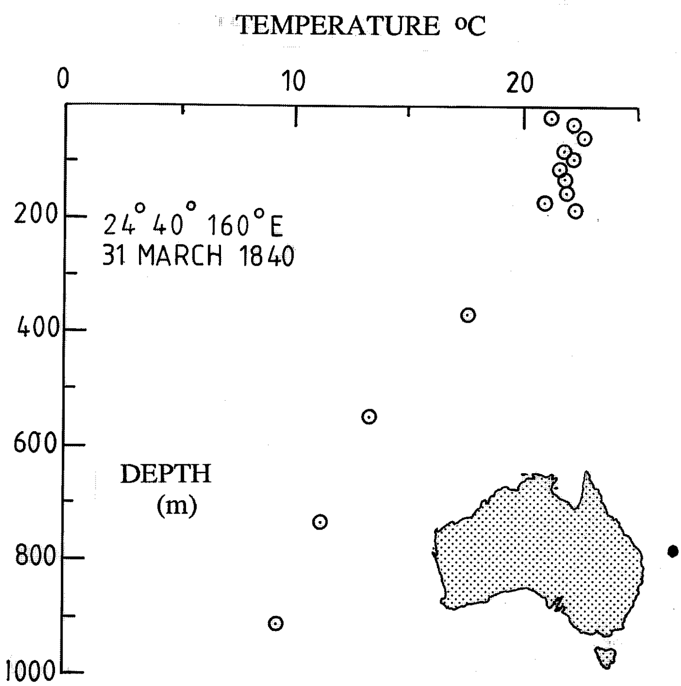
In July 1839, in the tropical Pacific waters east of Tahiti, at latitude 17°S, a deep-sea temperature measurement was attempted at 2,700 feet (1476 metres), which gave a temperature reading at that depth of 6.9°C. The surface waters were 23.3°C. It is possible that the bottom temperature could have been lower still, in view of the fact that Wilkes, like Ross, was using thermometers which had not been protected against distortion by hydrostatic pressure at great depths.

A few days later, whilst still in the tropics, Wilkes in the *Vincennes* made a vertical series of temperature measurements at the successive depths of 300 feet (91m), 600 feet (183m), 1200 feet (366m) and 1800 feet (548m). The surface temperature was 23.8°C. The profile showed a regular temperature decrease down to a temperature of 10°C.

5.3
Lieutenant Charles Wilkes, leader of the United States Exploring Expedition of 1838-1842, reproduced from Wilkes (1844)

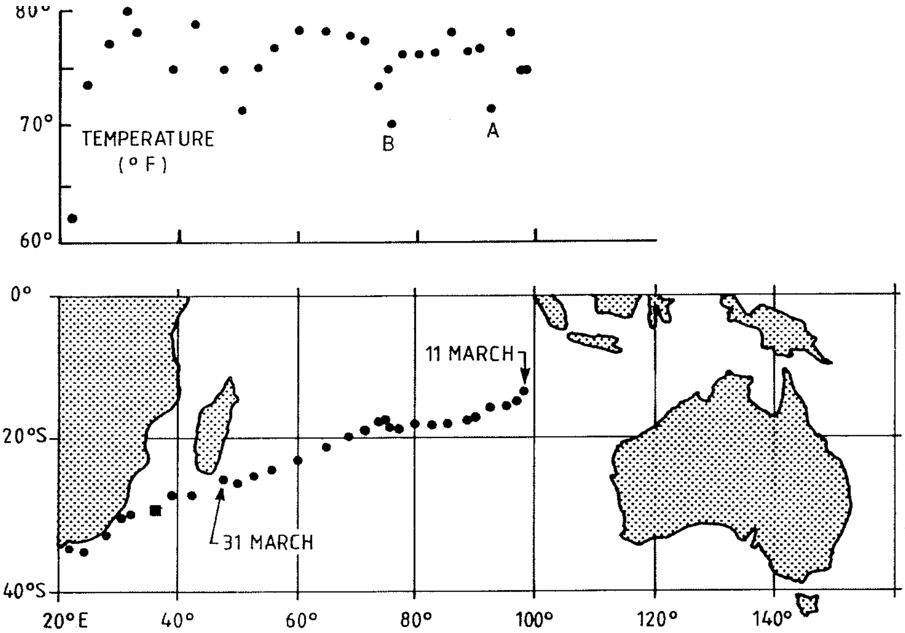
Several other serial temperature casts were made from the *Peacock,* en route from Sydney to Tonga in 1840. They are recorded in the unpublished journal of Frederic D. Stuart, Captain's clerk, aboard the *Peacock.* The most detailed of these was a vertical series measured in March 1840, to the east of Australia at 25°40' S 160° E. As shown in Figure 5.4, it consisted of a cast at 14 levels in the north Tasman Sea. The measurements of temperature were made at 60 feet (18m) intervals down to 600 feet (183m) then at 600 feet (183m) intervals down to 3000 feet (915m). At the depth of 915 metres the temperature was only 49°F (9.4°C). The error for distortion of the thermometer to this depth would have been close to 1°C. The surface temperature was 75°F (23.8°C).

In addition to such random temperature casts, a systematic sampling was pursued by two of the ships which were ordered to halt twice daily on their homeward route from Singapore to New York, by way of Rio de Janeiro to measure the temperature at a regular depth of 100 fathoms. The data, which has not previously been published, has been extracted from the extant journals and drawn as a section for the Indian Ocean in Figure 5.5. In the closing stages of this return stage, when the long voyage must have seemed never-ending, the deep-sea thermometer suddenly disappeared from the *Porpoise* and not even for Captain Ringgold's proffered reward of hundred dollars was any information forthcoming. The next day, however, a new sounding apparatus was prepared, and the daily stoppages contined [Stanton (1975) p.278]. Meanwhile the *Vincennes*, after calling at Cape Town, forged ahead, stopping only occasionally for soundings. There were grumbles that Wilkes wished to be the first to arrive home in order to enjoy the welcoming acclaim for himself.



5.4
A serial temperature cast taken in the Tasman Sea in 1840 from the* Peacock. *One can see the 200m thick mixed layer at about 22°C overlying the colder waters of the thermocline. Many thermometers were attached to a sounding line to make this profile.

Sea-surface temperatures were recorded regularly throughout the voyage by the expedition. These may be extracted from the microfilm copies of the unpublished journals of the officers (see, for example Wilkes's journal, volume 1), but, as it transpired, these measurements were not tabulated and published.



5.5
A temperature section across the Indian Ocean taken at the regular depth of 100 fathoms from the* Porpoise *and the* Oregon *in1842 on the homeward track of the United States Exploring Expedition. These measurements have been extracted from the manuscript journal of Lieutenant E. J.de Haven, 18 July 1841-12 June, 1842. The temperatures at points A and B are inexplicably lower than their neighbours.

Water samples for salinity analysis were collected from different latitudes en route and particular attention was given to experiments to determine the degree of light penetration in the ocean. The method was described by Wilkes (1848)

> *The mode of obtaining results was to let down a pot, bottom upwards, painted white, some eighteen inches in diameter, by the deep-sea line until it was lost sight of, noting the depth at which it*

> *disappeared, and then again its reappearance, the mean being taken for the result; these seldom differed more than a fathom; the eye was placed five feet above the surface in the direction with the line by which the pot was held.*

These experiments, said Wilkes, were conducted when the sea was nearly calm and quite smooth. They were carried out frequently and at every hour of the day, from early morning until late in the evening. The altitude of the sun was measured at each trial. At first, he said, it seemed that the depth at which an object could be seen depended upon the intensity of the light as well as the angle at which the rays of sunshine fell upon the surface of the ocean:

> *They undoubtedly have some effect, but seldom made a greater difference than 1 and 1/2 fathoms. Under different latitudes and in different temperatures of the water, the anomalies far exceeded this and were indeed too great not to excite enquiry and call attention to other causes.*

Two examples of such experiments were reported in the appendix to volume three of Wilkes's (1844) narrative. The greatest depth, he observed, at which the test object could be perceived was 30 fathoms (180ft, 55m). His conclusions were:

> *There is little doubt that the great cause of the variation noticed in the temperature of the waters affected in a great degree the transmission of the rays of light, or their absorption. In water at the temperature of 78° to 80°, the white object described was discernible at depths of 180 feet, while in water at 36°, it was lost sight of at 40 feet. The object gradually diminished until it disappeared.*

This simple experiment with a white disk to determine the transmission of visible light through sea water has continued to be employed by oceanographers, although a more sophisticated method is available which makes use of a lamp and a photo-electric cell. The findings are given as the absorption coefficient of the water, which is measured at a series of depths to give a vertical profile of this water property. We now believe it is not the temperature itself which influences the depth to which the Secchi-disk can be seen, but rather the biological activity, which is often related to the temperature of the waters. Cold waters are often nutrient-rich and this supports increased plankton production, which in turn reduces transparency. The absorption coefficient can be useful, along with other properties of temperature and salinity, for the identification of water masses away from their source of origin.

In a paper presented to the Philosophical Society of Philadelphia (1859), based on his unpublished volume 24 of the narrative, Wilkes concluded that the 'depth at which the solar light was completely absorbed' gave support to the theory that the oceans must be warmed largely by heat emanating from the earth's crust. If, he argued, solar light penetrated no further than 30 fathoms, this was insufficient to explain the temperature of the seas. This topic had been under discussion by scientists for some decades. It had been considered and rejected by François Péron three decades earlier. The volume on physics, which was planned by Wilkes did not eventuate but the Philosophical Society of Philadelphia holds two pre-print chapters of this unpublished volume and it is from these chapters that Wilkes's conclusions about the dependence of ocean temperatures upon heat from the earth's crust have been extracted. We now know that indeed solar energy provides the heat in the ocean and it is transferred from the surface ocean by conduction and vertical advection.

The American Exploring Expedition Reaches Sydney

Unlike Baudin in the *Géographe*, Wilkes sailed into Port Jackson, Australia not only without assistance but with considerable flair. The startled residents at Sydney Cove found the American ships riding at anchor on the morning of 30 November 1839. The *Vincennes* and the *Peacock* had sailed boldly through the narrow heads in the darkness of the previous night, guided by the South Head light and the expertise of the quartermaster of the *Vincennes*, who was familiar with the harbour. There was consternation among the port authorities that the entry had not been detected by those on duty at the semaphore station at South Head. The *Porpoise* and the *Flying Fish* joined the squadron later in the morning.

Fort Macquarie, the site of the modern Opera House, was made available to the squadron as a site for an observatory. All the vessels were overhauled, caulked, painted and provisioned. The residents of Sydney, nevertheless, were anxious about the expedition's preparedness for their projected voyage to the Antarctic. They expected that the ships would have been of stronger construction to work amongst the ice, for they had heard that English and Russian ships were reinforced for such work.

> *They enquired whether we had compartments in our ships to prevent them from sinking? How we intended to keep ourselves warm? What kind of anti-scorbutic we were to use? And where were our great ice-saws?* [Wilkes (1845) p.275]

A contemporary American historian, [Jenkins (1850) p.282] writing of the rival British Antarctic expedition led by James Clark Ross, commented:

> *Unlike those of the French and the Americans, his [Ross'] vessels were amply provided with suitable stores and necessaries, and so strongly fortified to penetrate the ice, that he at one time forced them through a thick belt two hundred miles across, which would have completely destroyed any other craft, into the open sea beyond.*

A serious deficiency for the American cruise was the poor quality of the boots and heavy clothing issued by the Navy. The large open portholes of the ships were also unsuitable. William Hudson, the captain of the *Peacock*, reported to Wilkes at Sydney that his ship was in very poor condition for the hazardous work ahead in high latitude waters. To have commenced extensive repairs, however, would have meant missing the best season for the cruise to the south. As it transpired, the *Peacock* was so severely damaged by a collision with an ice-floe that Captain Hudson had to return to Sydney, less a rudder, in late January for repairs. The *Peacock* rejoined the expedition at Tonga in May. The little *Flying Fish* was so severely undermanned that, when sickness reduced their numbers, the crew were hard put to handle the vessel and were lucky to survive the perils of the southern gales and the ice-strewn waters.

When the American squadron sailed from Sydney on 26 December 1839 to explore the Antarctic regions, the expedition's civilian scientists stayed behind in the port. It was an opportunity to naturalise and to pack up their Pacific collections and send them home. They found their stay in the flourishing colony very pleasant. James Dana made friends with the Reverend William C. Clarke, who was an enthusiastic geologist.

Arrangements were made for the naturalists to join the expedition three months later at the Bay of Islands in New Zealand.

A rendezvous for the squadron was appointed at Macquarie Island, at 54°30'S, on much the same latitude as Cape Horn, in case the ships could not keep together. The *Peacock* and the *Flying Fish* both made landfall there but without making contact because of the fogs. Three subsurface temperature measurements were made in the vicinity that revealed temperatures below zero, just as had been recorded near Cape Horn. The deepest cast was at 5100 feet (1554 metres).

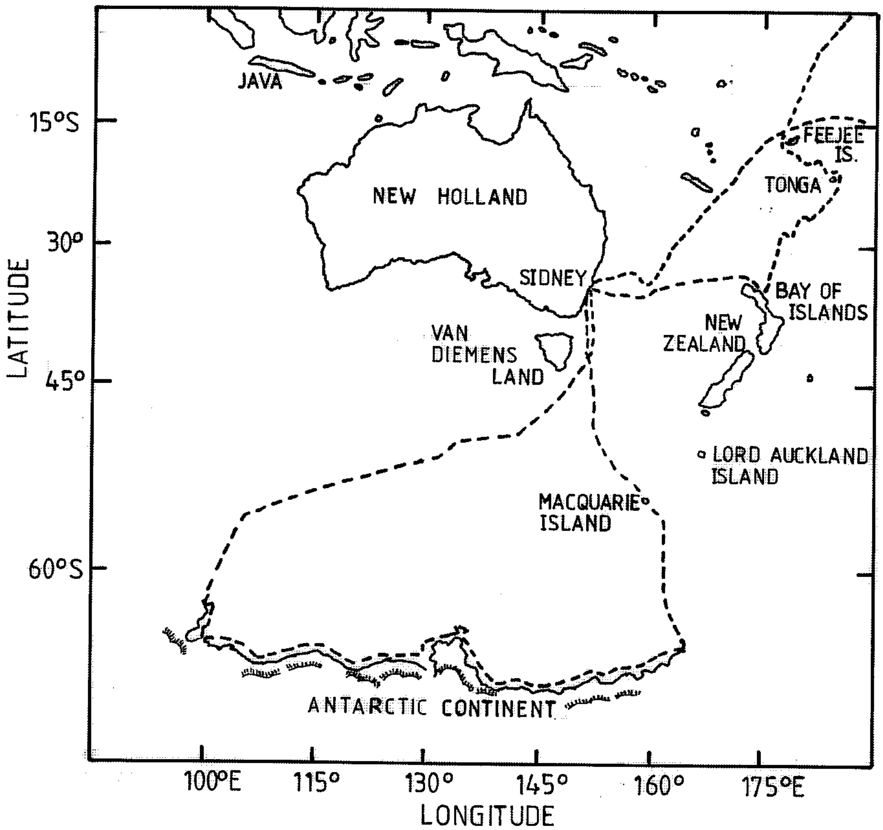
Thereafter, each of the ships sailed at great risk as far south as they were capable, then turned westward to follow the ice barrier, behind which they saw indications of land. Because of the fog and mist there was considerable uncertainty about the presence of land. Sounding for shallower water or a muddy sea floor was pursued as evidence. On 30 January, 1840, Wilkes in the *Vincennes*, recorded an elevated area where black rocks were visible and entered in his journal '*Antarctic land discovered beyond cavil.'* A sounding revealed a rocky bottom at 35 fathoms. The *Vincennes* continued westward. On 12 February, at longitude 112°16' E, Wilkes, noting even higher land, was convinced that they had been coasting land for about 800 miles along what must now be concluded to be a continent. Finally, after passing longitude 105° E, at about the location reached by Cook in the *Resolution*, he turned north and made for Sydney on 21 February. The *Vincennes* sailed into Sydney Harbour on 12 March. The discovery of the Antarctic continent was announced in the *Sydney Morning Herald* of 13 March, 1840:

> *DISCOVERY OF THE ANTARCTIC CONTINENT*
>
> *Among the arrivals to be found in our shipping list of this day, is that of the United States ship* Vincennes, *under the command of Charles Wilkes, Esq. The* Vincennes *has been absent from this port almost eighty days, most of which time has been spent in southern exploration, and we are happy to have it in our power to announce, on the highest authority, that the researches of the exploring squadron after a southern continent have been completely successful. The land was first seen on the morning of the 19th of January, in latitude 64°20' south, longitude 154°18' east.*

> *The* Peacock (*which ship arrived in our harbour on the 22nd ultimo, much disabled from her contact with the ice*)*, we learn, obtained soundings in a high southern latitude, and established beyond doubt the existence of land in that direction. But the* Vincennes*, more fortunate in escaping injury, completed the discovery, and ran down the coast from 154° 18' to 97° 45' east longitude, about seventeen hundred miles, within a short distance of the land, often so near as to get soundings with a few fathoms of line, during which time she was constantly surrounded by ice islands and bergs, and experiencing many heavy gales of wind, exposing her constantly to shipwreck. We also understand that she has brought several specimens of rock and earth procured from the land, some of them weighing upwards of one hundred pounds.*
>
> *It is questionable whether this discovery can be of any essential benefit to commerce; but it cannot be otherwise than highly gratifying to Captain Wilkes and any officers engaged with him in this most interesting expedition, to have brought to a successful termination the high trust committed to them by their country, and it is hoped that so noble a commencement in the cause of science and discovery will induce the government of the United States to follow up by other expeditions that which is now on the point of termination.*

A critical statement here was that '*the land was first seen on the morning of January 19th*.' In the *Sydney Morning Herald* of the same day appeared a report from the *Hobart Town Courier* that Captain Dumont d'Urville's expedition in the *Astrolabe* and the *Zélée* had found Antarctic land at 66°S 130°E, which they had named *Terre Adélie* in honour of the commander's wife, and from which they had obtained samples of rock. The date of this discovery was also given as 19 January, but the time as the afternoon of that day.

The date of the first sighting of land, and even the time of day became crucial in the rival claims of the two nations, and for the reputation of the American commander. The logbooks of the *Vincennes* and the *Peacock*, it transpired, recorded no sighting on that day. Nor did Wilkes's journal. Rather his claim rested upon his recollection of a suggested sighting by a crew member, which, he said, he had dismissed at the time.



5.6
The track of the Vincennes of the United States Exploring Expedition, 1838-1842, showing their discovery of the coastline of the Antarctic continent, reproduced from Wilkes (1845). The announcement of this discovery appeared in the Sydney Morning Herald of 13 March, 1840. The British explorer, James Clark Ross, however, was soon to sail over some of the coastline defined in Wilkes's chart.

The American experience of successive sightings of land meant that they had the likely evidence of a continent rather than of just an island or group of islands. There had previously been other sightings of land in the Antarctic region reported by whalers and sealers such as those by Palmer, Biscoe and Balleny. They were now given more credence. Wilkes's discovery of a continuous coastline (see Figure 5.6) was very significant, but some of the American glory was tarnished on their return by the accusation of a false claim to priority on Wilkes's part. We shall return to this topic later.

The *Porpoise*, in its southern cruise towards New Zealand, was involved in a curious incident (30 January, in the vicinity of 64°S 135°E). In all that vast empty ocean, she sighted two vessels, which proved to be, not the *Vincennes* and the *Peacock*, which was their first thought, nor even the British *Erebus* and *Terror*, which was their second, but Dumont d'Urville's *Astrolabe* and *Zélée*. Commander Ringgold set a course to speak with the French vessels, but was unable to make contact, and it was the belief of the Americans that the French commander deliberately put on sail to avoid them [Stanton (1975) p.177]. Such was the nature of national rivalries. Dumont d'Urville's explanation [Biot (1848) p.719] was that he had anticipated that the *Porpoise*, because of the speed at which she was travelling, would pass him unless he opened his sails to the wind. The *Porpoise*, after exploration along the ice barrier sailed for the next rendezvous at the Bay of Islands, New Zealand, by way of the Auckland Islands. Here, by coincidence, they again sighted the French corvettes, approaching the islands as the *Porpoise* was leaving.

The *Vincennes* joined the *Porpoise* and the *Flying Fish* at the Bay of Islands. From here, in April, Wilkes despatched a letter to Hobart to the commander of the British expedition whom he knew was expected to call there. His letter offered Ross advice about the conditions in the Antarctic area which the Americans had covered and enclosed a tracing of a chart he had made showing the areas of land which indicated the coastline of the southern continent. Whatever Wilkes's motives in doing so, this action was to rebound upon him, for, subsequently, Ross was to challenge part of his 'continent', in its easternmost extent, by declaring that his ships had sailed straight through it.

The U. S. Ex. Ex., as the American exploring expedition came to be called, returned to New York in June and July 1842. After leaving New Zealand, the squadron had spent some considerable time surveying in the mid-Pacific before sailing to the western coasts of North America. Extensive exploration there ultimately led to American occupation of the area. Here the *Peacock*, unfortunately, was wrecked on the bar at the mouth of the Columbia river, which now divides the states of Washington and Oregon, but then was the site of an outpost of the Hudson's Bay Company. A replacement vessel was procured and named the *Oregon*. In November 1841 the fleet left for a passage of the Pacific to the Philippines and Singapore. The *Flying Fish* was considered unfit to complete the lengthy circumnavigation by way of the Cape of Good Hope, and was sold in Singapore. Thus of the six original vessels only two completed the voyage of almost four years' duration.

Return Home and Courts-martial

On his return home in June 1842, Wilkes, far from being greeted with acclaim, found his reception insultingly cool. He was aggrieved also to find himself left off the promotions list for the year. Dumont d'Urville had been promoted to the rank of Rear-Admiral, a month after his return to France in November 1840. James Clark Ross was knighted soon after his return to England in September 1843. Wilkes was summoned before a court-martial to face charges brought by three of his officers and by the assistant surgeon of the *Porpoise*, Charles F. Guillou. He, in turn, had also filed charges against each of them. The proceedings lasted more than three months, and the airing of the grievances on both sides, detracted from the reputation of the commander and distracted attention from the very real achievements of the expedition. A succession of officers testified to the personality of their commander. He was described as extremely excitable, as 'violent, overbearing and insulting', 'incoherent and rude', 'his manner exceedingly overbearing and offensive to a gentleman', and more in the same vein. His leadership qualities were under strong attack.

Appointed in the last stages of a long-protracted exercise to get the expedition under way, Wilkes's fitness for his role was, indeed, dubious. He seems to have been decidedly autocratic and insensitive to the feelings of his officers. Certainly he was in charge of an expedition 'of a non-military nature', but it was almost impossible for his officers, raised in the tradition of naval service, not to have the usual expectations of naval personnel. At Orange Harbour Wilkes had promptly rearranged and reassigned this personnel so that they were serving on, or in command of different vessels to those to which they had grown accustomed. At Callao, there were further reassignments of duties, some with the aim of despatching home on the *Relief* disgruntled and disaffected officers, some of whom had requested a court of inquiry to investigate reprimands received from Wilkes. Throughout the voyage his officers faced a succession of reprimands, suspensions and, in some cases, dismissal. Their commander declared he had no time to waste upon inquiries. He had no time for courts-martial, either, before ordering, for seaman and marine alike, punishment more severe than the dozen lashes the U.S. Navy regulations permitted without a court-martial.

Charles Wilkes was commanding his expedition with the rank of Lieutenant. This in itself was not unusual, although the number of ships was. But on 18 July, 1839, as the *Vincennes* led the fleet of four ships from Callao into the Pacific, the blue broad pennant was seen raised to the masthead to signify command by an officer with the rank of Captain. The same procedure was observed upon the *Peacock.* Wilkes had decided that his responsibilities warranted this acting rank and had accorded it to himself in the interest of better discipline. Some of those writing in private journals waited breathlessly for an encounter with a naval vessel with a commander of similar or higher rank!

The commander's technique of 'breaking up cabals' persisted as the voyage continued, his suspicious nature often viewing mere camaraderie as plotting against him. We are reminded of the Baudin expedition to *Terres Australes* at the opening of the century. There are similarities, too, in the stories of dissatisfied scientists, unable to pursue their interests on land by the commander's disinclination to send boats ashore to land or retrieve them. Great was the disappointment on the American expedition when Wilkes ordered an immediate running survey of some islands of the Tuamotu Group, which were the first Pacific atolls they reached, while the naturalists were left to 'peer through their spyglasses' [Stanton (1975) p.116]. They had only a day to wait, however, and even then the surf was so strong that landing was difficult and two men, in their impatience and eagerness, swam to the beach to get there.

The island was Clermont Tonnere (Reao). The expedition's landing was received in a decidedly unfriendly fashion by the Polynesian inhabitants. Although Wilkes's instructions forbade the use of force, except in self defence, dismayed by the hail of stones and clubs which ensued on this, their first encounter with the islanders, he fired his weapon and ordered the others to do likewise, before which, wounded, the natives withdrew into the trees.

It was the first of many such encounters with Pacific Islanders. In the *Feeje* Islands, a cutter from the *Vincennes* was purloined, or, according to their custom, 'salvaged' by the natives. It was eventually recovered, but, because some small objects were not returned with it, Wilkes sent in a landing party which set fire to the village. He had given orders to shoot any who resisted, but the villagers had fled promptly from the scene.

A worse incident occurred later, when, in a skirmish with the natives on Malolo Island, three Fijians and two American officers were killed. A party of eighty Americans was landed on the beach, with orders to destroy everything and everybody, except the women and children. The islanders had retreated to stockades, but they were no match for the firepower of the Americans and soon their two villages were in flames and the inhabitants decimated. It was estimated that 87 Fijians had been killed. The next day a party of forty, mainly women, crawled before Wilkes and his party, making an abject appeal for mercy. Their lives were spared in return for provisioning the ships with yams and coconuts, after a lecture on the might of the Great Nation, whose representatives the natives had so heinously abused.

The charge of cruelty to natives was one of the seven charges brought against his commander by Dr. Guillou, along with 'oppression', 'disobedience of orders', 'illegal punishments', 'violation of terms of enlistment', 'scandalous conduct tending to the destruction of good morals', and 'conduct unbecoming an officer'. The only charge on which a conviction was delivered was that of illegal punishment, on which Wilkes was convicted on seventeen instances and sentenced to a public reprimand.

The accusation which occasioned most interest was that of deliberate falsehood in reporting to the Secretary of the Navy on 11 March, 1840, that:

> *On the morning of the nineteenth of January we saw Land to the Southward and Eastward with many indications of being in its vicinity, such as penguins, Seal, and the discoloration of the water, but the impenetrable barrier of the ice prevented our nearer approach to it.* [Stanton (1975) p.285]

The charge of a false claim to priority of discovery, so important to the nation's international honour, was rescued by the evidence that high land had been sighted from the masthead by two officers of the *Peacock* on 16 January, 1840. Although not entered in the log of that day, this evidence was confidently and convincingly given at the inquiry.

Publication of Results

The expedition was not over when the ships returned home. Although many specimens were lost in the wreck of the *Peacock* at the Columbia River, there was still an amazing collection of specimens and artefacts to be sorted, housed, classified and described. Some of the boxes, crates and kegs, despatched from ports en route, had already arrived and were being picked over. There was a desperate need for storage room and no well-established national museum to receive them. The botanical specimens alone numbered about fifty thousand items. The decision was taken to make available some space in the newly constructed Patents Office at Washington and to place the collections under the charge of Charles Pickering, the biologist of the expedition. When Pickering resigned in June 1843, Wilkes took over his position. To these duties, and the writing of his narrative, he now devoted the same tireless energy that he had exhibited on the voyage. His term in charge of the scientific collections was interrupted only by the outbreak of the Civil War in 1861, in which he served.

If there were any doubts about Wilkes's right, or his literary capacity to produce the narrative, they were promptly nullified by his refusal to hand over to the Navy Department the ships' logbooks and the journals which all the officers had been ordered to keep. Some friends in Congress ratified his action by the passage of bill giving him the sole control of these documents. After all, it was a European tradition, since the time of James Cook, for commanders to produce the official narrative. And the documents, asserted Wilkes, might well be altered and prejudice his case at the pending court-martial.

Just as he had once hoped that only naval officers would be needed for the scientific work on the voyage, now Wilkes hoped to have all the work on the collections of natural history carried out by those who had collected them. The task was not as simple as he envisaged. Some of the scientist-collectors declined the work; some saw the need for specialist attention; some found working in Washington, where the library facilities were minimal, a virtual impossibility, so gradually contracts had to be arranged for outside, academic specialists to assist. Slowly the volumes came from the press, providing work for artists and engravers. Nothing was spared in the quality of the productions, which were designed to be presentations to governments world-wide. In all, nineteen scientific reports were written at a cost to the government of nearly $300,000.

The first five volumes of the series consisted of Wilkes's narrative of the cruise and were printed in 1844. The government funded only limited copies of the *Narrative.* They were very handsome, gilt-edged volumes, bearing the crest of the United States, and intended mainly as copies for other enlightened nations but Wilkes secured copyright and brought out privately a cheaper version, which sold well. Subsequent abridged versions were published in England also. The map, showing the deduced coastline of the newest continent which appeared in Wilkes's 1845 edition is here reproduced as Figure 5.6. The publication renewed the gossip about dubious claims to geographic priority, and made the calls upon the public purse a little more difficult. Some reviewers commented upon the propriety of the bitter recriminations against the officers of the expedition which were evident in Wilkes' account, others on the evidence of hasty preparation [Jenkins (1850) Introd.].

The next report, volume six, was Horatio Hale's *Ethnography and Philology* (1846). In the same year appeared James D. Dana's *Zoophytes* with volumes on *Geology* in 1849, on *Crustacea* in 1852 and 1853, and an atlas in 1855. The volumes on *Mammalogy and Ornithology,* on *Races of Man,* on *Mollusca and Shells* and volumes on botany were written or revised by eminent scientists who had not participated in the cruise. Wilkes himself contributed volume eleven, *Meteorology,* in 1851 and volume twenty-three, *Hydrography* in 1873. Two volumes of charts appeared in 1850 and 1858, a matter of pride to Americans to be able to show some independence from the chartmaking of the British Admiralty. Shepherding these reports through the press and ensuring the funding for them, in the face of no great enthusiasm from the public, was a source of pride to Charles Wilkes. There might be grumbles against his 'quarterdeck discipline' from the scientists, but the work continued over a period of thirty years and contained a wealth of information on the Pacific region. It is a shame, in the present context, that the potentially valuable physical measurements to be included in the volume on *Physics*, written by Wilkes, and actually in press, failed to appear. In 1873 a new chairman of the Library Committee of Congress, which had responsibility for the publications, brought the expedition finally to a conclusion by withholding payment to the publishers who were printing this report. Printing ceased also on four other reports.

First Indian Ocean Temperature Section

Since Wilkes's volume on the physics of the ocean was never published, we have made a search of the manuscript journals of the expedition members for subsurface data with potential climatological value. Some serial casts in the Tasman Sea have been plotted, (see, for example, Figure 5.4) and a very early, possibly the earliest, temperature section through the Indian Ocean from the measurements from the *Porpoise* and *Oregon* on the homeward track. These observations were not available for Joseph Prestwich, when he was making his compilation and analysis of world-wide deep-sea temperature data to 1868. Figure 5.5 indicates that the subsurface temperature, measured by the Americans consistently at 100 fathoms (200m), was remarkably constant except for the points marked A and B. There is no immediate explanation for these low readings and we assume they must be simple errors. The 100-fathom readings appear higher than we would expect from soundings of this century. Wilkes on the *Vincennes* also reports some 100-fathom temperatures from the same area and, while there are only a few readings, they are generally consistent with those taken on the *Oregon.*

The manuscript sources are widely scattered. They have been combed by William Stanton (1975) to produce a fascinating account of the many interesting aspects of the Expedition. The work on physical oceanography is, however, one further aspect which still warrants research.

Maury's *The Physical Geography of the Sea*

While Wilkes worked at directing the publication of the results of the American Exploring Expedition for the United States Library of Congress, another naval officer Matthew Fontaine Maury was appointed superintendent, 1842, of the Depot of Charts and Instruments, which was subsequently restructured in 1844, as the Naval Observatory and Hydrographic Office, a position which he put to novel use and which ultimately earned him international renown in the field of practical navigation.

5.7
Matthew Fontaine Maury, Superintendent of the United States Naval Observatory, was an important figure in the history of oceanography. He pioneered the production of wind and current charts of great value for the masters of sailing ships. From the **Illustrated London News** ***of 1866.***

Matthew Maury had entered the United States Navy as a midshipman at the age of nineteen and his service on the high seas took him across the Atlantic, around South America and around the world. His career as a writer began in 1834 with the publication of an article on the problems of navigation in the vicinity of Cape Horn, followed by a series of pseudonymous newspaper articles, mainly on the topic of the deficiences, as he saw it, of the training available to the naval officer of his time. A severe injury sustained in a carriage accident in October 1839, which deprived him of full use of his right leg thereafter, meant that he saw no more active service. Instead, in July 1842 he entered upon the desk career, which gave him access to the accumulated stock of logbooks of the ships of the United States Navy. From these he published in 1847 a set of *Wind and Current Charts*, designed to assist the masters of sailing ships world-wide.

In addition, Maury instigated a scheme for masters of both naval and merchant ships to fill in specially prepared forms and charts from which he compiled further wind and current charts and the *Sailing Directions* which accompanied them. The charts showed also the haunts of whales, the hunting of which was at that time a major maritime industry. At the same time Maury collected measurements of ocean temperatures, depths, and bottom sediments. From his published sailing directions and other papers about the science of the sea Maury produced *The Physical Geography of the Sea and its Meteorology* in 1855. He played a leading part in the organisation of an international Maritime Conference held in Brussels in 1853 to form a plan of uniform marine meteorological observations to be followed by vessels of all nations. He was honoured internationally for his work for navigational science. However his book, *The Physical Geography of the Sea and its Meteorology*, which first appeared in 1855, although written in a colourful and confident style, is a poor description of physical oceanography, often physically unsound and poorly organised.

Leighly (1968), the editor of the Harvard Press reprint of the eighth edition of Maury's work, has commented:

> *But Maury was not content with putting useful information into the hands of practial men. The observations he collected demanded physical explanation, which he was bold enough to attempt. To his efforts at their interpretation he brought a lively imagination and unlimited self-confidence, but only the most superficial knowledge of physical science. The combination of these qualities led him into grandiose but often fantastic generalisations concerning the circulation of the atmosphere and the oceans, which were justly rejected by his scientific contemporaries* .

Despite these shortcomings, Maury's work, since it was unique in its field, ran to many editions; it was translated into several languages, and the final edition, published in 1861, was kept in print for 20 years. His *Wind and Current Charts* were of great value to the merchant ships of those times and especially to the speedy clipper ships, enabling them to carry cargo and passengers across the oceans in ever-decreasing times. In the introduction to the first edition of his book, Maury (1855, p.8) presents a calculation of the saving that his sailing directions could make to freight costs. He suggests the sailing directions shortened the passages from the eastern states to California by thirty days, to Australia by twenty days, and to Rio de Janeiro by ten days. This, he calculated, corresponded to a saving for United States freight of $2,250,000 per annum. He was able to claim:

> *Never before has such a corp of observers been enlisted in the cause of any department of physical science as is that which is now about to be engaged in advancing our knowledge of the Physical Geography of the Sea, and never before have men felt such an interest with regard to this knowledge.*

Maury and Wilkes were contributors to oceanographic knowledge in the pioneering days of American science. In their time they had to battle against a public lack of interest in anything other than the most practical aspects of science. Their achievements are all the more noteworthy.

Surveying North Pacific Waters

In the 1850s, following the gold rushes in California, there was increased maritime activity in the North Pacific. Hundreds of vessels from the western seaboard of North America were ranging far and wide in search of whale oil and whalebone as far north as the Bering Sea. American whalers and traders, sailing so far from home, needed the security of access to harbours where the provision of wood and water would be available. Moreover, in this decade, the invention of steam power allowed the addition of a coal-burning engine to sailing ships as an auxiliary source of power. There were good markets in Asian ports and hopes were high of establishing profitable trade routes between the U.S.A. and China with improved shipping facilities. For this venture a supply of coal was also desirable for this marvellous new source of power. Access to Chinese ports had been procured by treaties enforced by Britain and France in the 1840s but, except for the one guarded island of Deshima in the port of Nagasaki, the harbours of the Japanese archipelago had for two centuries been firmly closed to Europeans.

In 1853 the American Congress sent a squadron of four armed steam-assisted ships under the command of Commodore Matthew C. Perry to attempt to negotiate a treaty of trade and friendship with the Japanese Emperor. When his offer was rejected, Perry withdrew, only to return six months later with an even larger naval force. The outcome was the Treaty of Kanagawa, March 31, 1854, by which provisions and fuel were to be available for sale to American ships and assistance to be provided for shipwrecked Americans. With the treaty ports of Nagasaki, Shimoda and Hakodate now open to their traders, the Americans embarked on an extensive surveying mission to survey the waters of the North Pacific islands and coastlines. The expedition was instructed to chart trans-Pacific routes over which it was planned that steamships would soon be making their way from San Francisco to Shanghai. A Great Circle Route by way of the Aleutian Islands was envisaged as well as a more direct route by the Sandwich Islands (Hawaii). The surveying squadron of five ships, under the command of Cadwallader Ringgold, included the same *Vincennes* in which the Antarctic continent had been discovered and its consort the *Porpoise.* Command of the fleet passed to Lieutenant John Rodgers in 1854 when Ringgold was found unfit for service. One of their support ships, the *John Hancock,* was a small steamer and the location of sources of coal for future use was one of the aims of the mission. On one occasion to maintain their dwindling fuel supply the crew spent a strenuous week digging and loading coal from a seam which they discovered on the isolated coast of Kamchatka.

In the instructions for the surveying expedition the importance to the nation of the acquisition of knowledge over a wide range of the sciences was stressed and a number of civilians were appointed as naturalists. The ships' libraries were provided with copies of the narratives of previous North Pacific navigators such as Krusenstern, Golovnin, Broughton and Laperouse. They carried copies of Ino Chukei's map of Nippon which had been smuggled out of Nagasaki by the Dutch physician, J. F. Siebold, residing at the one European trading port allowed in Japan. The Smithsonian Institute in Washington was organised to receive and distribute natural history specimens acquired on the surveys.

Appointed to the surveying fleet as senior astronomer and hydrographer was Lieutenant John Brooke, who was the inventor of an innovative deep-sea sounding device which had been effectively employed to chart a route for a trans-Atlantic cable. He had served a year at the Naval

Observatory under Matthew Maury, with whom he readily cooperated in the acquisition of knowledge to reduce the hazards of the ocean. Maury was able to include this information in updated versions of his published *Sailing Instructions*. Sea floor samples sent by Maury to a West Point Military Academy professor of chemistry enabled the publication of a series of articles on sea-bed deposits.

The danger of charting in unfamiliar waters, sometimes along precipitous fogbound coastlines, was high. The terms of the treaty were often strained when surveying parties took to small boats and camped ashore on uninhabited northern shores. Typhoon weather caused the loss of two vessels: the *Porpoise* off Taiwan in September 1854 and the *Fenimore Cooper* which had to be run aground in Tokyo Bay in August 1860.

The Kuroshio Current

The name Kuroshio is commonly applied to the continuous band of strong currents which flow close along the continental slope between Taiwan and Cape Inubozaki, in Honshu. A valuable achievement of the United States surveying expedition to the Pacific was the clearer delineation of the features of this current the presence of which had already been noted by European navigators. The first who were able to measure the ship drift occasioned by this current were Captains James King and John Gore in 1779 in the *Discovery* and the *Resolution* since they had available the precision chronometers supplied to James Cook's third voyage. Thereafter the current was depicted in no great detail on early nineteenth century charts by Europeans as a long continuous stream flowing through the East China Sea and they coastal waters of Southern Japan. They recognized the Kuroshio Current as originating from the North Pacific Equatorial Current.

Whilst making their running surveys of the coastlines not only of Formosa and the main Japanese Islands but also of the island chains to the south and north of Japan each of the participating ships of the U.S. fleet kept records of air and water temperatures and current vectors. From these records Lieutenant Silas Bent was able to produce a more detailed description of the Kuroshio than that which had been provided by any of the earlier voyagers. He presented this information and a chart in a paper to the American Geographical and Statistical Society in 1856, describing the current as “the Japanese Gulf Stream”. Near its origin at the southern end of Formosa (Taiwan) wrote Bent, the Kuroshio was seen to be contracted in width to about one hundred miles, but to the north of the Ryuku Islands the stream had a width of about five hundred miles. There was, he noted, a marked increase in temperature both of the atmosphere and the water the moment the stream was entered and the maximum temperature, 86ºF, (30ºC) of the water was very similar to that of the Gulf Stream. Around latitude 40ºN there was evidence that the current took a more easterly direction, “allowing a cold current to intervene between it and the coast”.

The officers from these surveying voyages were still working on the preparation and publication of their nautical charts when their work was abruptly interrupted in 1861 by the outbreak of the American Civil War, in which many of them now served. No official narrative of the China Sea-North Pacific-Bering Strait Expedition was ever published by the Congress as it had for the earlier Wilkes expedition but various charts were printed as needed over the years and Lieutenant Maury used some of the oceanographic data in later editions of *The Physical Geography of the Sea.*

It would appear that in Japan the Kuroshio current was first known locally merely as short fragmented currents near the Izu Islands and had appeared as such on contemporary maps. Because of the Edict of Exclusion which introduced two centuries of isolation for Japan and the ban on sea going vessels, the concept of the Kuroshio as a continuous extended stream, part of the general North Pacific circulation, was not possible for the Japanese until they had access to Western sources.

The history of the local recognition and knowledge of the Kuroshio current has been traced by Hideo Kawai (1998) in an exhaustive examination of Japanese and Chinese literary references, charts and records. The term *Kuroshio,* he concludes, was derived as a synonym for *Kurose Gawa,* (a river over blackish shallows) applied by the inhabitants of the Izu Islands for the branch of the current that flows over shallow water above the Izu Ridge. In a local history of the Izu Islands, *Izu Kaito Fudo,* (1781) there is a description quoted by Kawai of two particularly swift ocean streams in this area which sometimes flowed as visible rapids.

> "They call these streams *Kuroshio* or *Yamashio* in this island. Once a boat meets these streams, it is carried tens of *ri* in the twinkling of an eye. Hence seamen are always terrified by these streams" [Kawai (1998) p.535].

He has found depictions of the current as narrow stippled bands in other early geographical works, as on the pilot chart included in the *Nanpo Kaitoshi [Geography of Southern Islands] (1791)*. The *Kurose Gawa* is shown flowing between the islands of Hachijo Jima and Mikura Jima in the Izu group. Again there is mention of the seamen's fear of being carried away by this powerful current. There is no suggestion of the phenomenon as part of a long continuing stream.

In an area little frequented by ocean-going ships, a current such as the Kuroshio could only be identified easily when it flowed over a shallow area where the bottom topography caused a visible disturbance in the surface or where it flowed close to landmarks which acted as points of reference for the motion of drifting objects. In the 1850s when their long period of isolation came to an end the Japanese government began an active policy of assimilating the naval techniques of the Western nations. In 1855 a naval Institute was established at Nagasaki. Naval officers were sent abroad to study Western systems and technology. When the Shogunate ended in 1867 the Japanese Navy had 8 Western-style steam warships. A Hydrographic Branch of the Japanese Navy was established in 1872. By 1893 this branch of the Navy was initiating a drift-bottle program to study the Kuroshio east and south of Japan. Oceanographic research into Japanese waters increased rapidly into the next century.

6

Oceanography: The New Profession

With the discovery of gold in California, Australia and western Canada in the 1850s the populations of these newly settled regions on the Pacific rim grew rapidly. The influx of people and the wealth engendered by the discovery of gold slowly brought changes to intellectual life. In Australia, the Universities of Sydney and Melbourne were both established in that decade and attracted qualified academics from Britain to offer leadership. By 1869 the University of California had opened its doors but it took until 1888 for the Catholic University of Chile to be established.

The Australian Museum, which began in Sydney as collections in the house of the Judge Advocate (1827), in that of the Chief Justice (1836) and in the office of the Surveyor General (1840), was incorporated by an act of the New South Wales Parliament in 1853 and given a permanent home [Etheridge (1919)]. There was sufficient community interest in natural history to support the establishment of colonial museums also in Adelaide, Melbourne and Brisbane in the 1850s. Amongst the immigrants of this early era were many educated Europeans who chose to stay in the colonies to pursue their scientific interests. Their numbers began to swell the membership of the learned societies. We have the interesting situation in 1860 of the exploring expedition of Burke and Wills being organised by the Royal Society of Victoria into the vast empty spaces of the continent, with explorer-scientists travelling into the unknown interior by camel, as others had travelled into the southern oceans by ship. The hardships and the dangers were comparable, if not similar. Amongst those who supported this expedition, and actually participated in its earliest stages was a young German scientist, and member of the Royal Society of Victoria, Georg von Neumayer.

Georg von Neumayer, Maritime Meteorologist

Neumayer had first reached Australia's shores in 1852 working his passage as a ship's mate and had soon joined the crowds thronging to the Victorian goldfields. He was then 26 years old and a graduate (PhD, 1849) of the Technical University of Munich in Bavaria. His special field was terrestrial magnetism, but he was also very interested in marine meteorology and had made a study of the work of Matthew Fontaine Maury on the physical geography of the oceans.

We do not know if Neumayer made a fortune at the Victorian goldfields, but he did develop an interest in the Australian region. He had spent some time on magnetic research at the Ross Observatory at Hobart and on his return to Europe in 1854, with support from scientific friends, such as Alexander von Humboldt, he successfully promoted the value of magnetical studies in Victoria. With funding for this purpose and with £2000 worth of scientific instruments provided by Prince Maximilian of Bavaria, he returned to Melbourne in 1857 to establish there a magnetical and meteorological observatory [Loewe (1965)]. After a few years of working in temporary quarters, 'Professor' Neumayer, as he came to be called, eventually obtained a permanent building and employment by the Colonial Government of Victoria. He became Director of the Melbourne Flagstaff Observatory in 1859 and Director of the Magnetic Survey of the Colony. In his capacity as government meteorologist, he had control of various weather stations which were set up around the countryside.

Neumayer's lifestyle now involved extensive travelling throughout the colony to make magnetic surveys. He climbed Mount Kosciusko, the highest point in Australia. When the Royal Society of Victoria promoted the ill-fated Burke and Wills expedition to cross the continent from south to north, he travelled with the party as far as Menindee on the Darling River. The surveyor, and second-in-charge, W. C. Wills, had worked as one of his assistants at the observatory.

Neumayer instigated the collection of meteorological and oceanographic information from the captains of the many sailing ships which were entering the now busy port of Melbourne, along the lines of the program organised by Maury in the United States. Of his staff of four assistants (by 1859), one was employed in processing this data in the interests of safer and more efficient navigation. The local material was prepared for publication in the form of tables for latitudinal belts between Australia and New Zealand and for meridional strips along the coast of New South Wales and Victoria, which indicated likely sailing conditions for each three-monthly period of the year.

The Melbourne observatory supplied participating captains with barometers, hygrometers and thermometers and with blank forms and instructions for the systematic collection of data. They were asked to supply, as well as the daily current rate and direction, the wind force and direction, the magnetic variation of the compass, the sea-surface temperature, the barometric pressure and the temperature of the atmosphere for 4 a.m., 9 a.m., noon, 3 p.m., 8 p.m. and midnight.

Into Port Melbourne at this time came not only local traders but sailing vessels from Europe, Asia and America. It was the heyday of the fast clipper ship, seeking ever faster times by using the Great-Circle route. A Great-Circle route for the North Atlantic passage had been promoted in 1849 by watchmaker, John Townson, at the time of the gold rush to California. The principle was soon extended to the sea route to Australia. Lured by the news of the 1851 gold strike in Victoria, thousands of paying passengers from Europe, eager to reach their Eldorado in the shortest possible time, patronised the clippers which advertised the shortest passages. These were obtained by using a route through the Atlantic which did not call at the Cape of Good Hope but ventured far to the south, usually along latitude 50 degrees, or as far as was possible without putting the ship at risk from drifting icebergs. The ships carried Maury's *Wind and Current Charts*, which were constantly corrected in the observatory at Washington from the abstract logs supplied by participating navigators. Freed at last from the trading restrictions of the British Navigation Acts, American sailing ships were soon to be found in large numbers on the Australian run, servicing that growing market. The influx of immigrants from overseas caused the population of Victoria to grow sevenfold between 1851 and 1860; the population of Australia doubled in six years, between 1852 and 1858.

In this context, Neumayer, at Melbourne Observatory, also collected meteorological information and sailing times from the masters of ships reaching Melbourne from Europe, Mauritius, India and China. He compiled a chart of the most effective routes for each quarter of the year and published a report of the information gleaned for the period 1856-62.

This included averaged sightings of icebergs for each month of the year. Colonial finances for science remained tight and Neumayer was obliged to publish his final report in Germany since the Victorian government failed to authorise the funds for it.

6.1
Dr Georg von Neumayer, Director of the Melbourne Observatory 1858-64 and of the Deutsche Seewarte, Hamburg, 1876-1909. He contributed to the recording of oceanographic information which allowed sailing ships to make faster passages to Australia. Courtesy of the German Hydrographic Institute in Hamburg

After seven years in Victoria, Neumayer returned to Germany, where he played a distinguished role, first as Hydrographer for the German Admiralty, and, from 1876, as Director of the *Deutsche Seewarte,* the German Marine Observatory at Hamburg. He is seen in this role in Figure6.1. Neumayer continued to foster ocean science in all its aspects. He is given credit for convincing the German Admiralty and the Chancellory of the value of a global cruise for ocean science and this resulted in the first deep-sea expedition of the German Reich by the *Gazelle,* 1874-1876. There is an Antarctic Base near 10° W named in Neumayer's honour. An Australian Antarctic expedition was one of his suggestions when he was in Melbourne and at the turn of the century he successfully organised a German expedition to the south polar regions, the 1901-03 expedition in the steam-assisted sailing vessel *Gauss*. Under his leadership the *Deutsche Seewarte* at Hamburg made notable contributions to oceanography and meteorology, especially in Polar research.

Oceanography as a Career

In the nineteenth century a few positions were slowly emerging for career-scientists in government employment and in academies, museums and universities. Some few of these positions were available for oceanographers. Matthew Fontaine Maury, we recall, was Superintendent of Charts and Instruments in the US Navy from 1842 and this allowed him to write the widely read *The Physical Geography of the Sea.* In Victoria Neumayer pursued marine meteorology in his role as Director of the Flagstaff Observatory. In December 1872, the British Admiralty despatched an exploratory expedition in HMS *Challenger* to make a global survey expressly for science and primarily for ocean science. The *Challenger* was manned by naval officers who were given the task of superintending the routine collection of physical measurements of the oceans and the atmosphere, but the overall scientific program was directed by civilian scientists who drew their income from and directed their life's work towards the advancement of the marine sciences. Government funding was provided not only for the world cruise of the *Challenger*, but for the analysis of the collected specimens and data after the cruise and for the publication of the scientific reports by Her Majesty's Stationery Office. The follow-up activity extended over a period of twenty years, financed by grants of more than £50,000. The whole undertaking was of such significance that it has come to be recognised as a landmark in the development of the science of the sea, providing the impetus for greatly increased investigation of the oceans by other nations also. It can be recognised as a landmark also for the establishment of oceanography as a career.

Ocean Cable Telegraphy

The second half of the nineteenth century saw considerable improvements in ocean technology. The availability of steam power was a big advantage. The development of underwater telegraphic communication provided an impetus for probing the ocean depths. A knowledge of the nature of the sea floor now had a practical value for cable laying and a knowledge of the prevailing temperature was important also because electrical transmission through the cable core is related to the operating temperature. Survey ships were employed to sound the routes for cables and to obtain sea-floor samples. Investigation was aided by the availability of steam power to “hold station”. The first submarine cable across the British Channel was laid in 1851 and by 1858 a cable spanned the North Atlantic. Although defective insulation caused the signals to fail in a few weeks, other shorter cables were successfully laid and the trans-Atlantic cable was replaced in 1866. Australian businessmen quickly followed the European model and laid a cable across Bass Strait in 1859. The governments of Victoria and Tasmania contributed to the costs but unfortunately it, too, operated for only a few weeks. The US Survey Ship *Tuscarora* (1873-74) examined two possible routes across the North Pacific, one between the parallels of 20° N and 30° N to the Bonin Islands and Yokohama, Japan, the other following a great circle course from Yokohama along the line of the Kurile and Aleutian Islands. Many cable failures were the result of inadequate knowlwdge of the sea bed. The need for information by cable engineers encouraged the development of sounding and sampling technology.

The design of thermometers was also improving. Electric thermometers were invented which could give continuous readings with depth. Better water-bottles and bottom-samplers were devised for sampling the waters and sediments of the ocean. These will be discussed in more detail later in this chapter.

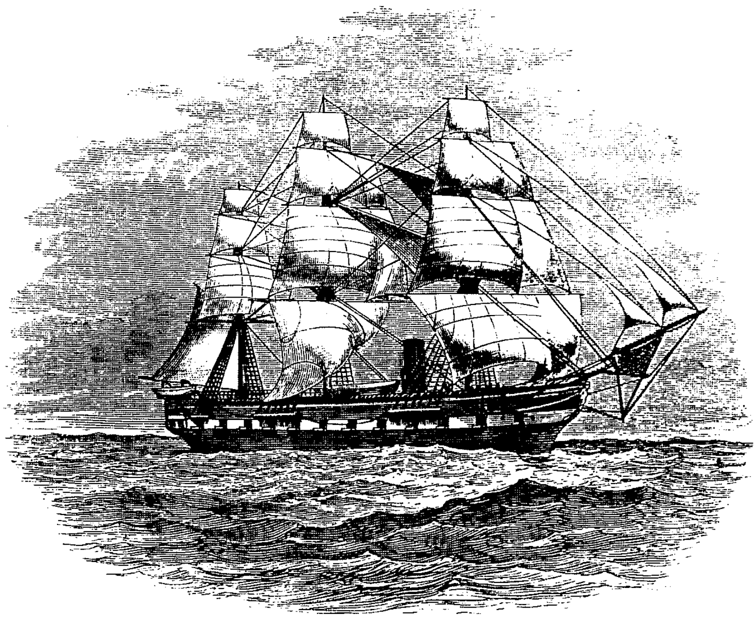
The Azoic Zone

Investigation of the deep ocean in this era was promoted not only by the spur of ocean telegraphy but also by the increased interest in marine biology. In this field the name of Edward Forbes is remembered for the development of new concepts about the vertical distribution of plants and animals in the sea. His researches in the Mediterranean led him in 1843 to define the zones of marine life which he predicted would prevail in any vertical profile of the sea. Plants, which depended on sunlight, would, he suggested, be found only in the layers closest to the surface; animals which fed on the plants would be found only within range of this zone; animals which fed on one another could exist to a lower level, say to 300 fathoms, but below that, he speculated, there would be an 'azoic zone', devoid of all marine organisms. His theory of this stratification and of the 'azoic zone' was plausible and intriguing and widely accepted. As time passed evidence continued to be found for the zonal distribution of marine flora and fauna but conflicting evidence emerged against the 'azoic zone'. We have noted that both on Arctic and Antarctic expeditions British investigators had obtained some examples of marine life from great depths. There was a general reluctance however to believe this evidence. Perhaps, it was suggested, the examples were the result of creatures attaching themselves to the sounding apparatus at levels closer to the surface. In Norway in the 1860s, however, dredging by the eminent Professor Michael Sars and his son George Ossian Sars brought up living specimens from depths of more than 300 fathoms. In the Florida straits dredging by the US Coast Survey brought up sea life from depths beyond 500 fathoms. The challenge to test Forbes's famous theory more extensively inspired two English scientists to make a series of short cruises, dredging at depth in the North Atlantic, firstly on HMS *Lightning*, in 1868, then on HMS *Porcupine* in 1869 and 1870. One of them, Charles Wyville Thomson, had been a pupil of Forbes. His researches and those of his colleague, William Carpenter, revealed that marine life was still to be found to the amazing depth of over 2500 fathoms. Experimentation with improved thermometers on the *Porcupine* also gave the British scientists convincing proof that the long-held concept of constant 4°C bottom water was indeed a fallacy as Lenz had suggested some twenty years earlier. The interest of the scientific community was aroused and with it the desire to explore the abyss more fully. The Association for the Advancement of Science and the Royal

Society of London gave their support to Carpenter's suggestion that a world cruise especially to explore the deep oceans would be both timely and rewarding. An appeal to national pride was also made to maintain Britain's scientific supremacy against growing interest in marine research by other nations.

A Global Cruise Exclusively for Science

When the decision was made to mount the proposed expedition, six civilian scientists were selected by a committee of the Royal Society to conduct the research. Charles Wyville Thomson, now Professor of Natural History at Edinburgh University was made Director of the scientific staff, at a salary of £1000 per annum.



6.2
HMS Challenger, ***a full-rigged spar-decked corvette of 2300 tons displacement with a 1,230 horse-power steam engine. The extended cruise of the world's oceans by HMS*** **Challenger,** ***December 1872-May 1876, the longest continuous oceanographic expedition to date, marked the beginning of a new emphasis on ocean science. The analysis of its vast collections occupied the attention of many eminent scientists for nearly twenty years. The centre of this activity was the University of Edinburgh, Scotland.***

He was a member of the Royal Society and had practical experience from his participation in the Atlantic cruises of the *Porcupine* and the *Lightning*. The three naturalists chosen as his assistants were: Henry N. Moseley, John Murray and a German biologist, Rudolph von Willemoes-Suhm. John Y. Buchanan was appointed as chemist to the expedition and John J. Wild as artist and secretary. Willemoes-Suhm, a young man, died in the course of the voyage. The Hydrographer, Rear-Admiral Sir George Richards, saw to the logistics of the enterprise. HMS *Challenger*, a corvette of 2300 tons with auxiliary steam power, was placed under the command of Captain George S. Nares, FRS. The *Challenger* is shown in Figure 6.2 running before a strong wind. In the refitting of the ship, a good deal of extra space was provided by the removal of all but two of the guns. Extra cabins and laboratories were provided for the scientists, providing better accommodation than had been available on earlier voyages, and there were to be no distractions, such as the policing of the seas, to interrupt the systematic scientific observations. The expenses for the scientific staff totalled £15,000; the expenses for the maintenance of the *Challenger* and the pay of the officers and crew totalled £75,000 [Burstyn (1968) p.608].

Physical Oceanography

One of the aims of the *Challenger* expedition was to further the investigation of the physical properties of the oceans, properties which, it was realised, were vital to the distribution of marine plants and animals. Physical oceanography, as we have seen, had long been included as one of the aims of the naval expeditions of exploration that traversed the oceans of the world. It is clear that extensive measurements had, in many cases, been undertaken without an hypothesis to test or without adequate knowledge of the previous results. However, pressed by the scientific societies, the governments of the day had been prepared to include physical observations in the instructions for the cruises. On many voyages funds had been provided for civilian scientists of natural history to provide expert knowledge. Not so with the physics of the sea. The training of naval officers was usually considered adequate to direct physical oceanographic measurements. This was still the case in the arrangements for the cruise of HMS *Challenger*. The ship's officers were responsible for the deep-sea sounding and the collection of water and sediment samples and of temperature measurements, as well as the routine meteorological, magnetical and navigational bservations. Lieutenants T. H. Tizard and G. R. Bethell were in charge of the deep-sea temperature measurements, which were now required to be taken as a vertical series. Although considerable resources were devoted to making these measurements, the presence of a physicist on board would have been beneficial for the direction of the program of physical oceanography [Burstyn (1968)]. There was some hesitancy, for example, in the interpretation of the data and some uncertainty about the validity of the pressure corrections being applied to the readings of the thermometers [Deacon (1968)]. They did not persist with some of the new apparatus, when it found to be troublesome.

The scientific program for the cruise is here reproduced in part from Wyville Thompson (1877). The instructions for the physical observations reveal a more detailed and comprehensive program than that of earlier British scientific voyages:

> PHYSICAL OBSERVATIONS
>
> *In crossing the great Ocean-basins, observations should be made at stations the positions of which are carefully determined, chosen so far as possible at equal distances, the length of the intervals being of course dependent on circumstances. At each station should be noted the time of the different observations, the state of the weather, the temperature of the surface of the sea, the depth, the bottom temperature determined by the mean of two Miller-Casella thermometers, the specific gravity of the surface and bottom-water. The nature of the bottom should be determined by the use of a sounding-instrument constructed to bring up samples of the bottom, and also, if possible, by a haul of the dredge. When practicable, the amount and nature of the gases contained in the water, and the amount and nature of the salts and organic matter, should be ascertained. As frequently as possible, especially in the path of currents, serial temperature-soundings ought to be taken either with the instrument of Mr Siemens or with the Miller-Casella thermometer, and in the latter case at intervals of 10, 50, or 100 fathoms, to determine the depth and volume of masses of moving water derived from different sources.*

Without the requirement to show the flag or intervene in Pacific island politics, the *Challenger*, was expected to carry firm traverses across the ocean basins, latitudinally and/or longitudinally, halting at regularly-spaced 'stations' about a hundred miles apart to make systematic probes of the deep sea. The sails were furled for an extended day's activities. Steam was now available as auxiliary power to lower dredges and sounding rods. In his narrative Lieutenant Spry (1877), one of the five engineers serving on the *Challenger*, stressed the value of their available steam power as a means of holding the vessel in position on-station while the deep-sea investigations proceeded. We remember the disappointment of earlier investigators such as Péron, and Dortet de Tessan, at the few favourable opportunities that arose for such work in a ship dependent on sail-power alone.

The Siemens instrument mentioned in the instructions was part of the new technology available for deep-sea investigation. It was a metal-resistance thermometer, introduced in Germany in 1866 by Werner and Wilhelm Siemens, making use of the fact that the electrical resistance of solid metals is a function of temperature. The Siemens thermometer, as described by Matthaus (1968), consisted of two temperature-sensitive resistances in a Wheatstone-bridge connection. One of these was lowered into the sea on a weighted electrical cable. The other was warmed or cooled in an oil-or-water bath until a galvanometer reading showed no deflection. The temperature of the bath, measured with a mercury thermometer, gave the temperature of the sea at the location of the first resistance.

The Miller-and-Casella thermometer was an improved version of the Six-type maximum and minimum thermometer of earlier decades. To resist the pressure of deep water the Miller-and-Casella thermometer had a double bulb. The outer bulb was partially filled with spirit, upon which the water pressure acted rather than on the inner bulb. The thermometers were tested by hydraulic pressure and considered trustworthy up to 3000 fathoms. Corrections for hydrostatic pressure were supplied for each thermometer, but it was later shown that the corrections had been too large. In 1874 a different measuring principle was introduced in the reversing thermometer devised by Negretti and Zambra, and part-way through the *Challenger* cruise when they reached Hong Kong this thermometer also became available for deep-sea temperature measurements. It was first used for serial temperature measurents in the

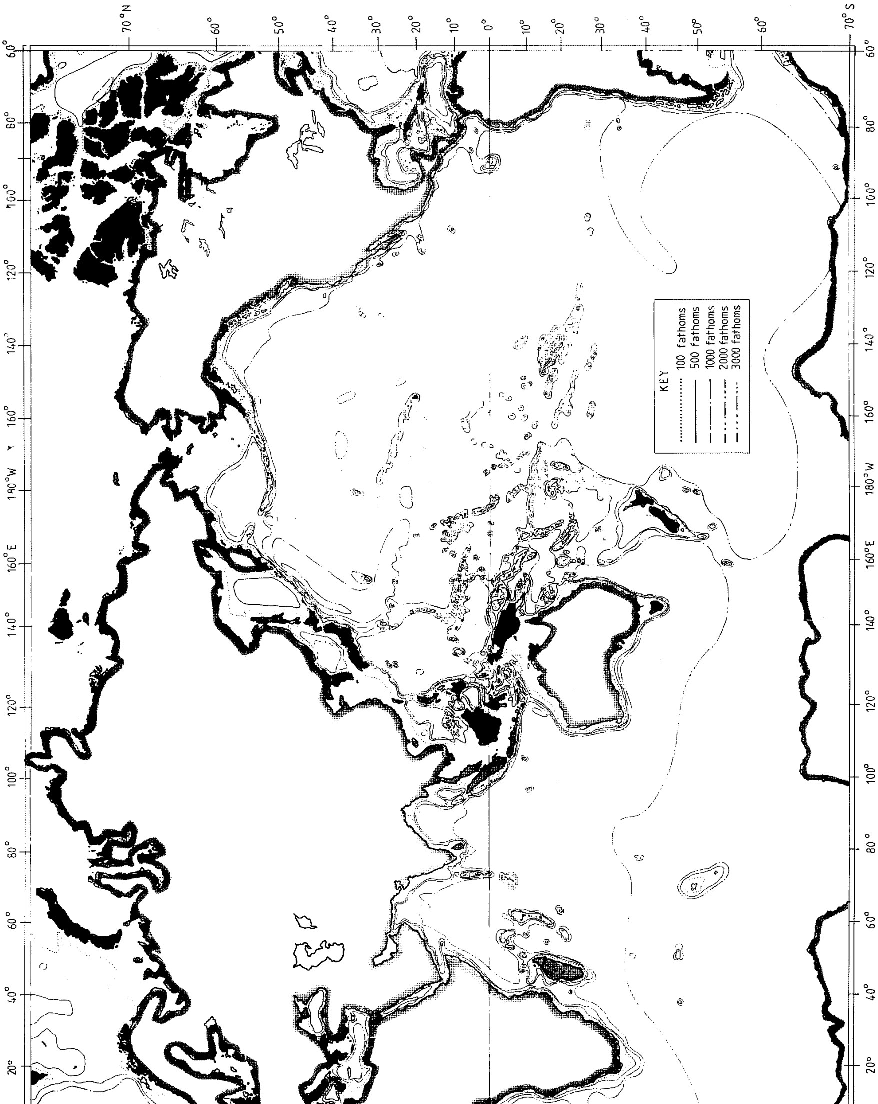
Sulu Sea. This reversing thermometer, which did not require indexes, eventually, with improvements, replaced the Six-type thermometer for deep-sea use. It was so designed that the mercury thread would be broken at the time of reversing and thus reveal the direct temperature for the depth at which it was reversed.

As a result of the detailed, serial measuring of the deep-ocean temperatures by the *Challenger* team, it was possible to present, at the end of the voyage, not just isolated single-depth temperatures, but latitudinal or longitudinal cross-sections or vertical temperature profiles for the ocean basins.

The instructions stressed the importance of the collection of sea-bed samples and also the investigation of the depth and topography of the ocean floors:

> *The simple determination of the depth of the ocean at tolerably regular distances throughout the entire voyage is an object of such primary importance that it should be carried out whenever possible, even when circumstances may not admit of dredging, or of anything beyond sounding. The investigation of various problems relating to the past history of the globe, its geography at different geological epochs, and the existing distribution of animals and plants, as well as the nature and causes of oceanic circulation, will be greatly aided by a more accurate knowledge of the contour of the sea-bed.*

When, at the end of three and a half years, the *Challenger* had completed its cruise of 68,890 miles, enough soundings had indeed been collected to establish the average depth and the main contours of the ocean basins. Murray (1885) produced a world map of which we have reproduced part as Figure 6.3. The bathymetry indicated by the contours of 100, 500, 1000, 2000 and 3000 fathoms made it clear that the average depth of each of the ocean basins was over 2000 fathoms, but it could give no indication of the great complexity of the submarine landscape. Maury had pioneered the way with a map of the bathymetry of the Atlantic, but the *Challenger* world map was the first of its kind and a landmark in oceanography. The features of the sea floor we now see on modern maps are, of course, much richer in detail. Only with the advent of the acoustic echo-sounder did it become possible to depict the variety and detail of the



6.3
The first bathygraphical representation of the floor of the Pacific and Indian Oceans, drawn after the extensive sea-bed investigations of the* Challenger *expedition. Other information came from the preliminary surveying of the sea-floor to prepare for the laying of telegraph cables. Redrafted from Tizard, Moseley, Buchanan and Murray (1884)

sea-floor topography: the mountain peaks rising higher than Mount Everest, the canyons on the continental slope as deep as the Grand Canyon of the Colorado River, the mountain systems running for thousands of miles beneath the surface and the vast trenches six or seven miles deep (deep enough to contain seven Grand Canyons).

The deepest spot probed on the *Challenger* voyage was measured in the Marianas Trench of the Pacific Ocean as 4475 fathoms, at latitude 11°24'N, longitude 143°16'E. The Pacific Ocean also received considerable attention in 1874 and 1875 from the investigative cruises of the German ship *Gazelle* and the United States' *Tuscarora* and it became clear that it had a greater average depth than the other oceans. It is now known that the Pacific also contains more of the great sea-bed trenches, and that they form a series of seismologically active fractures of the earth's crust. A twentieth-century namesake of the *Challenger,* commanded by G. S. Ritchie, carrying three scientists from Cambridge University on a world scientific voyage, 1950-1952, mainly for seismic surveying, confirmed the great depth of the Marianas Trench, by measuring there a depth of 5940 fathoms [Gaskell and Ritchie (1953)], and in the International Geophysical Year of 1957 the Russian ship *Vitiaz* found in the Marianas Trench an even greater depth of slightly more than 6000 fathoms. In 1960, by the marvel of twentieth-century technology, the bathyscape *Trieste,* designed by Auguste Picard, and manned by his son Jacques Picard and US Navy Lieutenant Don Walsh, made a five-hour descent to settle on the bottom ooze of this great trench at a depth of 5966 fathoms.

Depth-sounding on the nineteenth-century *Challenger* cruise was carried out using fine hemp rope coiled on a three-metre-diameter drum. With a 200-pound (90kg) lead weight attached, the line would run out freely. The only way still to tell when the lead hit bottom was to time the descent of the rope with a stopwatch and to note when the speed slackened. Despite some prior contemporary experimentation with fine steel wire for sounding, the British expedition persisted with hempen rope of various dimensions, finest for sounding, thicker for dredging and trawling. Lieutenant Spry [(1877) p.29] described the markings on the line:

> *It is marked at every 25 fathoms, the 25th and 75th fathom being white, the 50 fathom marks red, and the 100 fathom marks blue.*

> *Worsted is used to mark the line and the number of hundreds are distinguished by tucking the worsted under and over the strands of the line, one tuck for each hundred fathoms. This leaves the line perfectly smooth. . . . The line is kept on reels (three thousand fathoms on each) conveniently situated near the sounding platform.*

Thick india-rubber bands were used to fashion accumulators which could take the strain of the weighted lead-lines and even-out the motion of the ship. Steam power was now available for the task of winding in the sounding-line. Even with this advantage, the whole operation could take several hours. The suggestion had already been made that an echo from the bed of the ocean might expedite the proceedings but fifty years were to elapse before this technology was developed.

The evidence of their soundings and temperature sections, combined with salinity signals, suggested to the *Challenger* scientists that there might be a dividing ridge in the North Atlantic Ocean. This hypothesis was tested and confirmed by observations obtained a few years after the return of the *Challenger:* in 1880 from the survey ship, HMS *Knight Errant*; and in 1882 from HMS *Triton*. The ridge was named in memory of Wyville Thomson, who died in March 1882. Subsequent investigations demonstrated the great extent of this underwater mountain range which divides the Atlantic from north to south, forming a barrier to water flow in the movement of bottom fauna. By the end of the nineteenth century it was no longer possible to conceive of the ocean floors as vast, monotonous plains as had once been the case, and it was realised that the bottom topography of the oceans could block and channel the movement of deep water.

The systematic collection of sea-surface and atmospheric temperatures was still part of the scientific program of investigative cruises. Regular recording every two hours night and day throughout the voyage of the *Challenger* was required and the maintenance of a comparison between the temperature of the two media:

> *In case of a marked discordance, the condition or conditions of that discordance should be sought in (a) the direction and force of the wind, (b) the direction and rate of movement of the ocean surface-water, (c) the hygrometric state of the atmosphere. When the air is very dry, there is reason to believe that the temperature of the*

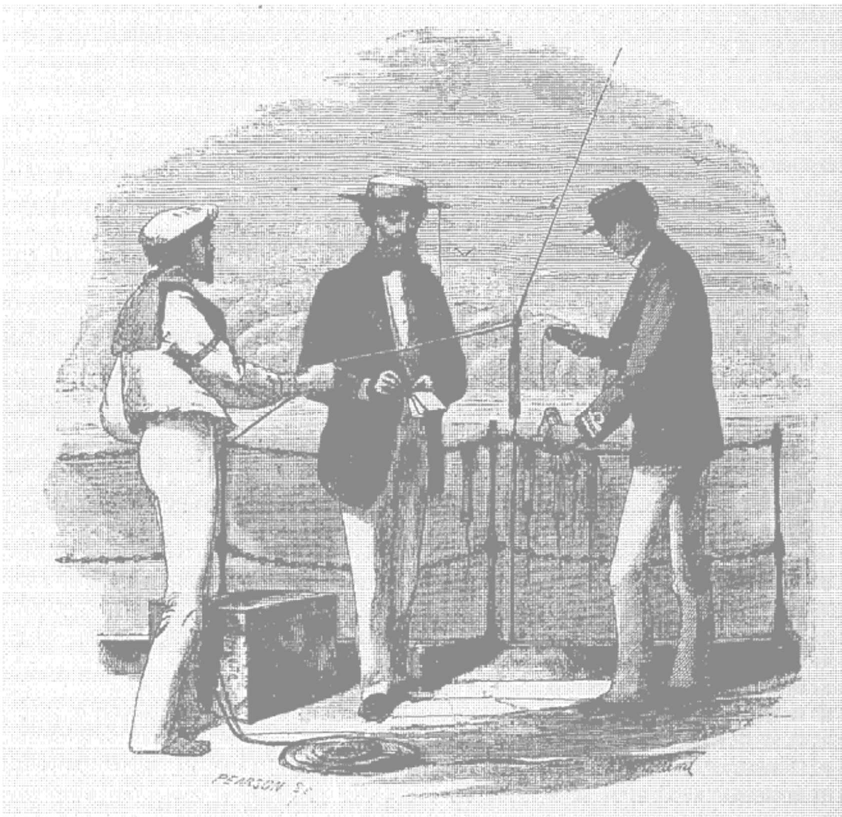
> *surface of the sea is reduced by excessive evaporation, and that it may be below that of the subsurface stratum a few fathoms deep. It will be desirable therefore, that every opportunity should be taken of comparing the temperature at the surface with the temperature of the subsurface stratum, - say at every 5 fathoms down to 20 fathoms.*

The investigation of subsurface temperatures at different levels was to be pursued with a view to determining temperature profiles:

> *Temperature Soundings - The determination of the temperature, not merely of the bottom of the ocean, over a wide geographical range, but of its various intermediate strata, is one of the most important objects of the expedition; and should therefore, be systematically prosecuted on a method which should secure comparable results . . .*
>
> *It will probably be found sufficient in the first instance to take, with each deep bottom sounding, serial soundings at every 250 fathoms, down to 1,250 fathoms; and then to fill up the intervals in as much detail as may seem desirable: thus, where the fall is very small between one 250 and the next, or between any one and the bottom, no intermediate observation will be needed: but where an abrupt difference of several degrees shows itself, it should be ascertained by intermediate observations whether this difference is sudden or gradual.*

The ship's team worked assiduously at these repetitive tasks, making 374 deep-sea soundings and 255 serial temperature casts throughout the voyage. At 4475 fathoms, which was the greatest depth attained, most of the thermometers were crushed, as a result, said Spry [(1877) p.273], of the enormous pressure, 'some five tons on the square inch'. However one stood the test, and showed a temperature of 33.9°F (1.05°C), when the surface temperature was 80° (26.6°C)'. The illustration in Figure 6.4 shows deep-sea thermometers being read on board the *Challenger.*

The Siemens electrical resistance thermometer was tested in the early stages of the voyage but proved troublesome to operate. Its use had been recommended because it did not require to be hauled up for each reading in a vertical series, but it proved difficult to read accurately and at Cape Town it was decided to dispense with its use and send it home. The criticism has been made of the *Challenger* team that they did not persist with some of the new technology available to them. This was so in the case of a sounding machine, which used steel piano wire instead of hemp rope. It was devised and used successfully in June 1872 by Sir William Thomson [later Lord Kelvin] but the drum collapsed when it was tried on the *Challenger* [Deacon (1971) p.336]. The advantage of a machine with steel wire, which subsequently was widely used, was that it did not require as much storage space as the reels of heavy rope. On the 1874-75 Pacific cruise of the US *Tuscarora* good results were obtained with improved versions of the wire sounding-machine. This stimulated further progress in the development of an efficient sounding machine [See McConnell (1982)].\



6.4
Reading deep-sea thermometers on board* HMS Challenger*. The profiles obtained from serial measurements, routine on this expedition, gave a more detailed picture of the subsurface temperatures than that from any previous expedition. From Tizard, Moseley, Buchanan and Murray, (1884)* Narrative of the Cruise of H.M.S *Challenger, Vol 1.

The Southern Ocean was designated a region of special concern in the instructions.

The research program was pursued by sailing south in the Indian Ocean beyond Kerguelen and Heard islands and beyond latitude 65°S.

There was great interest among the explorers to see if they would sight the Antarctic land-mass proposed by Charles Wilkes thirty years earlier. When they were within six miles of his proposed land, a sounding revealed the sea floor to be at 1800 fathoms (10,800 feet) which did not suggest a continental shelf. Further approach was made impossible by the ice pack and no land was visible. It was concluded that Wilkes's "*Termination Land* "did not extend as far as he had claimed.

In this latitude the expedition found, beneath the ice-strewn upper layer, water which was 3°C warmer at 500 fathoms depth than at the surface [Deacon (1971) p.342]. Such temperature inversions, we recall, had been found in high latitudes a century earlier by Wales and Forster on the *Resolution*, but, now according to Lieutenant Spry (1877 p.106) it came as a surprise to the officer-scientists. If this were so, it illustrated how unacquainted some of those taking the measurements were with what had been discovered previously in the way of ocean physics. Had they read carefully the Royal Society's instructions, they would have found reference to the phenomenon. Now the expedition encountered the inadequacy of the maximum and minimum thermometer in such a circumstance, because it measured only extremes of temperature and could not reveal inversions of temperature at intermediate depths. And, of course, they no longer had the Siemens thermometer, which had been recommended for serial measurements.

Information was sought to test the belief that in the highest latitudes:

> *The cause of the temperature of the surface-water being below that of the subsurface stratum, in the neighbourhood of melting ice, is that the water cooled by the ice, by admixture with the water derived from its liquefaction, is also rendered less salt, and therefore floats upon the warmer and saltier water beneath. Here the determination of Specific Gravities will afford the clue.*

In other instances where it was noted that there was not a regular decrease in temperature with depth it was suggested that:

> *A warm current may be found beneath a colder stratum; and the use of the "current-drag" might show its direction and rate. In other cases, again, it may happen that a warm submarine spring is discharging itself, - as is known to occur near the island of Ascension. In such a case, it would be desirable to trace it as nearly as may be to its source, and to ascertain its composition.*

It was hoped that the *Challenger* observations would provide evidence about the presumed movement of surface water towards the polar regions and an underflow of bottom water from these regions back towards the equator:

> *The determination of Surface Currents will, of course, be a part of the regular routine, but it is particularly desirable that accurate observations should be made along the line of sounding in the Southern Ocean, as to the existence of what has been described as a general "Southerly set" of oceanic water, the rate of which is probably very slow. It is also very important that endeavours should be made to test by the "current drag", whether any underflow can be shown to exist from either Polar basin towards the Equatorial region.*

As with the resistance thermometer, only limited use was made on the *Challenger* of the 'current drag'. This piece of apparatus consisted of four vertical canvas fins, stretched onto iron bars [Deacon (1971) p.339]. It was moored by a line to a buoy or a boat and had the capacity to show the direction of an undercurrent.

The reef-building activities of coral continued to be of interest as well as any anomalous variations in water temperature:

> *In connection with the limitation of the area and depth of the reef-building corals, it will be very important to ascertain the rate of reduction of temperature from the surface downwards in the region of their greatest activity; as it has been suggested that the limitation of living reef-builders to 20 fathoms may be a thermal one.*

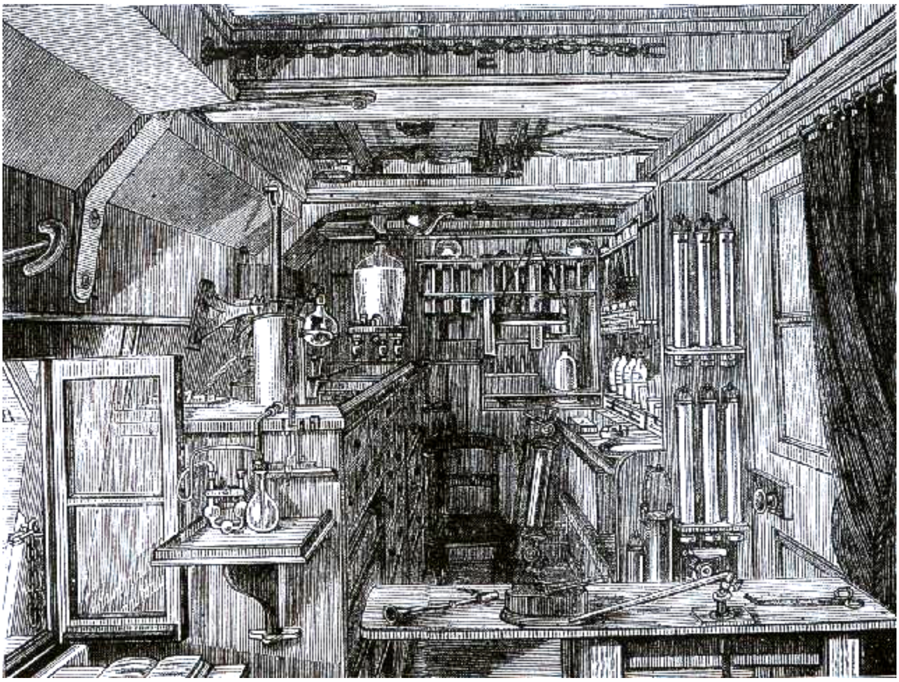
The instructions also included:

> *Tidal Observations - No opportunity of making tidal observations should be lost. Careful observations made by aid of a properly placed tide-pole in any part of the world will be valuable. Accurate measurements of the sea-level once every hour (best every lunar hour, i.e. at intervals of 1h 2m of solar time) for a lunar fortnight (the time of course being kept) would be very valuable information.*
>
> *Bench-marks - In reference to the interesting question of the elevation or subsidence of land, it will be very desirable, when sufficient tidal observations can be obtained to settle the mean level of the sea, that permanent bench-marks should be established, recording the date and height above such mean level. Even recording the height to which the tide rose on a certain day and time would render a comparison possible in future years.*
>
> *A good determination of the mean sea-level by the simple operation of taking means may be made, in less than two days, with even a moderate number of observations properly distributed so as to subdivide both solar and lunar days into not less than three equal parts.*
>
> *Besides taking observations on the ordinary waves of the sea when at all remarkable, the Scientific Staff should carefully note the circumstances of any waves attributable to earthquakes.*
>
> *Specific Gravity - The specific gravity of the surface- and bottom-water should be carefully compared, whenever soundings are taken; and whenever serial soundings are taken, the specific gravity at intermediate depths should be ascertained. Every determination of specific gravity should be made with careful attention to temperature; and the requisite correction should be applied from the best Table for its reduction to the uniform standard of 60°. It would be well to check the most important results by the balance; samples being preserved for examination in harbour. Wherever the temperature of the surface is high - especially, of course, in the Intertropical region - samples should be collected at every 10 fathoms, for the purpose of ascertaining whether any effect*

> *is produced upon the specific gravity of the upper stratum by evaporation, and how far down this effect extends.*

The measurement of specific gravity at intermediate depths procured some important data. John Buchanan noted that in the Atlantic the specific gravity of the water, reduced to a uniform temperature, decreased with depth down to 400-500 fathoms (800-1000 m) and then increased slightly towards the bottom. He had discovered the existence of a layer of water of relatively low salinity at a depth of 800-1000 metres, and although the significance of the discovery was not immediately recognised it was in fact an indication of the presence of a subsurface, northward-moving water mass, now known as the Antarctic Intermediate water. This water originates on the ocean surface of subantarctic areas of the Southern Ocean and it descends to its appropriate intermediate density level at the Subtropical Convergence [Deacon (1968)]. Further analysis of the serial measurements of the *Challenger* and of later expeditions revealed the far-reaching spreading at depth in the Pacific and Indian oceans also of low-salinity water masses from higher southern latitudes, even across the equator and into the northern hemisphere. As the science of oceanography advanced, recognition of water-masses by their salinity, temperature and dissolved-oxygen characteristics became the usual way of determining their extent and their flow-patterns, since direct measurement of their movement so far below the surface has been too difficult.

Estimation of light penetration in the oceans had been a feature of exploratory voyages for some decades. This was of considerable interest for the understanding of the distribution of marine plants and animals. On the voyage of the *Uranie* early in the century the naturalists J. R. Quoy and J. Gaimard had observed, for example, that reef-building corals were active only in shallow, illuminated waters. The instructions for the *Challenger* required these observations to be made by the traditional method and by some photographic apparatus designed by Siemens, but we cannot see in the published results any tables of light transmission or of Secchi-disk depths. Perhaps this was one facet of the instructions not followed.



6.5
Chemical Laboratory on board the HMS Challenger

The instructions for the *Challenger* expedition included a comprehensive program of chemical observations:

CHEMICAL OBSERVATIONS

Challenger was fitted with a chemical laboratory, shown in Fig 6.5.

1. Samples of sea-water should be collected for chemical analysis at the surface and at various depths, and in various conditions. Each sample should be placed in a Winchester quart glass-stoppered bottle, the stopper being tied down with tape and sealed in such a manner that the contents cannot be tampered with.

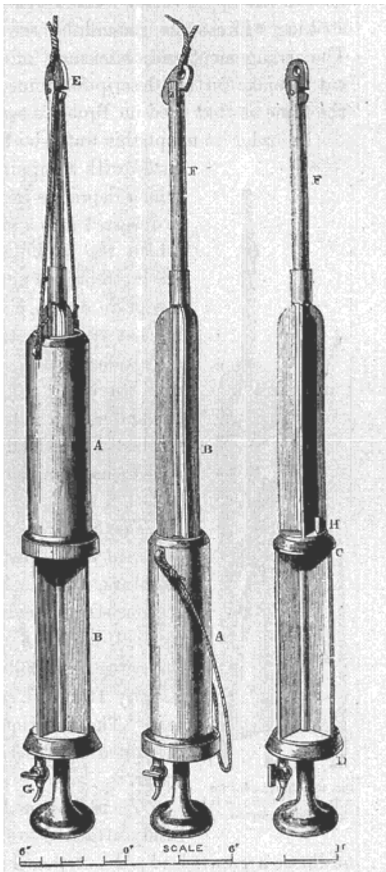
2. Portions of the same samples should be, immediately after their collection, boiled in vacuo, the gases collected, their volume determined as accurately as may be, and a portion, not less than one cubic inch, hermetically sealed in a glass tube, to be sent home at any time for complete analysis.

> *3. Frequent samples of sea-water taken at the surface, and others taken beneath as opportunity offers, should have determinations of chlorine made upon them at once, or as soon as convenient. This operation could easily be carried on in any but very heavy weather. On the other hand, it is not thought that any trustworthy analyses of gases could be made on board ship, unless in harbour or in the calmest weather.*

Improved water bottles were available for water sampling on the *Challenger*. Two types were used. The slip water bottle, shown in Figure 6.6 and as described by Spry (1877), consisted of 'a brass rod, with three radiating rings to strengthen it, and to act as a guide for a brass cylinder which encloses the water'. The bottle was fastened to the sounding-line and was provided with a small line which kept the cylinder suspended above the chambered seating while the bottle was descending. When the bottle reached the bottom and the strain was released from the sounding line and from the small line, the cylinder fell to its seating, trapping a specimen of the bottom-water within the compartments.

Another sampler bottle was designed of three-inch-diameter brass tubing with stop-cocks fitted at each end. Water could flow through freely while the bottle was descending, but on ascent the stop-cocks closed, enclosing water from any desired depth. This type was designed by Buchanan for use at intermediate depths.

The water samples collected by the *Challenger* expedition from a variety of depths and locations were subjected to detailed analysis in the 1880s [Dittmar (1884)] and it was demonstrated that, in spite of the variations in the total concentration of dissolved salts which were to be found at different geographical locations and at different depths, the ratios of the more abundant components remained almost constant in all the oceans of the world. This was confirmation of a hypothesis that had been suggested by chemists working on the chemical composition of sea water, Alexander Marcet (1819) and Georg Forchhammer (1865). Very few water samples from the Pacific were available to these earlier scientists. The *Challenger* expedition supplied data from a wider sampling than had previously been possible.



6.6
One type of water bottle used to take deep-sea samples on* HMS Challenger*, reproduced from Wyville Thomson (1877). The view on the left shows the bottle ready for deployment with the cover held up by a strop. When the cover is released deep in the ocean, the sample is trapped by the cover, as shown in the middle view. On recovery the sample is withdrawn from the tap near the bottom of the bottle.

The confirmation of the almost constant ratios of chemical ions in ocean water was a valuable step towards the process of unravelling the circulation patterns of deep water-masses. By establishing the percentage of one major component, dissolved sodium chloride, it became possible to calculate the total salinity of a water sample to a satisfactory degree of accuracy. The use of the coefficient of chlorine, a method introduced by Forchhammer and reinforced by Dittmar, provided a simpler and speedier process than a complete chemical analysis. And since salinity is a 'conservative' property, which in deep-ocean water varies only by mixing at the boundaries of adjacent water masses, its determination, combined with the determination of temperature, aids the identification of different water masses and the tracking of their movements.

During the 1920s the Scandinavian meteorologists, V. Bjerknes and B. Helland-Hansen developed mathematical theories, that allowed data on water temperatures and salinities to be translated into the speed and direction of currents. In the 1960s a better means of establishing salinity was devised. This was achieved by measuring the electrical conductivity of sea water with an electrical salinometer [see chapter seven].

Sea-floor Sampling

> *4. Such samples of the sea-bottom as are brought up should be carefully dried and preserved for examination and analysis.*
>
> *5. The gas contained in the swimming-bladders of fishes caught near the surface and at different depths should be preserved for analysis. In each case the species, sex, and size, and especially the depth at which the fish was caught, should be stated.*

Nowadays research vessels assess fish numbers by the strength of the acoustic reflection from their swim-bladders.

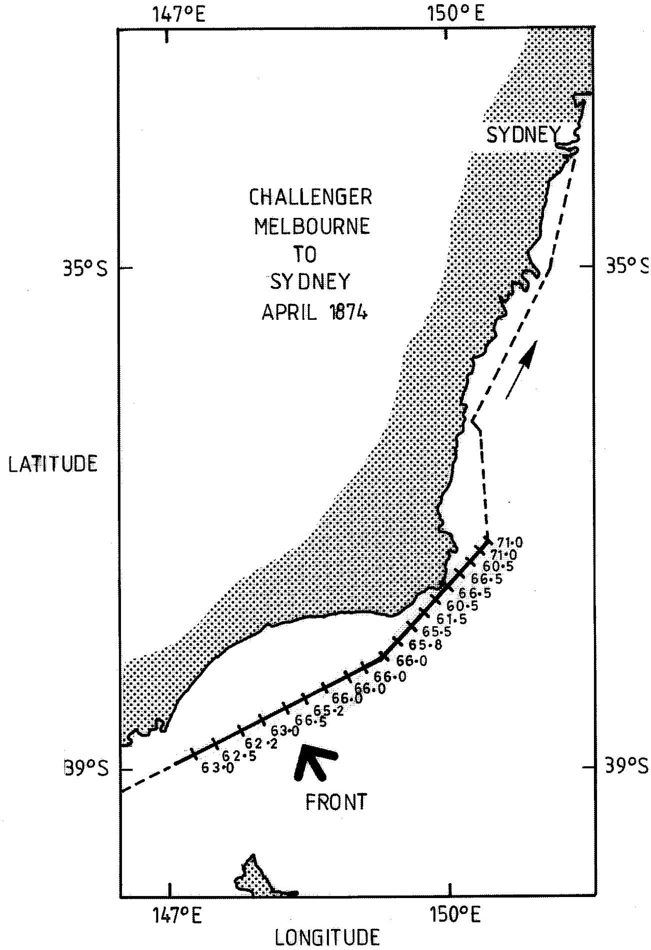
Samples of the sea floor at great depth were collected from the *Challenger* by two types of hollow sounding-rods. One, known as the 'Hydra' consisted of a brass tube one inch in diameter onto which sounding weights could be attached. Cylindrical cast-iron sinkers, averaging one hundredweight (50.8kg) each, were designed to fall from the rod on impact with the sea floor and the tubular rod to bring back a sample. The other, the *Challenger* team's preferred variation on the Hydra, designed by Lieutenant C. W. Baillie, had a rod of a bigger diameter and was capable of bringing up a larger sample.

In soundings of moderate depth the *Challenger* scientists found the sea floor covered with a pale grey ooze, which, under the microscope, revealed limy remains of tiny marine animals called foraminifera, but at depths over 3000 fathoms the samples were of dark clay. The origin of the clay gave rise to some speculation. When even the clay was found to be inhabited by marine life in the form of annelid worms, it was further evidence that, even at these very great depths, the ocean was not completely devoid of living creatures. Almost a century later the lamps of the bathyscaphe *Trieste* picked out a more complex creature in the dark depths of the Marianas Trench, a flatfish, about a foot in length.

***HMS Challenger* in Pacific Waters**

The Challenger cruise began December 1872 from Portsmouth and spent the next year in the Atlantic. In 1874, after a stay at the Cape of Good Hope and an exploration southwards in the Indian Ocean, as far as latitude 66º33'S, they reached the port of Melbourne in March, in the English colony of Victoria where they were warmly received and felt that they were at last in a place "that seemed just like home." The narrative of the cruise mentions dredging and trawling in Bass Strait and temperature measurements off the New South Wales coast north of Gabo Island at a depth of 2200 fathoms.

From their tabled two-hourly sea-surface temperatures, plotted for midday in Figure 6.7, the surface front in Eastern Bass Strait, discussed by Godfrey, Jones, Maxwell and Scott (1980), was evident almost a century before modern oceanographers recognised its existence. At the Bass Strait front the boundary between the warm Tasman Sea water and the cold Bass Strait waterleads to a sinking of the cold water below that of the lighter warm water. This cold water, sinking below the surface as it leaves the continental shelf, produces a large underwater waterfall. The new generation of marine explorer, searching for oil, is probing the sea under this cascade of Bass Strait water. But despite the passage of more than a hundred years, our uncertainty remains large. What current speeds are achieved? Are strong currents more likely in winter than in summer? Will the current bend the oil-exploration ship's drill stem? The Bass Strait water appears to spread out across the Tasman Sea at depths of a few hundred metres, carrying with it its characteristic temperature and salinity signal. These large lenses of Bass strait water, that were near the surface some years ago, are now forming part of the ocean thermocline.



6.7
Sea-surface temperatures, in degrees Fahrenheit, measured in 1874 on the cruise of* HMS Challenger, *reveal the presence of the Bass Strait front. The temperatures are available in Wyville Thomson and Murray (1885). The colder Bass Strait water of about 63°F is separated from the warmer Tasman Sea water carried from the tropics by the East Australian Current.

Off the New South Wales south coast at a station ten miles east of the 100 fathom line they noted that the warm current (71°F) was running southwards at one and a half miles per hour but that 'the temperature of 71° was very superficial, as at 50 fathoms the thermometer registered 65.2°. The next day the ship continued northwards but closer inshore and it was noticed that the surface temperature dropped to 68.5°F and there was little or no current. They had moved inshore of the warm, southward-flowing East Australian Current, which, however, was again encountered, close in shore, from Jervis Bay to Port Jackson [Tizard et al (1884) p.464].

In Australia the routine of the expedition's work at sea was relieved by the hospitality they received from the citizens of Melbourne and Sydney during their two month’s stay. While the *Challenger* was in harbour at Sydney, Wyville Thomson and Murray and a small party procured a passage to Maryborough, Queensland, in order to investigate the fauna in the upper reaches of the Mary River. They were delighted to find a kindred soul in Mr. Sheridan, the Collector of Customs at Maryborough, 'a man of great intelligence and considerable special knowledge of natural science', who not only accompanied them but thereafter took the trouble to collect and forward specimens of the species of fauna in which they were interested. By such contacts could the interests of amateur scientists be enlivened in the remote outposts of empire and mutually fruitful lines of communication opened. Before their departure from Sydney the visitors entertained the colonial scientists of that city on a day-long dredging and trawling party outside the heads, demonstrating their expertise and equipment in search of rare specimens. The finds were not spectacular but the good fellowship was rewarding.

While the *Challenger* sailed across the Tasman Sea to Wellington, New Zealand, a line of soundings was made over the edge of the continental shelf to assist with a proposed submarine cable to connect Australia with Wakapuaka, New Zealand. The information obtained in the section between Sydney and Wellington showed the ocean floor, for the greater part of the way across, to be composed of mud and sand and to be suitable for laying a cable. The Eastern Extension, Australasia and China Telegraph Company laid this cable in 1876, using the vessels *Hibernia* and *Edinburgh.* The distance was 1283 nautical miles.

During the passage of the Tasman Sea, the *Challenger* experienced the southward set of the warm East Australian Current when 20 miles from Sydney. The current continued to be evident until 50 miles from land, at which point the temperature gradually decreased. The temperature was noted and the velocity of the current estimated to average between one and one and a half miles per hour:

> *The highest temperature registered in the heart of the stream was 70.7°. The impossibility of mooring a boat by the dredge or trawl rope, in order to obtain a good observation of the speed of the current in the centre of the stream, was much regretted, but the weather was very unfavourable, there being strong breezes with considerable swell, so the rate could only be estimated whilst sounding, and calculated from the differences between the position of the ship by D.R.* [dead reckoning] *and observation.* [Tizard et al. (1884) p.464]

This survey allowed the drawing of the first temperature section across the East Australian current.

After a voyage through the Dutch archipelago, visiting the famous Spice islands of Amboina, Banda, Ternate and Tidore the *Challenger* spent a week in Spanish Manila before heading for Hong Kong. They anchored off the naval yards of the British colony where they spent seven weeks, restocking and repairing their vessel. There was mail from home and a supply of the new Negretti and Zambra reversing thermometers. At Hong Kong a change of command was effected when Captain Nares received an appointment from the Admiralty as commander of a new Arctic Expedition fitting out in England. The new commander of the *Challenger* was Captain Frank Thomson .

The Sulu Sea and other partially enclosed seas of the Indonesian Archipelago, to the north of Australia, were discovered to be separated by submarine ridges of varying heights. The serial measurements there of subsurface temperature with the new Negretti and Zambra reversing thermometers revealed that the usual decrease with depth ceased at or near the level of the dividing ridges. This was interpreted to be due to the fact that colder water of polar origin could not penetrate these enclosed seas, in much the same way as it had already been demonstrated that colder water did not penetrate the straits of Gibraltar into the Mediterranean Sea. The concept of this feature of the general ocean circulation was slowly emerging from the probing of the sea-bed contours. Otherwise, as observed by earlier expeditions, the *Challenger* team found in equatorial regions that a relatively thin layer of warm water overlay the colder water at depth.

In April 1875 the *Challenger* reached Yokosuka, at the entrance to Yedo (Tokyo) Bay. The officers were impressed by the busy scene of merchant vessels, trading junks and warships crowding the bay. A week was spent effecting repairs to the damaged rudder of the *Challenger* in the docks of Yokosuka, a week which passed very pleasantly for the ship's officers visiting the sights of an area which had only so recently been opened up for Western visitors. When repairs were complete the *Challenger* took soundings of Uraga channel at the entrance to the bay. It proved to have an average depth of 350 fathoms. Then the ship sailed to Kobe in Osaka Bay. There was a favourable opportunity to dredge for marine fauna in the Inland Sea.

When the party returned to Yedo Bay a demonstration of the *Challenger's* equipment and techniques was provided for the officers of the Japanese Imperial Naval Academy, a branch of which was established at Yedo.The demonstration was organised as a social event, "a dredging picnic", in the bay, with a number of American and French residents and Japanese government officials invited. A large group of Japanese ladies was included. The sounding lines were demonstrated, the trawl lowered to bring up shells, stones and marine specimens upon the deck, water samples were gathered and thermometers were lowered to record the serial water temperatures. The sounding lines revealed that the average depth of the bay was 120 fathoms. There was lunch and music to follow the serious scientific business.

With the ship stocked with stores and provisions and a fresh supply of coal, the expedition sailed June 2 to cross the Pacific to Honolulu. A route was chosen to be intermediate between those surveyed from San Francisco for undersea cables the previous year by U.S. *Tuscarora.*

At a distance of about 1000 miles from the Hawaiian Islands, at a depth of 2740 fathoms, the *Challenger*'s trawl brought up a large number of rounded "potato-sized" stones which proved to be composed of layers of manganese peroxide of iron which were of great interest to the scientists. Some were formed around a small nucleus of pumice stone. In one a giant shark's tooth was embedded. More were found at subsequent depths of over 3000 fathoms. It was a significant discovery. It is now known that these nodules contain other minerals as well as manganese, such as cobalt and nickel and special ships are designed to suck them from the sea floor.

Two weeks were spent at Honolulu where the visitors observed the influence of western missionaries and traders upon native Polynesian society. To repay hospitality the Royal family and Court dignitaries were invited on board and the details of the scientific apparatus once again demonstrated, this time to the accompaniment of the ship's band's rendition of the Hawaiian National Anthem.

In the South Pacific the *Challenger* called at Tahiti in the Society Islands where the native hospitality was again a welcome break from the continuous routine of sounding and dredging at sea. Excursions were arranged to places of interest and beauty. Of particular interest was the promontory named Point Venus, which was the site from which Captain Cook and his scientists had successfully observed the transit of the planet Venus in 1796.

From Tahiti the *Challenger* steered for Valparaiso, on the coast of Chile, but the winds did not favour their progress and they were obliged to lengthen their voyage by sailing further south to catch the westerly winds around latitude 40ºS. They had been becalmed for 9 days in the humid tropics. However here they again found large fields of manganese nodules. The expedition reached the deep-water bay of Valparaiso. Here the town had a very European aspect and the bay was busy with sailing ships and coastal steamers. Valparaiso was the port for the larger city of Santiago to which it was joined by rail. The naturalists traveled to Santiago but did not report any contact with fellow scientists. The first university in Chile was founded in 1888 at Santiago.

At Valparaiso shore-based observations were recorded, the ship was "swung " as usual to determine any errors of the compass and dipping needle before leaving the Pacific and making their way through the Magellan Straits into the Atlantic Ocean.

By May 1876 they were back home in England after an absence of three and a half years and a voyage of 68,890 miles.

An International Outlook

On the return of the *Challenger,* Wyville Thomson was given charge of the analytical reports and their publication. As in the case of the United

States Exploring Expedition, nationalistic questions were raised, as to who should study the collection brought home by the expedition. There were some hard feelings when Wyville Thomson insisted on distributing the work to those he considered most qualified, irrespective of nationality. He enlisted from the United States, for example, the expertise of Alexander Agassiz, with whom he had collaborated on previous research [Deacon (1971) p.367]. Agassiz, whose continued interest in maritime science was to gain him a pre-eminent position in oceanography into the twentieth century, came especially to the *Challenger* office in Edinburgh from Cambridge, Massachusetts, to work on the marine collections. The office Wyville Thomson created was visited by scientists from many countries, who came to view the collections or help with the sorting. It became what Charnock (1973) has described as an 'invisible college of marine science'.

The report on the classification and distribution of deep-sea deposits, which represented a very new aspect of ocean science, was prepared jointly by John Murray and a Belgian geologist and mineralogist, A. F. Renard, who produced a series of charts of the distribution of sea-floor sediments. The era of international cooperation in ocean sciences, as we have noted, had already commenced in a limited way with the coordinated marine observations organised at the Brussels conference of 1853. The work on the *Challenger* collections ushered in an era when opportunities became greater for cooperation between marine scientists of different nations.

This follow-up activity extended over a period of twenty years financed, as we have said, by successive grants totalling more than £50,000. The whole undertaking in the prosperous era of Queen Victoria was an example of government-funded 'big science'. Burstyn (1968) estimates that by the completion of the fifty volumes of results, the total cost of this great scientific enterprise was in the order of £200,000.

A Profitable Outcome

One very tangible benefit of the *Challenger* expedition, first to the British Government and later to the Commonwealth of Australia, was the discovery of the Christmas Island phosphates. It has been pointed out, [Herdman (1923)], that the British Government made more in royalties from this commodity alone than the entire cost of the *Challenger* expedition and its report. The phosphate deposits of this island in the Indian Ocean were discovered as a result of a collection of coral samples arranged by John Murray to supplement those that had been gathered by the *Challenger*. The discovery enabled Murray, who had taken charge of the production of the *Challenger* reports after the death of Wyville Thomson, to persuade the British Government to annex the island, and grant a licence for the operation of the Christmas Island Phosphate Company. Murray chose to spend his personal income from this venture on oceanographic research. With it he was able to help finance an Atlantic cruise of the Norwegian research vessel, the *Michael Sars*, in which he took part [Burstyn (1975)]. John Murray, who had taken over the responsibility for the organisation of the *Challenger* reports after the untimely death of Wyville Thomson in 1882, received a knighthood for his contributions to oceanography.

7

As Sail Gives Way to Steam

The world cruise of HMS *Challenger* and the publication of its findings aroused great interest internationally and provided the impetus for subsequent oceanographic cruises by other European nations and by the United States of America. The *Challenger* reports, published over twenty years, encompassed not only the work of the scientists and officers who took part in the voyage, but often, as the years passed, included the findings of subsequent cruises by other countries.

The Cruise of the *Gazelle*

In 1874, before the *Challenger* had returned to Britain, the recently established German Reich mounted a similar though not as extensive global expedition for ocean science in the steam-assisted *Gazelle.* Captain of the *Gazelle* was Baron von Schleinitz. The instigator of the oceanographic projects was Georg von Neumayer, now returned from Australia and serving as the Hydrographer for the German Admiralty. One object of the voyage was to convey a team of six astronomers to Kerguelen Island in the South Indian Ocean, to observe the forthcoming eclipse of the sun by the planet Venus. It was known that the year 1874 would provide the first occurrence of this event since that observed by James Cook at Tahiti 105 years previously. It was also intended that German Naval officers would gain experience in hydrological measurements and, prior to the voyage, they received special training from Neumayer in the instruments they would be employing. They were required to record atmospheric and ocean conditions six times a day and to collect samples of deep-sea deposits and pelagic organisms. Only one civilian scientist sailed on the *Gazelle.*

After a visit to Kerguelen Island and Mauritius the *Gazelle* sailed to barren Dirk Hartog Island on the West Australian coast and then northwards into the Indonesian Archipelago. In these islands, as for so many of earlier voyagers, the crew began to suffer from dysentery and tropical fevers and the decision was taken to seek refreshments along the Queensland coast where time was spent at Port Curtis and Brisbane. Nevertheless the lives of twelve seamen were lost to these illnesses. From Brisbane in October 1875 the *Gazelle* crossed the Tasman Sea to the North Island of New Zealand and in February 1876, after a passage through the straits of Magellan, the expedition met the *Challenger* in Montevideo harbour. Their captains agreed to pursue different routes homeward through the Atlantic to maximise their combined coverage of that ocean.

In the official account of the cruise, *Hydrographisches Amt d. Admiralitat* (1888), published by the German Admiralty, the scientific data were evaluated by a variety of experts. The deep-sea temperatures sections were plotted with comments on the deep flow of cold Antarctic water, adding to the understanding of ocean circulation. Lenz's view of a symmetrical circulation of the world ocean in the meridional direction (see chapter 3) could soon be modified by the additional data available. Lenz had suggested that two opposite branches of polar deep and bottom water were joining and rising at the equator, thereby contributing to the relatively cold water found at shallow depths beneath equatorial waters. In the early decades of the twentieth century the temperature and density observations of the *Gazelle* were employed by German oceanographers in combination with those of the *Challenger* towards the speculation that most of the cold bottom waters of all the oceans, including the North Atlantic, were derived mainly from Antarctic water [Wust (1968)].

In the closing decades of the nineteenth century, not only Germany but also Norway, France, Austria, Russia, Denmark, Italy, Portugal and the United States all supported oceanographic research cruises. Some were in the waters adjacent to their homelands, but others involved circumnavigations on the *Challenger* model. Of these latter there were the voyages of the *Enterprise* (1883-1886) from the United States, the *Vettor Pisani (1882-1885)* from Italy and the *Vitiaz* (1886-89) from Russia. In the Pacific these cruises concentrated mainly on the Northern Hemisphere.

The Cruise of the *Vitiaz*

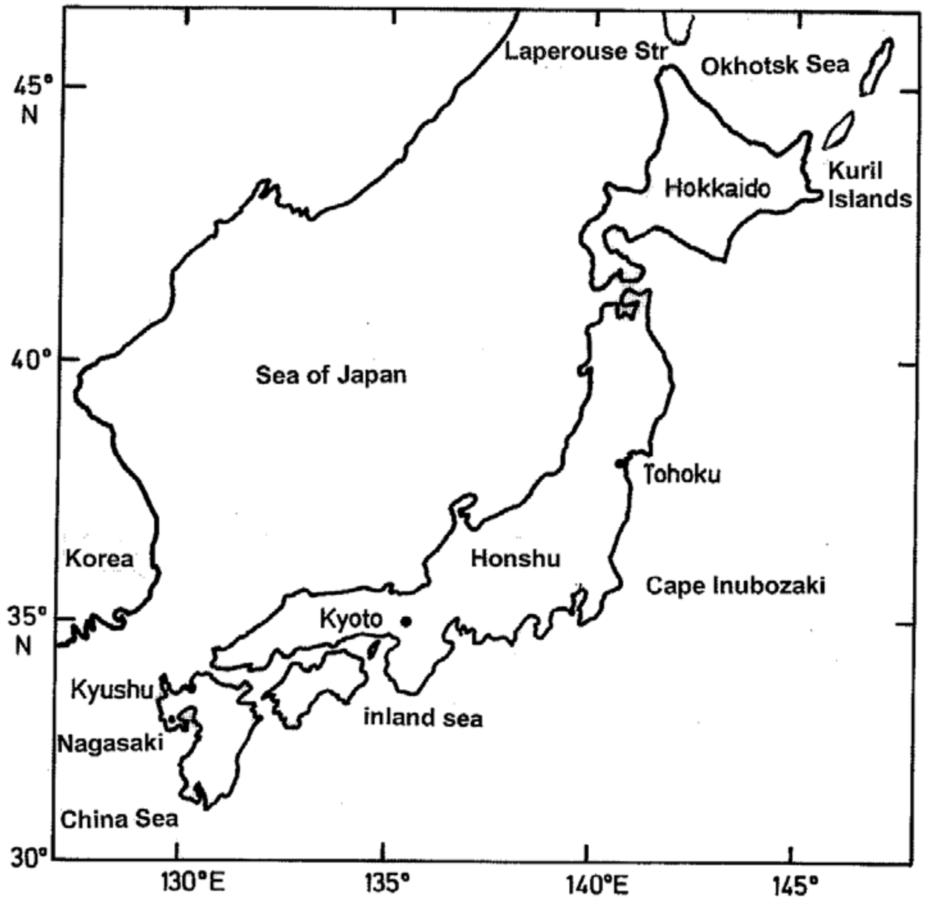
Between the years 1886 and 1889 an extensive cruise of the North Pacific was conducted in the Russian corvette *Vitiaz*, under the command of S. O. Makarov. Throughout the cruise, meteorological and hydrological observations were recorded every four hours, even every hour where current boundaries were being investigated. More detailed observations were carried out at a series of "stations", particularly in the Sea of Japan, the Okhotsk Sea, around the Kurile islands, in the straits of Formosa and Korea, and in the strait between Hokkaido and Sakhalin, called Laperouse Strait. Measurements of specific gravity and temperature at depths down to 400 metres (and sometimes 800 metres) at the *Vitiaz* stations allowed the recognition of sharp lines between neighbouring water-masses (later called "front currents"). These observations, combined with those of his predecessors and with entries in the logbooks of merchant shipping were the basis of Makarov's work *Le Vitiaz et l'Océan Pacifique,* published in 1894 in St Petersburg in both Russian and French.

Makarov described the Kuroshio as bathing both coasts of Formosa in its north-easterly advance and postulated the existence of a branch which, to the south of Formosa, turned to the west and passed around the China Sea. The principal current, on reaching the coast of Japan, he said, divided once more and a branch current entered the Sea of Japan by the Korean strait. This branch he called the Tsusima Current, a name already assigned to it by a German geographer.

The Tsusima current, Makarov pointed out, did not occupy the whole of the Korean Strait, but keeping to its eastern side, passed up along the coast of Japan to the north-east and reached the Sangar Strait between Honshu and Hokkaido. His observations of specific gravity played a large part in Makarov's deductions and he concluded that only a small part of the warm water mass was drawn off by the Sangar Strait. The rest of the water which had entered by the Korean Strait continued to the north and part of it entered Laperouse Strait.

The principal current of the Kuroshio, said Makarov, did not touch the jutting capes of Japan nor did it enter the Inland Sea. It moved up the coast of Japan as far as Cape Inubozaki (which is north of Tokyo Bay) and then turned to the east. Some observations from vessels sailing between

Kamchatka and Japan nevertheless revealed that, in the last months of summer, some of the warm water moved farther north than the parallel of Cape Inubozaki. However, to make a judgment, he wrote, the northern limit of the Kuroshio scarcely passed the parallel of 40ºN, and the water was then directed to the east.



7.1
The seas around Japan

Makarov's work was a major synthesis of the knowledge of the Kuroshio system acquired from European and American voyages and survey cruises up to the 1890s.

Cooperative Research for Fisheries Conservation

Towards the end of the nineteenth century much hardship was occasioned to the countries bordering North Atlantic waters by the depletion of fish stocks in their traditional fishing grounds. The Scandinavian nations were particularly concerned and their scientists devoted much thought and energy towards an understanding of variations in ocean conditions and the interaction of weather and sea, which might explain the variations in fish stocks. The Norwegian government commissioned the construction of a well-equipped research vessel, named the *Michael Sars*, especially to study the physical conditions of temperature and salinity which might be causing the fluctuations. Other European nations contributed also with research cruises. The governments of maritime countries were prepared to finance fisheries research because it was seen to have the very practical goal of ensuring continuation of a vital food resource. The realisation of their common purpose led to the establishment. in 1902 of the International Commission for the Exploration of the Sea (ICES) with its headquarters in Copenhagen, and later an international laboratory in Christiania (Oslo). At the laboratory water samples were tested and instruments developed and tested for specific needs. The aim of the international commission was to coordinate and standardise the research projects of most of the Atlantic countries, which included Canada and the United States of America. There was a change in emphasis from the long voyages of exploration of the preceding eras to shorter more intensive local cruises. Attention was given particularly to the formulation and testing of theoretical concepts about the dynamic structure of the ocean basins and shallow seas. Interaction between the atmosphere and the oceans became a topic for special investigation.

The establishment of the ICES was an important step towards the international cooperation which is now recognised to be vital for the advancement of oceanography. In the 20th century the scientists of Western Europe followed up their investigation of the marine environment with the development of mathematical procedures to construct further theories of the movement of the water masses of the oceans. By the end of the nineteenth century Scandinavia had become pre-eminent in marine science, and, motivated by the need to understand the migrations of food fish, was particularly active in physical oceanography. In 1894 ships from Sweden, Denmark, Germany, Scotland and Norway combined in a coordinated series of surveys in their adjoining waters, observing temperatures at regular measured depths and testing the samples for salinity.

The great diversity of life in the oceans revealed by the scientific voyages of the nineteenth century occasioned a marked increase in enthusiasm for marine biology and zoology. Local amateur societies for marine science flourished in Europe and in Europe's colonial dominions. It was soon realised that marine biology could best be served by the establishment of onshore laboratories where sustained investigation into the life cycles of marine animals and plants would be possible. Among the first of such laboratories was that established at Naples in 1872 by a German zoologist, Anton Dohrn. The land on the Bay of Naples was granted by the Italian government with finance provided by the German government, and it was supported by scientific societies in various parts of the world who were able to rent space in the *Stazione Zoologica* for sponsored scientists. In 1882 the Italian Navy supported the three year circumnavigation by the corvette *Vettor Pisani,* a sailing vessel with auxiliary steam power, carrying a naval officer, Gaetano Chierchia, (later Vice Admiral) who was specially trained at the Naples laboratory to take deep-sea soundings and temperatures and to collect and preserve marine organisms obtained from a variety of depths. The later decades of the nineteenth century saw the establishment by many countries of a series of shore stations, with constant access to circulating sea-water for the maintenance of live marine specimens. In time many of the marine laboratories extended their coverage to research in physical oceanography and fisheries and some maintained their own research vessels.

Marine Institutions on the Pacific Rim

Of considerable significance for knowledge of the dynamics of the Pacific Ocean was the establishment of the Scripps Institution of Oceanography at La Jolla near San Diego on the west coast of the United States. It was founded in 1903 as an independent marine biological research laboratory for a local scientific society but burgeoned under the generous patronage of the wealthy family whose name it bears and eventually in 1912 became part of the University of California. Its first vessel was a privately owned yacht donated by the philanthropist E W Scripps. Later it acquired a purpose built ship which was named R.V.

Alexander Agassiz. This institution now possesses a fleet of research vessels and has become more concerned with the physical and chemical aspects than the biological aspects of the Pacific. Other laboratories concerned with fishery investigations of the North Pacific have been established on the coasts of Canada and California, while Russia, China and Japan also maintain marine stations and research vessels that pursue varied aspects of marine knowledge.

The next marine laboratory on the North Pacific coast was the Canadian biological research laboratory established in 1905 at Departure Bay in Nanaimo Harbour, British Columbia. There was concern at the time about the depletion of the local salmon and halibut fisheries which were a vital resource for a canning industry that had existed since 1870. The completion of the transcontinental railway gave access to the markets of the inland and eastern states. By 1892 refrigerated cars were available for the transport also of fresh fish. In 1905 the Federal Government of Canada set up the British Columbia Fisheries Commission at the instigation of the Royal Society of Canada whose members saw the need for a scientific basis for the management of the nation’s marine resources. During its early years the activities of the Pacific Biological Station established at Departure Bay were not as wide-ranging , according to Johnstone (1977), as at the St Andrews station on the Atlantic coast where cooperation with the laboratories of western Europe was more readily available. In 1913 a vessel was purchased for activities over a wider range at Departure Bay. The choice was not for a sailing vessel but for a 40 foot gasoline launch with a 20 horse power engine. A second laboratory was established further north on the Pacific coast in 1923 at Prince Rupert.

Elsewhere in the Pacific the Napoleonic wars in Europe had hastened the demise of Spanish power in their South American colonies. In 1808, the throne of Spain was usurped by Napoleon’s brother Joseph. The last Spanish naval expedition to this region which was described in Chapter 1 was lead by Malaspina in the 1790s. By 1818, after many years of warfare, the former colony of Chile had successfully established its independence. Subsequently the surveillance of its long coastline was taken over by the Chilean Navy and soon the production also of local naval charts. Their first hydrographic survey was commenced in December 1834 in the brigantine *Aquiles.* Commander Roberto Simpson charted the outlet of the Rio Bueno and adjacent coastlines as far south as

40ºS latitude. Then in May 1874 a Hydrographic Institute was set up within the Chilean Navy and Captain Francisco Vidal de Gourmez became the first Director of the Institute. By this time Captain Gourmez had already carried out extensive coastal surveys of the major ports of the country from Valparaiso to the Chonos archipelago, adding to the knowledge already acquired by visiting British vessels, *Adventure* and *Beagle* in the 1820s and 1830s and the *Challenger* between 1873 and 1874. After the establishment of their Hydrographic Institute in 1874, surveys from ships of the Chilean Navy became increasingly scientific, involving observations of temperature, salinity, currents and tides in adjacent waters and the results have been published in the yearbooks of the Institute. Naval resources have also been expended on investigation of Chile’s Antarctic territories and it was the Chilean Navy ship *Yelcho*, which was responsible for the rescue of the British Antarctic expedition led by Sir Ernest Shackleton on board the *Endurance* in August 1916 [Barros, 1980].

In the North Pacific, as we have seen, the most comprehensive oceanographic report of the late 19th century came from a Russian survey in the *Vitiaz.* In Admiral Makarov’s report in 1894 he cited no contribution from the littoral peoples of Asia. The Americans and the British had been active in this region following the treaty of Yedo in 1858 when several Japanese ports were opened to foreign trade. The British Admiralty sent several surveying vessels, notably HMS *Actaeon* and HMS *Sylvia,* into Asian waters. These were sailing ships but they had the assistance often of small gunboats with 60 hp steam power. The Japanese government assisted with guides and interpreters. Some young Japanese officers were trained in the art of nautical surveying. A Hydrographic Branch of the Japanese Navy was then established in 1872. and by 1882 the Surveying Office of the Japanese Admiralty had produced numerous local coastal charts and sailing directions. British surveying in the area ceased in 1883. From Nitani (1972) and Kitano (1980) we learn that a scientific survey of the Kuroshio current, east and south of Japan, was initiated by the Japanese Navy 1893-96 using drift bottles. Systematic fisheries research was organised by the Ministry of Agriculture and Commerce in 1885 and a Fisheries Research Institute was established in 1898. In the twentieth century Japanese oceanographic research was greatly increased under the stimulus of their Fisheries Department.

It was not until the 1920s that China began to participate in the new scientific directions the study of the sea was taking elsewhere. One might have expected that a country which was at one stage in history was the most advanced nation of the world in ship building and the science of ocean navigation would have maintained that lead but it was not to be. From at least the 9th century C.E. Chinese junks had been sailing on an established sea-route out of the Pacific and into the Indian Ocean as far as the shores of Ceylon and the Malabar coast of India (Song, 1986). Ahead of European nations, they had extended the art of ocean navigation by the invention of the floating magnetic compass, the control of their ships by the use of the stern-post rudder and the safety of their voyages by dividing the bodies of their seagoing vessels into water tight compartments. Their sails mounted on multiple masts, were strengthened with bamboo strips and could face the strongest winds. As had the Arab people in the Indian Ocean, the Chinese people had become familiar with the behaviour of the seasonal monsoon winds and timed their departure and return voyages accordingly. These trading voyages reached their peak early in the 15th century when the third Ming emperor, Xhu Di, despatched a series of giant “treasure fleets” beyond south-east Asia and India even as far as the Red Sea, the Persian Gulf and the coast of East Africa. This was almost a century before Columbus had crossed the Atlantic, Vasco Da Gama had sailed from Portugal around Africa into the Indian Ocean or Magellan from Spain into the Pacific.

In seven epic trading voyages between 1405 and 1433 ambassadors from foreign countries were brought in Chinese ships to pay their respects to the Chinese Emperor and exchange gifts. Communication in the languages of Persia, India and Africa was fostered by the establishment of a language school in Nanjing and an account of the voyages was composed by a Chinese linguist, Ma Huan, who sailed on several voyages as interpreter. The foreign ambassadors returned to their homes with gifts of fine porcelain, lacquerware and silk, almanacs and printed books. Admiral Zheng He recorded the routes for these voyages in detailed strip maps which showed not only the positions of the guiding stars but also details of significant hazards and landmarks. They were amended on successive voyages. But, after the death of Emperor Zhu Di, except for one final voyage in 1834 China withdrew into a period of official isolation. Instead of embarking on an extended program of oceanic exploration and colonisation as did the maritime nations of Western Europe, China looked inward. The shipyards became idle.

Overseas voyages were forbidden [Levathes, 1994]. Consequently China lost the initiative in the conquest of the sea and it was not until the 1920s that institutions were set up to improve the situation and foster the scientific arts of seamanship and navigation.

A start was made towards improved navigation in 1922 when a separate department was set up within the Ministry of the Navy for the production of charts and sailing directions. In 1925 the headquarters of this bureau was established in Shanghai to administer hydrography and maritime affairs generally. In the next decade more than 30 charts were produced and one volume of maps of navigation channels. In the same year marine biology was fostered at the University of Amoy (Xiamen) leading to the publication of new research in the area of fisheries In 1928 the first institution of modern oceanography was established at Qingdao Observatory on Shandong Peninsula. A twice-yearly journal was produced recording research on the properties of sea water, tidal phenomena and sea floor sediments.

This progress is reported in a review by Yang, Chen, and Wang (2003) who record a significant event in 1935. In that year a branch of the Pacific Science Association was established in Nanjing leading to contact with the scientific community of the wider world. There followed a period of expansion. Biological research was strengthened at the Universities of Shandong and Xiamen. The Ministry of the Navy established an observatory in the Dongsha islands in the South China Sea. In 1935-1936 the Beijing Academy of Science, in conjunction with the Municipality of Qingdao, organised a comprehensive scientific survey of Qingdao harbour and nearby ocean waters in the Yellow Sea. At the same time the Academy organised a similar investigation of the Bohai Sea Since then the Beijing Academy of Science and Academia Sinica have established marine research facilities at other coastal sites, notably at Yantai and Dinghai.

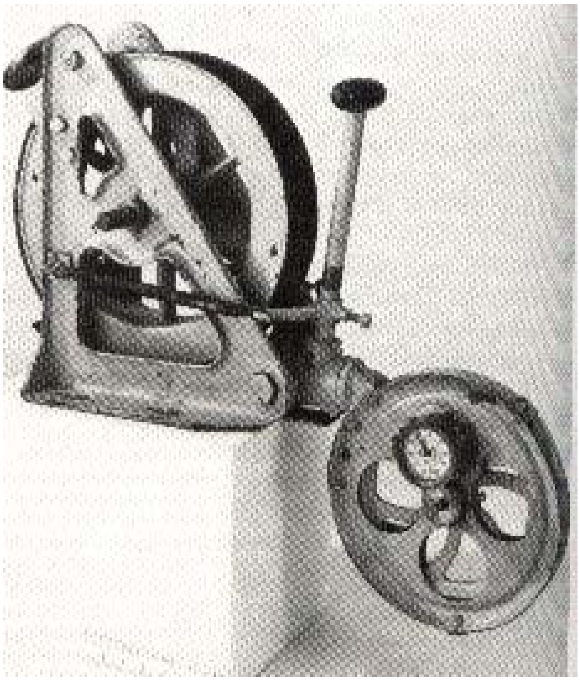
Since these early beginnings, the oceanographic sciences have expanded in China by the establishment of additional educational institutions and the construction and deployment of ocean-going research ships. A land mark event for China was the ability to send two research ships into the West Pacific in 1979 for observational assignments to participate in the First Global Atmospheric Experiment. [Wang and Chin, 1990].

Ocean Technology

In the closing days of sail, as the industrial revolution in Europe brought about many changes in technology, considerable progress was made in the equipment available for ocean research. Improvements in manufacturing processes provided new materials with better insulating properties for water bottles and thermometers. New heat and chemical treatment of the latex from the rubber plant improved its effectiveness as a watertight seal for deep-sea instruments and its strength and elasticity for use as accumulators in sounding equipment. The accumulator allowed a loop in the sounding wire to shorten and extend with the rolling of the ship. The advent of steam power was a great advantage for holding position and handling equipment. Probing the ocean depths had always been a laborious and difficult procedure requiring several hours of manual labour to manage the bulky coils of hempen rope with its attached lead weight. The procedure was usually carried out from rowing boats that could be steadied with the oars in the manner of Fig 4.3. Then in England a sounding machine, using piano wire, was developed by Sir William Thomson (known as Lord Kelvin in later years). It was used on the USS *Tuscarora* and then on the U.S. Coast Survey vessel *Blake* where Lieutenant Charles Sigsbee made modifications to Thomson's machine and used it with great results probing the sea floor of the Gulf of Mexico in 1874-75. In subsequent years a further innovation on the *Blake* was the successful extension of steel wire to the dredging equipment. This had been the suggestion of Alexander Agassiz, a wealthy engineer with marine science training who designed and financed the venture from his personal fortune. He sailed on several cruises of the Coast Survey and published the results in the *Bulletin of the Museum of Comparative Zoology* of Harvard University, Boston. When in 1882 the U.S. Fisheries Commission constructed the *Albatross*, a steam-assisted sailing ship specifically for marine research it was fitted with this new equipment and used steel cable for dredging, trawling and anchoring operations.

The *Albatross* spent many years in both the Atlantic and the Pacific Ocean primarily as a biological research ship but also recording deep-sea soundings and serial temperatures. A number of years were spent along the coastlines of Alaska and the Aleutian islands where the fur seal and salmon fisheries were a valuable resource. Of the several scientists who sailed with the *Albatross* in the Pacific the most famous was Alexander

Agassiz. In 1900 the surveys by Agassiz from the *Albatross,* when added to information previously observed on the *Challenger* in its passage from Tahiti to Chile, revealed the existence of the large submarine plateau in that area now known as the Albatross Plateau.



7.2
The Lucas sounding Machine first tested 1878-1879.

The British companies handling the construction and maintenance of submarine telegraph lines at this time were naturally very interested in the new technologies associated with probing the sea bed. The Telegraph Construction and Maintenance Company developed a sounding machine patented in 1887 by Francis Lucas. There were both steam and hand-operated models. The device consisted of a drum of fine wire which was led out over the side of a ship by a 'meter-wheel', which counted the number of turns and thus the length of wire deployed. The meter-wheel was so arranged that a brake was applied to the drum of wire when the sounding weight was on the sea floor and the load taken off. The reading on the meter-wheel was recorded and the drum of wire rewound. By 1898 the compact and efficient Lucas sounding machine, which halved the time once required for sounding, had superseded the use of the hemp line in the British Navy.

Private Philanthropy for Marine Science

The scale of the research required for the scientific study of the oceans is now so immense that, like the even greater scale of modern space research, only national or even international resources suffice for its implementation. In the closing years of the days of sail, however, a contribution by a few wealthy men of science was of considerable significance. We have already mentioned in chapter six the contribution of Sir John Murray whose wealth came from the exploitation of the phosphates discovered on Christmas Island in the Indian Ocean. Murray, who became the editor of the *Challenger* reports after the death of Sir Charles Wyville Thomson, analysed and classified not only the deep-sea sediment samples from that expedition but also those provided by the ships of other countries. There were increasing contributions available also from the probes of cable laying ships. With the assistance of a Belgian geologist Alphonse F. Renard, he compiled and published a series of charts of the distribution of marine sediments. He is now regarded as having laid the foundation for the science of submarine geology. To pursue his interests in marine science Murray's wealth allowed him to contribute to many projects such as laboratory facilities in Scotland and in 1910 to pay for the considerable expenses of a four-month Atlantic cruise in the *Michael Sars*, loaned to him by the Norwegian government [Deacon, 1971].

Another enthusiastic supporter of marine science in Europe at this time was the hereditary Prince Albert 1 of Monaco. From 1885 he was in a position to support his enthusiasm for marine zoology by annual voyages in his private schooner *Hirondelle*. With the help of scientists invited on board the cruises he was able to improve the maps of the surface currents of the North Atlantic by tracing the paths of marked floats designed and released for this purpose. The copper-clad glass spheres contained messages in nine languages requesting their return with a note about the date and place of recovery. Soon he was able to employ more powerful steam yachts for this work and to introduce new apparatus such as closing nets and reversing water bottles to extend his interest in the habitat of marine flora and fauna. He not only commanded his various ships but directed the program of marine research. [McConnell (1982)] By 1910 he had financed and built his own, now world-famous museum and research centre at Monaco -the *Musée Océanographique.* He was responsible also for the foundation of an Oceanographic Institute in Paris. He undertook the compilation and publication of a series of bathymetric charts which had been suggested at an International Geographical Congress held in Berlin in 1902. Such charts had been made practical because of the increase in information about the sea bed then available from numerous telegraph soundings and research cruises. They appeared in the form of 24 charts in 1904.

In the United States of America Alexander Agassiz, the son of an immigrant Swiss zoologist, was, as we have seen, in a position not only to employ his engineering training towards the successful modification of deep sea equipment but to contribute to this end the personal wealth he had created by the successful management of a copper mine in which his family were major shareholders. He was also active in generating further private financial support for marine research from among his many influential contacts. As Director of the Museum of Comparative Zoology, a position that his father had held before him, Agassiz was an inspiration to the many students who attended his lectures. From his own resources he enlarged the museum and extended its scientific holdings by the extensive collections he gathered on his marine expeditions. It was a time of meagre government support for natural science but great interest among scientists in rival theories about life in the sea. Agassiz, for instance, was intent on testing Charles Darwin's "subsidence theory" of the origin of the many coral atolls in the Pacific and he participated in many surveying cruises of vessels, such as the *Blake* and the *Albatross,* to test current theories about deep-sea biology. His contribution to marine science was recognised by naming after him the first research yacht built for the Scripps Institute of California.

As mentioned already, the establishment of the prestigious Scripps Institution on the coast of the western Pacific was itself underpinned by the generous endowments of the Scripps family. Day (2002) noted how E W Scripps believed his fortune, acquired from newspaper publishing, could be invested in marine research for the benefit of mankind. Between 1900 and 1920 the Carnegie Institute, another organization funded by private philanthropy, sponsored extensive cruises to understand the earth's magnetic fields.

An Australian National Program

In 1901 the six British colonies in Australia were federated to form the Commonwealth of Australia. Marine investigation on Australia's continental shelf to this date had progressed from the survey sketching of its first explorers, both British and French, to the detailed hydrographic work of the British Navy and then to joint ventures between the British Navy and the various Colonial governments. Some systematic observation and recording of oceanic phenomena were instigated by Australian scientists. At Melbourne University T.W.Fowler applied to the masters of various intercolonial steamships regularly proceeding along the Australian coastline to gather water samples which he then tested for density. The temperature of the water at the time of collection had been noted. His results were published in a paper delivered to the Australasian Association for the Advancement of Science. This Association (known since 1930 as ANZAAS) was formed in 1888. The attendances at the early AAAS congresses reflected the popularity of science and the awareness of the benefits science could bring to the living conditions of mankind.

In the 19th century there was little funding available from the colonial governments for scientific research. All the more noteworthy is the achievement of Henry Chamberlain Russell who was the Director of the Sydney Observatory. Russell was an Australian-born scientist and one of the very early graduates of Sydney University (B.A., 1859). As the Government Astronomer in New South Wales he is remembered for the establishment of a network of meteorological stations throughout the country and the release from 1879 onwards of the first daily weather maps to the press. This was made possible by the extension of telegraphic communication to all the capital cities in the 1870s and by collaboration between the observatories of Sydney, Melbourne and Adelaide. Russell also set up a study of the Australian coastal waters by the distribution and collection of drift bottles. For his drift bottle program Russell, like Fowler, enlisted the cooperation of the masters of coastal shipping who agreed to set the bottles afloat in a variety of locations. Supported in wooden cradles, these bottles contained “current papers”, which invited the finders to return them to Sydney Observatory. The destinations, assumed tracks, time and rate of travel of the bottles were tabulated, charted and discussed by Russell in a series of papers published in the *Proceedings of the Royal Society of New South Wales,* 1894-1902. Included also was information about the rate and direction of the coastal currents gathered from ships coming into Sydney Harbour. The big uncertainty in the drift bottle analysis was in the determination of the precise route taken by the drifting bottles, which, particularly for long distances, could only be conjectured. The capacity to monitor the movement of drifting buoys was not achieved until the advent of satellite-sensing, well into the twentieth century

The first sustained program of marine research in Australian waters came with Federation. Between March 1909 and December 1914 the Commonwealth Government supported an extensive investigation of the coastal waters of south-eastern Australia under the direction of a Norwegian-born fisheries expert, Harald Cristian Dannevig, who was appointed Commonwealth Director of Fisheries in July 1908. The aim of the program was to locate trawlable fishing grounds suitable for extensive commercial development adjacent to the main centres of population. In 1906 when the Commonwealth Government was planning to acquire a research trawler for investigation of possible coastal fishing grounds, Dannevig's advice was sought. Harald Dannevig had come to Australia in 1902 to take up a position with the New South Wales Government as Superintendent of Fisheries Investigations and Fish Culture. He was born near Arendal, Norway. His father was the first to introduce fish culture into Norway. As a young man Dannevig, whose portrait is shown in Figure 7.3, studied at the Christiania (now Oslo) University where there was a strong interest in marine science, led by the eminent zoologist Georg Ossian Sars.

On the long voyage to Sydney in the *Oroya* Dannevig supervised the successful transportation of live adult fish designed to establish favoured European food fish in Australian fishing grounds. Little was known at the time about the palatability or the availability of fish from the waters off the Australian coasts. It was assumed that European fish would be better. The acclimatisation program, however, had only limited success. Dannevig designed and constructed a fish hatchery at Port Hacking, near Sydney, where he also conducted experiments with local fish. Dannevig (1907) was interested not only in fish culture, however, but also the physical conditions that influenced the abundance of fish at sea.

7.3
Harald Cristian Dannevig, an oceanographer of Norwegian birth, was the Director of the Australian Commonwealth's first marine science program, 1909-14. Courtesy of O. Dannevig, private collection

Dannevig's (1906) report to the Federal Authorities reveals his concern that the vessel secured be more than a commercial fishing trawler and that adequate provision be made for the specialised equipment necessary for scientific research. In line with his advice, a copy of the plans and specifications of the Norwegian research trawler, *Michael Sars*, was obtained through the agency of the Norwegian Ambassador in London. The *Michael Sars* had been built specifically for research. For such purpose a research vessel, FIS *Endeavour* was built at the New South Wales dockyard. Its design would appear to have been a good choice to conduct similar research in Australian coastal waters.

The FIS *Endeavour*

The *Endeavour* was constructed in Sydney and launched at Fitzroy Dock on 27 August, 1908. The 335-ton trawler, with two masts and a single funnel is described in detail by Dannevig (1909):

> *While resembling very much a modern trawler, her main winch is specially powerful, and carries 2,000 fathoms of two and a half in. and one and a half in. wire rope for trawling purposes. An additional reel attached to the fast running axle on the winch carries 1,500 fathoms of half inch wire rope for hydrographic observations. The starboard side is generally fitted and equipped for operating the large otter trawl (95 ft. headline), while on the port rail a Lucas Sounding Machine (5,000 fathoms of piano wire) and davits for various purposes have been fixed in. On the deck aft is provided a laboratory where all preliminary investigations are carried out. Here also is stored all the special apparatus, including deep-sea water bottles, thermometers, etc.*

The *Endeavour* Program

Dannevig (1909) is at pains to point out in his first report to Parliament the need to spend considerable time in sounding and survey work generally, for his object was to show how and where good fish might be obtained in quantity, rather than to bring large catches into port. Knowledge of the nature of the sea bottom, he said, was crucial to a trawling operation and a knowledge of the physical characteristics of the water-masses was valuable for an understanding of the movements of fishes. He wrote:

> *For the purpose of studying the currents and their relation to abundance of fish food and migrations, various investigations have been carried out in conjunction with the survey work . . . Bottom samples have been obtained from various depths down to 1200 fathoms and water samples and temperatures from all intermediate depths. Plankton collections from the surface have also been obtained particularly to ascertain the distribution of pelagic fish eggs.*

The first twelve cruises examined mainly Bass Strait and the coast of Tasmania, with some preliminary surveys of South Australian waters. Dannevig reported that: “In the quite open portions of Bass Strait, where the tides are strong, there is an abundant growth of coral, sponges etc. which render trawling difficult, and in none of these places were many good fish met with.” The richest trawling grounds, he said, were to be found “in localities where a reversal of currents or eddies facilitate the accumulation of fish food”. In later cruises the investigations were carried into the Great Australian Bight and along the New South Wales coast.

The Commonwealth marine program, however, came to an abrupt end in December 1914. In November the *Endeavour* sailed south from Hobart to Macquarie Island to take supplies and a relieving officer to the meteorological station there. On the return voyage the trawler foundered in the Southern Ocean in tremendous seas, whipped up by gale-force winds. Dannevig lost his life, along with his biologist, Charles Harrison, and the entire ship's crew. A wide search was conducted but to no avail. It was wartime; ships were in scarce supply; the *Endeavour* was not replaced and the position of Commonwealth Director of Fisheries remained vacant.

Publication of the *Endeavour* Results

As part of this Commonwealth program, funds were allocated by the Department of Trade and Commerce to publish reports by Australian and overseas scientists on the biological and oceanographic findings of the *Endeavour* cruises in a series entitled *Fisheries*. The first appeared in 1911 and the series continued until 1933, so that the scientific results of the *Endeavour* program were still being produced long after the Director and the vessel had been lost.

As the program advanced, Dannevig prepared reports on the geological and meteorological aspects of the investigations. These were published in *Fisheries* in 1915, after his death, along with his obituary. Dannevig (1915a) discussed the physiography of Bass Strait, in the light of his soundings and investigations of the sediments. He attempted to relate the type and depth of the sediments to the tidal currents and the climatology of the surface waves. He suggested a general current drift, west to east, of the type recently reviewed by Tomczak et al. (1984). Dannevig (1915b) discussed the way in which wave action on the east coast of Australia could move sediments at depths of 40 fathoms (73metres) and attempted to explain the change in sediment composition that he had observed from the *Endeavour* in terms of the waves and currents. In Bass Strait he noted the 'deep indentation' in the shelf break into the Tasman Sea, presenting an 'abrupt and sharp margin', which we now call the Bass Canyon.

As was to be expected in a developing country, the program was presented essentially with a practical aim to assist commercial fisheries and was not merely for curiosity-driven scientific research. To fund purely oceanographic research on such a scale would probably have been as far beyond the imagination of the small population of Australia (less than four million) at the beginning of the twentieth century as it was beyond the inclination of the people of the United States one hundred years earlier.

The Australasian Antarctic Expedition

While the Commonwealth Government was carrying out its surveys from the *Endeavour,* the Australasian Association for the Advancement of Science (AAAS) gave its support to an expedition to place parties of scientists south of Australia on Macquarie Island and on the shores of King George V Land and Queen Mary Land in Antarctica. The organiser and leader of this expedition was 29-year-old Douglas Mawson, a geology lecturer at Adelaide University, and a graduate of Sydney University. Mawson had previous experience in the Antarctic from his participation in the British Antarctic expedition of 1907-1909, led by Ernest Shackleton. He was part of the nucleus of working scientists who benefited from the network provided by the Australian Association for the Advancement of Science. His appeal for subscriptions to equip an Australian Antarctic expedition was answered by donations from the public and from the AAAS. It was a project that appealed to the nationalism of the Australian people.

The shore parties were conveyed to Antarctica in the *Aurora,* a 600-ton wooden sailing vessel, purchased in Britain for this purpose. The 165-foot *Aurora,* shown in Figure 7.4, was equipped with an auxiliary coal-fired engine of 98 horse power, and had been strongly built for whaling and sealing in Arctic waters. Captain of the *Aurora* and second-in-command of the expedition was John King Davis. Arrangements were made for some oceanographic probing of the Antarctic area from the *Aurora,* which was refitted for that purpose. The *Aurora* left Hobart in December 1911 and crossed the region of the

Roaring Forties with the difficulties characteristic of these small vessels. The expedition set up the meteorological station on Macquarie Island, the reprovisioning of which, two years later, led to the loss of the *Endeavour.* This base served as a radio relay station, by means of which meteorological information could be conveyed from the Antarctic bases to the Melbourne weather bureau. It was the first time that radio was used in Antarctic exploration.

7.4
The Aurora alongside an icefloe at Wild's Depot on the Shackleton Ice Shelf during the Australasian Antarctic Expedition, 1911-1913, led by Douglas Mawson. The Captain of the Aurora, and second-in command of the expedition, John K. Davis, made five cruises in the Aurora to establish and relieve the wintering bases at Macquarie Island, on the Antarctic mainland and the Shackleton Ice Shelf. These cruises provided the opportunity for some early oceanographic probes of the Southern Ocean, in the course of which depth profiles were obtained from Tasmania to Antarctica.

The Australian Exploring Expedition was extended until the summer of 1913 and provided a wealth of scientific data, magnetic, meteorological, geological, biological and oceanographic from the Antarctic coast and continental shelf between longitudes 90°E and 155°E. Captain Davis from the *Aurora* obtained a small number of vertical temperature and salinity casts, using Richter and Ekman reversing thermometers. The depth soundings threw light on the sea floor profile of the Antarctic continental shelf in that sector. The reports on the field data, analysed by scientific experts, were published in a twenty-two-volume series, the *AAE Scientific Reports*, of which the *Hydrological Reports* appeared in 1940.

The outbreak of World War 1 soon after the return of the expedition interrupted the analysis of their findings. Mawson and several other of the scientists served in the armed forces. Robert Bage and Leslie Blake were killed in action and Charles Harrison, the biologist, was lost with the FIV *Endeavour*. After the war Mawson sorted the data and the collections and despatched them to experts both in Australia and overseas. The imagination of the Australian public was fired not only by the brilliant cine-photography of Frank Hurley (1925), and his beautifully illustrated *Argonauts of the South*, but also by the publication of Mawson's *Home of the Blizzard* and Davis's *With the* Aurora *in the Antarctic* - *1911-1914.*

The British, New Zealand and Australian Antarctic Expedition (BANZARE)

In the next decade energetic fund-raising in Australia, Britain and New Zealand allowed another expedition to the Antarctic regions to be planned and Mawson was appointed its leader.The combined British, Australian and New Zealand Antarctic research expedition sailed south in the summers of 1929-30 and 1930-31. The expedition chartered the strongly constructed, 485-ton *Discovery*, rigged as a three-masted barquentine, which had taken Robert Scott to the Antarctic in 1901 - not the most comfortable of vessels, but updated with instrumentation for oceanographic research. The modernisation included an echo-sounder, which greatly facilitated the sea floor mapping. The echo-sounding apparatus, designed by Dr Harvey Hayes of the U.S. Navy in the 1920s allowed an almost continuous series of soundings at close intervals over more than 30,000 miles in the Southern Ocean. The accuracy of the observations by the new technique was periodically checked against soundings by the Lucas machine.

The 1929-30 BANZARE summer cruise sailed from Cape Town to Kerguelen Island, where a base supply of coal was established for the auxiliary steam engines, which were so important for holding a 'station' or manoeuvring among icefields. Their coal stocks proved to be a limiting factor to the area probed by the *Discovery* since Captain Davis insisted on returning to Kerguelen when his coal stocks were educed to a critical level. The light seaplane carried on board enabled the expedition to survey the coastline more extensively than was possible from the ship, which was constantly prevented from approaching the land as closely as the scientists would have wished. The photographer, Frank Hurley, who was again a member of the party gained the opportunity for some brilliant aerial shots. His photography illuminated the scientific papers and popular lectures, which followed the expedition.

Captain Mawson's reports on the rich whaling grounds off Enderby Land, 'worth millions of pounds worth of products', had aroused public interest, and ensured funding for the second voyage despite a world-wide economic depression. The *Discovery* sailed south in November 1930, this time from Hobart, and proceeded, via Macquarie Island and the Balleny Islands, to explore the coastline of Antarctica between King George V Land and the previous year's discoveries. Aerial survey was again possible. There was also radio contact with Melbourne, and this time arrangements were made for coal supplies from a Norwegian whaler in the area. The echo-sounder added to the evidence of a continental mass beneath the ice. The geographical details provided by these cruises were significant in support of the claim by Australia to a sector of the Antarctic Continent in 1936.

The Council for Scientific and Industrial Research

Hydrographic work around Australia proceeded slowly after Federation. The Hydrographic Branch of the Royal Australian Navy was not established until 1921. Surveying was then conducted mostly with steam vessels of British origin. Their contribution to physical oceanography was limited. In 1926 the Council for Scientific and Industrial Research (CSIR, forerunner of the CSIRO), was established by the Australian Federal Government. It was not until 1936, twenty years after the demise of the *Endeavour* program, that special funding was provided by the

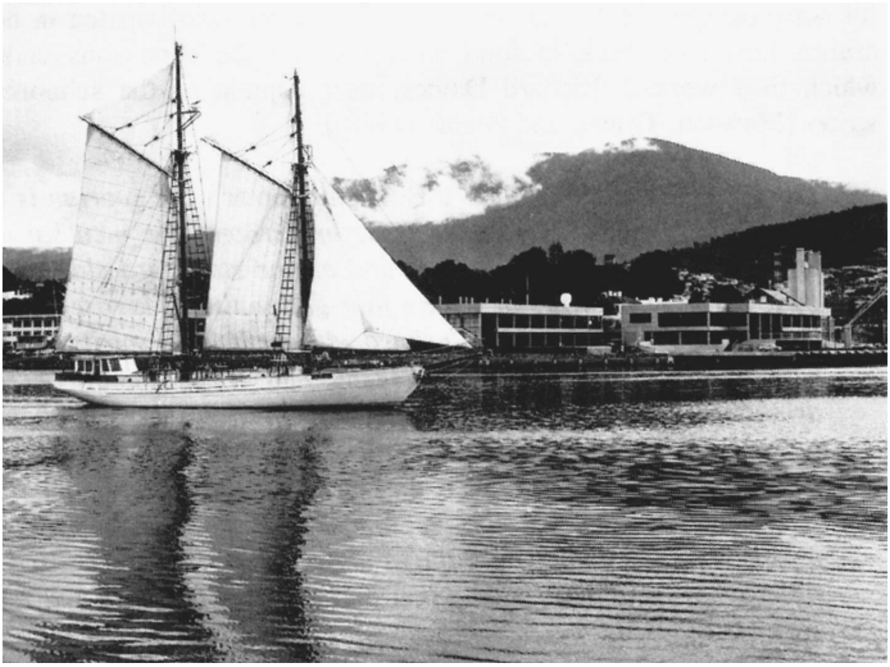
Commonwealth government to set up a fisheries section. In that year. a marine laboratory was built at the site of Dannevig's fish hatchery on Port Hacking, near Sydney and a research vessel, FRV *Warreen*, was constructed at Williamstown dockyard in Melbourne. It was built as a purse seiner, 85 feet in length. In 1940 the cruise program for the *Warreen* included not only investigation of fish stocks but also a hydrology program for a series of stations established at 50 metres depth in the waters of the continental shelf from Brisbane to Hobart. The regular collection of water samples and temperature and salinity data from the established stations was rendered more practicable by the fact that the *Warreen* had the advantage of steam power. The work of the *Warreen*, however was soon curtailed by the outbreak of World War II and was suspended in 1942 when the ship was commandeered by the Royal Australian Navy. After the war, when the *Warreen* was returned to the Division, the scientists were then engaged in hydrological research along the south-west coast of Western Australia, in support of the valuable rock lobster industry.

When the Fisheries Division of the CSIRO decided in 1950 to buy a research vessel for an ocean program in the Tasman Sea, the choice fell upon the *Derwent Hunter*, a 72-foot ketch-rigged Hobart fishing vessel, which was converted to schooner rig and given laboratory facilities and additional auxiliary diesel power. FRV *Derwent Hunter* was rigged with picturesque red sails. It served the CSIRO both for fisheries and physical oceanography until 1960. A big factor in the choice of sail power for extended offshore work was the independence from fuel supplies.

Now came a sustained national blue-water oceanography program. Between 1954 and 1959, the CSIRO schooner *Derwent Hunter* made a series of cruises within 500 miles of the East Australian coast between latitudes 30ºS and 37ºS. Using reversing thermometers and water bottles attached to 1000 metres of wire, Bruce Hamon (1961) was able to map the density structure of the waters off the coast. The contours of the height of the sea surface were calculated from the water density. He found the current to flow southwards or south-easterly usually within 60 miles of the edge of the continental shelf and estimated the volume transport of the current to be about half that of the Gulf Stream or of the Kuroshio. On several cruises he also detected a northerly or north-easterly flow of equal strength 70 to 200 miles to the east of the axis of the main current. The results of some cruises also showed the presence of an easterly flow off Sydney between the southerly and the northerly streams which suggested a possible eddy structure.

This suggestion was pursued over the next decade by Australian scientists within the Division of Fisheries and Oceanography of the CSIRO. From 1960 they were able to look at the current in more detail using the steam power of the frigate H.M.A.S. *Gascoyne* which was made available to them by the Royal Australian Navy. Ten years work by Bruce Hamon (2003) made clear the frequent presence of strong anti-clockwise eddies, about 150 miles in diameter, with surface speeds of about 4 knots per hour. Now with regular measurements of sea surface temperatures by satellite imagery, the East Australian Current is known to have a pronounced eddy structure (as have the Gulf Stream and the Kuroshio) and episodically to shed southwards a series of warm core eddies. Tracking the movement of these eddies and monitoring their disintegration or coalescence provides useful information for the fisheries industry. The occasional penetration southward of a warm-core eddy as far as the east coast of Tasmania, for example was found to affect the location of the valuable jack mackerel, which are known to have a temperature tolerance of between 13.5ºC and 16ºC.

The *Derwent Hunter* cruises of 1958 are noteworthy also for the first sea rials of an instrument developed by Bruce Hamon and Neil Brown that could be lowered on a single cable and transmit data directly to the ship. The electrical conductivity of sea-water is an indication of its salt content. Temperature also has a large has a large affect on the water’s conductivity. Determination of salinity could now be made in situ by the simultaneous measurement of electrical conductivity and temperature and by the automatic correction in the electrical circuit for the effect of temperature. This was a great improvement on the existing time-consuming procedure of collecting sea-water samples in preset depths and analysing them on board ship. Now temperature and salinity could be measured simultaneously at many depths and the salinometer showed many fine-scale variations in ocean properties. Neil Brown (1991) reports that Hamon made the first determination of the effect of pressure on the conductivity of sea-water in these trials. Klaus Wyrti (2002) recalls how when he used the new instument in the Solomon Sea that it was accurate to a degree unheard of at that time. The CTD (conductivity-temperature-depth recorder), as it is now called, is a idely used tool of modern oceanographers.



7.5
The CSIRO schooner* Derwent Hunter*, which was used for oceanographic research around the Australian coastline in the 1950s, is shown in front of the CSIRO facilities in Hobart, on the roof of which a satellite dish is clearly visible. Reproduced from* The Marine Studies Bulletin*, 1988

In 1956 George Humphreys, Chief of the CSIRO Division of Fisheries and Oceanography'. was able to take Australian oceanography into the international arena by Australia's participation in the 1960-65 International Indian Ocean Expedition (IIOE), to which thirteen nations contributed. Australian oceanographers had now joined the international collegiate of marine scientists and they have since participated in a variety of international programs.

Memories of *Derwent Hunter* Days

The *Derwent Hunter* was one of the last representative of the sailing era used for oceanographic research. Those who participated in her cruises now look back in fond amazement at the conditions under which they worked. Richard Davies, once captain of the schooner, writes [Mawson, Tranter and Pearce, 1988]:

> *To say that conditions aboard* Derwent Hunter *were spartan is to say the very least. . . . In the galley/messroom the men sat on benches across the forward end and on the starboard side, with their backs to the rows of square four-gallon tins of kerosene that fuelled the stove - which was primed with methylated spirits spiked with a dash of kerosene (so legend had it) to inhibit secret drinkers. Opening aft of the galley was the laboratory with the only sink for ablutions; this scientific space was shared by the mate and the scientific officer, and there was a settee for another scientist to sleep on, with his feet and shins in a wardrobe through a foreshortened door. The sail and chain locker forward housed a toilet with an idiosyncratic pump and one had to brave sea and spray to reach it.*

Perhaps Richard Davies's further description may help us to envisage the rugged and often boisterous conditions that marine scientists of the past two hundred years have endured. On a trans-Tasman cruise, that required a crossing of the subtropical convergence from Hobart to sample sub-antarctic water, the *Derwent Hunter* encountered winds of Beaufort scale 8/9 (40-50 knots) at latitude 44° 40' South. The main boom was carried away. First a deckhand severed two fingers while securing the mainsail. Then the mate fell on deck and injured his forehead:

> *In the afternoon, running under staysail only, we were lifted on a massive southwest swell and slammed by a very rough northwest sea travelling along its crest, which caused us to breach. Two of us fought the wheel, attempting to drive the vessel, surfboat-like, down the face, the sea piled over the deck to the boom chocks. At the end of this crazy ride, the* Hunter *lay in the trough, rolling water off the decks and, despite the wind at the crest, the staysail was idly flapping some 60 feet below. When the messdeck hatch slid open, it revealed five faces that, like ours, mirrored those in the Hokusai print.*

Such description would doubtless have struck a chord with the French officer-scientists of the *Astrolabe* facing the 'mountainous' waves of the South Indian ocean in 1826 or of the Americans on the *Peacock* in 1840, limping back to Sydney rudderless from their buffeting in the Southern ocean. The fortitude and endurance of pioneer oceanographers in the days of sail should not be forgotten. Times have changed. Oceanography is now undertaken from diesel ships with considerable improvements in equipment and in the standards of comfort. Measurements are made not only from the surface of the sea, but from submarines below it, from planes above, and, most recently, from space ships orbiting the earth.

8

Epilogue

During the period of our story we have seen the shift from the concealment of maritime knowledge for national economic advantage to international cooperation in marine science for the good of mankind. While for a century the Dutch East India Company tried to discover a passage south of New Guinea, Spanish trading companies concealed the knowledge of such a strait. At the end of the seventeenth century Dampier's books made widely available his knowledge of oceanic winds and currents. Then came a period when national prestige motivated the discovery and publishing of knowledge. The handsome, government-funded reports of Dumont d'Urville or Charles Wilkes are examples. In the second half of the nineteenth century, the global extent of trading routes and the need to improve the efficiency of transportation by sail power led to systems such as Maury's, whereby reports of oceanographic conditions were collected from ships both naval and commercial from all nations. Neumayer at the Melbourne observatory played a significant role for the use of great-circle routes to Australia. This was the start of the network of volunteer observer ships (VOS) now sending their data by satellite to central data centres around the world to allow the start of an ocean forecasting system that will benefit all marine operators.

The investigations of the early mariner-scientists were driven mostly by intellectual curiosity. They worked with the support of their governments, whose aims were sometimes more pragmatic. As a result of their labours we can now harvest the products of the seas with an efficiency that allows many of the world's inhabitants to live a more rewarding existence and enjoy a better quality of life than their ancestors. The science of oceanography, which developed from the exploration of the oceans and its boundaries, forms the basis of our twentieth-century management of the resources of the sea and its shoreline and is crucial to our understanding of the weather and the prediction of variations in climate.

There were a number of beacons along the path to our understanding of the oceans' ebb and flow. Outstanding was the development of the marine chronometer, that allowed the determination of position with sufficient precision for others to relocate the position of the observation. The accurate determination of longitude may well have been the most important technological advance in the development of the physical science of the sea. Not only could successive navigators now sail with greater assurance of finding their way safely, but now scientific observations could be checked, replicated or extended.

The first quarter of the nineteenth century saw great advances in natural science as fruitless speculation finally gave way to observation and measurement. The instrument maker played an important part in the new science. Improvements in thermometers, barometers and hyg-rometers advanced the accuracy of measurements of the atmosphere and the oceans. Slowly and laboriously data was collected to allow the formulation of global descriptions of properties such as currents, temperatures and salinity. Many of these measurements were taken by mariners who saw no immediate benefit for their work, but their observations formed the basis for later explanations of natural phenomena. The hopes of Bishop Watson (1782) were slowly being fulfilled. One might have hoped, he said, that, by his time:

> *In this age of philosophy and curious navigation, the degree of saltness in every latitude, and every season of the year, would have been ascertained by accurate experiments.*

The nineteenth century took up the challenge. Day in day out, every two, four or six hours the naval officers and scientists measured diligently the atmospheric and oceanic conditions along their long voyages of exploration and survey. Some few attempted generalisations of their work. Some were over-confident in the theories they proposed. Others were content to hope that some day, some 'more powerful mind', as Beaufort put it, might make order and system out of their voluminous, but systematic, collections.

Generalisations of the surface circulation of the oceans began to appear in the 1850s and around that time also Emil Lenz formulated the first model of the vertical circulation, with sinking at the poles and upwelling at the equator. Other concepts, such as that of the lifeless azoic zone in the ocean depths and of the bottom zone of stagnant water of constant 4°C temperature, had to await the needs of the submarine telegraph to provide the impetus for sufficient information by which they might be convincingly overturned.

Professional positions, funded to study marine science, were slow to emerge. Some were provided by the navies of the maritime nations, but with the demise of the sailing ship, the need to understand the physics of the sea declined. The costs of oceanographic research were outside the budgets of those organisations, the academies, learned societies and universities, that traditionally supported curiosity-motivated research. The expense of ocean research was formidable. In the northern hemisphere cooperative ventures between nations with common interests allowed some 'big' science towards the end of the nineteenth century. Prince Albert of Monaco was one who was able to use his own sailing vessels to carry international teams of experts for oceanographic research. He recognised the value of cooperation by all nations and he became the first president of what is now called the International Association for the Physical Sciences of the Oceans (IAPSO).

Oceanography has always thrown sailors and scientists together in close quarters. The authoritarian nature of navies, whether the military or the merchant marine, tended to be in conflict with the questioning nature of science. The cultures clashed and often, as we have seen, with destructive consequences. Baudin came to Australia on an epic voyage to transport to the other side of the globe people able to draw and record what they saw, but only a few of the French scientists persevered to return with a report for their Institute. Instead many chose to leave the authoritarian environment. Some expeditions, to avoid this conflict, e.g. those led by Wilkes and Ross, carried, by design, few physical scientists and instead relied on the inexpert to interpret the observations of the sea. Their lack of contemporary knowledge failed many of these earnest people. Ross's *Circle of Mean Temperature,* discussed in chapter four, was a concept based on a belief, already disproven, that the maximum density of sea water occurred at a temperature of 4°C.

Marine operators, commercial and military, have remained important financial supporters of marine science. With the end of the sailing era, however, the operation of vessels needed for physical oceanography has become less expensive (relatively) and it is now possible for oceanographers to be in charge of their own means of transport. Now the conflicts have declined and, as a group, mariner and scientist see more clearly their common purpose.

The age of sail gave way to the age of steam. Twentyfirst-century science can use the technology of the space age. The surface of the oceans can be observed and investigated from space. Satellites, orbiting hundreds of kilometres above the earth, sense the sea-surface temperature, the waves and surface winds, the fluctuations in currents and the clouds that shelter the ocean from the heat of the sun. This information can now be beamed to earth-stations or to ships at sea via other communication satellites hovering over the equator. Ships' masters, instead of making tedious calculations based on the distances between the sun and the moon, can now receive continuous updates of their position from a series of satellites put in place solely to aid navigation. Images and data obtained by remote-sensing can be organised and analysed by the use of computers. Sometimes the satellites are manned, as was the case when oceanographer Paul Scully-Power orbited the earth in the *Challenger* space-shuttle in 1984. From his small porthole he could observe great whirls and spirals on the surface of the ocean, the explanation of which is a puzzle to present-day oceanographers.

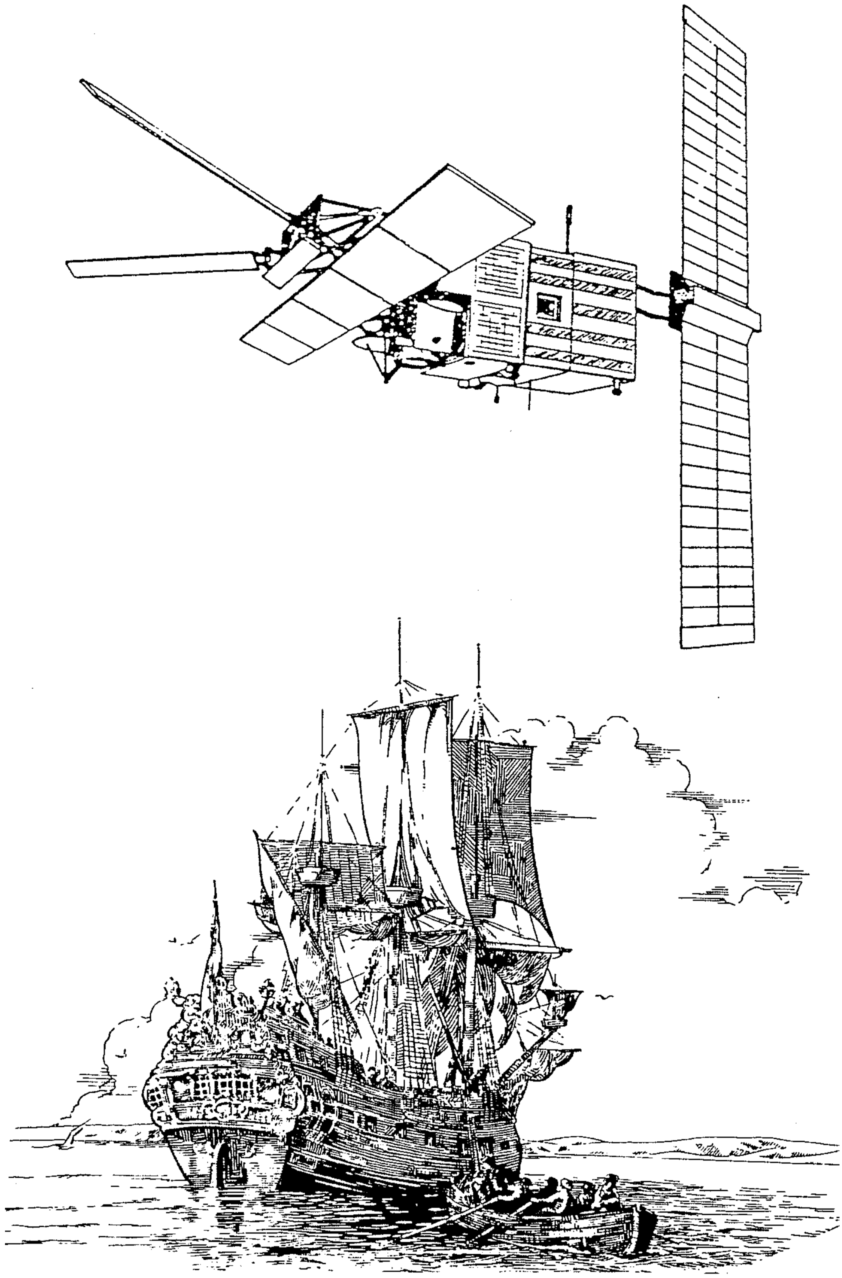
While the pioneer mid-nineteenth century efforts in oceanography by the USA were beset with the difficulties of disputation, inexperience and the paucity of back-up institutes of learning as well as by insufficient knowledge on the part of some of the practitioners, the second half of the twentieth century has been dominated by the wealth and technological prowess of the USA. The USSR has also invested heavily in oceanographic research and has published a handsome set of world atlases [Gorshkhov (1974)] depicting our knowledge of the marine climate.

No longer is it considered cost-effective to produce elaborate, illustrated volumes of the narrative of individual cruises or to typeset the tables of data. Publication, was, however, the key to the dissemination of knowledge and the development of concepts. Those expeditions that could not arrange adequate publication had small impact on the progress of marine science. Like the failure to publish the oceanographic observations of Malaspina, the failure to publish the physical observations undertaken during the Wilkes expedition is the reason for the small impact of these expeditions on physical science.

The pioneers in oceanography have earned our respect. Their story deserves to be recorded. In the third decade of the nineteenth century François Arago, posing his questions about the physics of the globe for the mariners of his times to investigate, could exclaim:

> *The progress of human knowledge demonstrates each day how ignorant, to be sure, our predecessors were; how in our turn shall we appear to those who must replace us?*

Our story, we hope, has served to show, not how ignorant, but how strongly motivated in the face of hardship and danger were those of our predecessors in marine science who probed the oceans in the pursuit of knowledge.



A modern ocean-sensing satellite and HMS* Roebuck*, in which William Dampier, a product of the burgeoning Age of Enlightenment sailed in search of Terra Australis.

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