Why We Study the Physics of the Ocean

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What Physical Oceanographers Really Do

By

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This book is dedicated to Henry Stommel who provided an early inspiration for me to write this book. It is also dedicated to my wife Dora and son Micah who have tolerated me writing it.

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1.0 INTRODUCTION

When I tell people I am a physical oceanographer the response is usually “that must be really interesting work.” These statements are generally based on a total misconception of what an oceanographer is or what he/she actually does in their science career. Most people think that oceanographers travel around the world with their SCUBA equipment collecting fish, corals and other things that reside in the sea. This misconception is due to the material generally presented on television which shows the more colorful activities of marine biology collecting samples as they SCUBA dive in tropical waters or of geologists in deep-sea submersibles studying hot vents at the bottom of the ocean. This is understandable as the producers of television shows want to provide material to the public that will grab their attention with images under the ocean rather than sitting on the surface. Other public presentations of oceanography have shown it as a search for sunken ships such as the Titanic or deep diving in 2-man submersibles in search of conditions at the bottom of the ocean.

Few TV shows have ever presented the need to understand the physics of the ocean itself. Nevertheless “oceanography” originally referred to the study of the ocean water itself as the other areas of marine research had separate existing categories. The study of life in the ocean was “marine biology,” while geology and chemistry were parts of their own disciplines. As marine science matured it was clear that there were sufficient chemical and geological problems in the ocean to have separate fields of chemical oceanography and geological oceanography. At the same time biological oceanography separated from marine biology in that the vertebrates of the ocean were the domain of marine biology and biological oceanography concentrated on the microscopic life in the oceans both in the water column (mostly restricted to the upper ocean) and life in the seabed.

Physical oceanography, meanwhile matured into a study of the dynamics and thermodynamics of the ocean itself. It is interesting to note that information from physical oceanography is often quite important for the other fields of oceanography. Knowledge of the currents at the sea surface, and deeper in the water column, is critical to understanding the distribution of chemicals in the ocean. This current information is quite critical in being able to resolve the distributions of marine zoo and phytoplankton, the subjects of biological oceanography. In addition, some understanding of ocean thermodynamics is critical to understanding the conditions in the upper euphotic zone of the ocean where the biological elements reside. Geology can also benefit from knowledge of the ocean currents in that much of the ocean bottom consists of layers of organic “ooze” laid down over many years. Again the ocean currents play a very important role in dictating where these elements reach the bottom.

It is perhaps this link between physical oceanography and the other three fields of oceanography that led to its being initially designated as oceanography before any of the others. Another possibility is that physics was already divided into numerous fields so that when applied to the ocean it was only logical that it be called physical oceanography. So, the important question is what do these physical oceanographers really do? How do they spend their time in their research and how does their work contribute to their understanding of a medium that covers two-thirds of the world’s surface? What are the important human consequences of the work being done by physical oceanographers and what can we expect from their labors in the future? Is there something the public should know about these efforts by a rather small community of scientists? For a place as large as the ocean the number of people studying it is relatively small. Nevertheless, they have developed technologies that have eliminated the need for scientists to spend a great deal of time at sea on research vessels and instead they can stay at home to analyze new data being collected by autonomous platforms and relayed home via satellite. These improvements, however, have provided a new “sea” of data requiring even more scientists to analyze them. It is this need for additional physical oceanographers that will likely limit progress in this research domain in the future.

The world of physical oceanography has gone from a few scientists collecting a limited amount of data and then teasing out of the data important conclusions about the ocean, to an overwhelming plethora of data collected by satellites and autonomous platforms relaying their data via satellites to scientists in their labs. We are now able to build on some amazing insight developed by intrepid pioneers so that we now no longer need to wonder what the mean state of the ocean looks like. Most of the measurements these early conclusions were based on were collected from a relatively small number of research ships sampling from the surface of the ocean. Modern physical oceanography has inherited the need to define and characterize the variability of the ocean on a variety of time and space scales. This is an extremely challenging condition to find ourselves in and as just mentioned physical oceanographers have been very successful at creating new measurement platforms to automate the collection of relevant physical data. The availability of Earth orbiting satellites has contributed significantly to this explosion of new autonomous measurement methods as well as to direct sensing from space of physical characteristics of the ocean. Now the challenge is turning this large amount of new data into information that one can use to improve the modern world that we live in.

So, one might ask what is the relevance of all this new research? How does any of this new insight into the physics of the ocean help humankind? Well, first we must realize that three-quarters of the world's largest cities are by the sea. In 2010 roughly 80% of the world's population lived within 62 miles of the coast with 40% of them within 37 miles of the coast. This means that some 634 million people live in the low-elevation areas that are only 30 ft above sea level. If all the glaciers and ice sheets at both poles were quickly melted the sea level would rise some 225 to 365 ft flooding all of these coastal cities and displacing the 634 million people that live there. People don't recognize the seriousness of this situation since the sea level is only rising at about 3 mm/year. The overall sea level rise only makes itself felt when dramatic events like hurricanes and tsunamis occur, flooding these coastal regions. Such natural disasters are becoming more frequent and increasingly devastating as the sea level slowly rises. The contributions to this sea level rise are many but they are all in the domain of study by physical oceanographers. This is only one very significant aspect of the work that physical oceanographers do. There are many others as will be revealed in this book. The central purpose of this book is to present what physical oceanographers do and demonstrate how this research is very relevant to human activities.

1.1 Physical Oceanography as a Science

Before we can introduce what physical oceanographers do we have to define what this area of science really is and what topics are included. One common element in physical oceanography is observing and understanding currents. One of the biggest problems is getting a handle on how the ocean advects properties throughout the world's ocean such as heat and nutrients. More recently, interest has developed in knowing how the currents carry pollutants and debris such as plastic, and how much debris is found to reside in the ocean. The early oceanographers had some indirect methods of estimating ocean currents. For the longer-term distributions, they primarily looked at the distributions of properties such as salinity, oxygen and various nutrients. These properties were largely advected by the ocean currents which were often measured directly with the current meters of the time. An indirect method was the development of the "dynamic method" by the geophysical school in Bergen, Norway in the late 19th century. With this technique the temperature and salinity vertical profiles were used to compute the vertical density profile and from the horizontal density gradients one could say something about the currents at the sea surface, while some deeper layer was assumed to have "no motion" which dictated that the horizontal pressure gradient was non-existent at that depth.

Many direct current measurements were made and where available they could be used together with the density profiles to correct the surface currents and the rest of the currents in the water column. It was very difficult to make these kinds of direct current measurements in the deep open-ocean and for many years these types of direct measurements were restricted to the shallow waters where a ship could be anchored. First in 1925 a German research vessel *Meteor* was able to anchor in the deep ocean (> 5,000 m) and make direct current measurements throughout the water column. One current meter was an ingenious device (Fig. 1.1) first developed by Prof. Walfrid Ekman working at the Bergen School. The meter had a large vane that oriented the entire instrument into the current and the current speed was measured by a ducted propeller which had a series of scaled gauges to measure the revolutions. The direction was measured by a small wooden circular tray with radial slots. This was mounted on a magnetic compass and small metal balls would feed through the system as the propeller rotated and then fall into the slots. By counting the number of balls in each slot over the period of time that the current measurement was taken you could find the dominant directions. The unit was started and stopped by dropping a "messenger" on a wire. This ingenious mechanical device continued in service up to the early 1960's.

Another way to measure ocean currents was to take the Lagrangian approach and follow the movement of a water parcel. Early efforts were made with "drift cards" that had to be followed by ship or were "launched" with information that whoever found the card should report back to the originator saying where and when it was found. This approach merely gave the starting and end points but could not reveal the complex current patterns between these end points. Later drifting buoys were developed that could again be followed by ship to record their movements. This approach became much more successful with the advent of satellite interrogation of ocean platforms that allowed the buoys to drift with the currents and report their positions by satellite. This Lagrangian approach also made it possible to follow subsurface ocean currents by tracking floats in the interior of the ocean that had been weighted to float at a specific density level or depth. These floats were tracked acoustically using sound which is most effective in the ocean. Today this has been expanded to buoys that measure currents at depth (usually 2,000 m) and periodically ascend (while measuring ocean

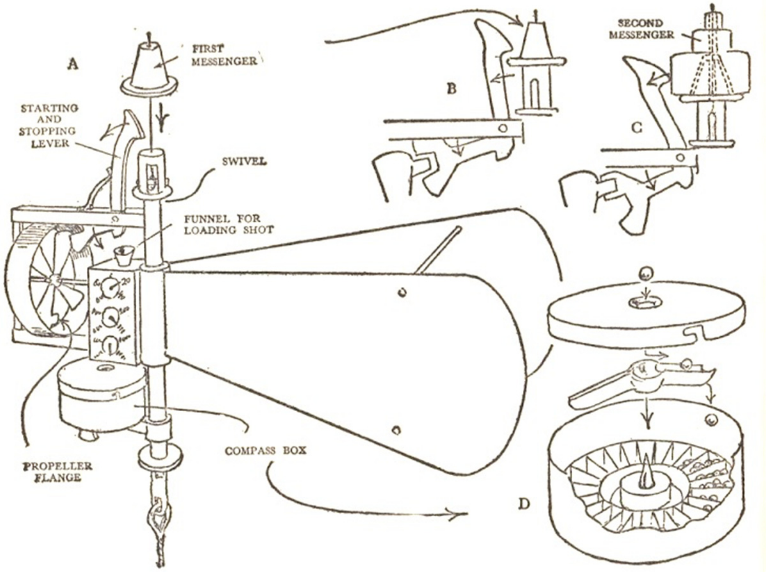

Fig. 1.1 Ekman current meter: A. full assembly, B. first messenger to start, C. second messenger to stop, and D. the compass tray with radial slots and falling metal balls.

properties) to the surface to report their data via satellite before they again descend to their operating depth. The emphasis today is on using technology to automate the collection of field data without the need to go out on research vessels and make the relevant measurements.

Measuring and monitoring ocean currents is certainly not all that physical oceanography is involved with. The density structure of the ocean is one of the fundamental research areas that has concerned physical oceanographers since the beginning. This density is generally considered as a function of temperature and salinity profiles. It is noted that for most of the ocean that temperature dictates the density while salinity only becomes important in polar regions or in areas where major river runoff occurs. The temperature information provides the link between physical oceanography and biological oceanography as the ocean conditions at the sea surface are critical inputs into the maintenance of life in the upper ocean. In addition ocean conditions at the sea surface are directly related to the exchange of heat and momentum between the ocean and the overlying atmosphere. These heat and momentum fluxes are closely linked to changes in weather and climate with the ocean acting as a large reservoir for both heat and momentum. Thus, knowledge of the ocean near surface temperature is a requisite for accurate forecasting of weather and climate changes over the Earth. These fluxes have proven very difficult to measure and study and therefore our exact knowledge of what they are and how they work to dictate both weather and climate is very poor at this time. A large amount of additional research is needed to be able to clearly define the role of the ocean in dictating the weather and climate of the Earth.

Physical oceanographers also study the tides of the world which have direct bearing on human activity. While tidal generating forces are clearly linked to the periodic behavior of celestial bodies the response of the ocean to these forces is very much dependent on the physical boundaries of the ocean (coastlines and the ocean bottom). Shallow water tides are very non-linear and their response presents a complex problem for study. Tides are also thought to give rise to phenomena such as internal waves that are also studied by physical oceanographers. Other ocean waves are also another large area of study for physical oceanographers. These waves range from surface capillary waves, directly driven by the wind and surface tension, through the well-known surface gravity waves (gravity versus buoyancy) to planetary …

Rossby waves driven by the Coriolis force and the horizontal pressure gradient (a function of the spatial distributions of temperature and salinity). Surface gravity wave behavior has interested physical scientists for generations presenting another non-linear problem for them to solve.

Throughout history and more so in modern times, physical oceanography has also included theoretical or dynamical studies aimed at explaining phenomena observed by the measurement community. Early on, these theoretical studies were all analytical mathematical models of some particular physical behavior of the ocean. Tides in particular lent themselves to analytical modeling while some of the earliest models of ocean circulation were analytical in nature and were focused on explaining some particular aspect of ocean currents. The introduction of digital computing revolutionized these theoretical studies making it possible to simulate increasingly complex aspects of the ocean using numerical methods. Today numerical simulations range from fairly simple models focused on a particular aspect of the ocean to large “primitive equation models” designed to simulate entire oceans in terms of all their physical and dynamical characteristics. Digital computing also revolutionized the observational community making it possible to analyze increasingly larger data sets generated by electronic sensors and their modern electronic recording systems. Even these systems, however, are not able to provide the space/time resolution to properly connect the physical ocean to the overlying atmosphere. Still, with all of this modern technology insight into the behavior of the ocean requires the skills of a seasoned practitioner of the physics of the ocean.

Taken together these many aspects of physical oceanography amount to a rather large domain of scientific questions that needs to be answered in order to really understand an important part of our planet. It is the physics of the ocean that ties the ocean to all of the other marine science disciplines that are linked to the ocean. In the subsequent chapters we will review these various topic areas in greater detail to understand just how physical oceanographers gain insight into the way ocean physics contributes to improvements in life on this planet. We will demonstrate the relevance of ocean research to the well-being of man on the Earth.

2.0 HISTORICAL DEVELOPMENT

Physical oceanography is a fairly young science being recognized as such around the beginning of the 20th century. As a science the earliest practitioners came from disciplines such as physical geography and geophysics. Many of the earliest discoveries that fed into physical oceanography were basic physics studies of Earth's science problems by early physicists and mathematicians. Newton's gravitational law was essential for understanding the tides in the ocean and LaPlace's theory directly addressed a description of the nonlinear tides. Stokes, a British mathematician worked on a theory of surface waves and demonstrated how waves actually slowly transport ocean water shoreward.

2.1 Benjamin Franklin

One of the earliest results of studying the ocean came from Benjamin Franklin who on his many voyages to Europe realized that some were rather quick while others took a long time. He assumed, correctly, that a strong current flowed from west to east and that ships could take advantage of this current and greatly shorten their transit times while ships that tried to sail against this current would greatly increase their transit times. He augmented his observations of ship travel with measurements of sea surface temperature made by collecting a surface sample of sea water in a wooden bucket and then measuring its temperature. He also observed the abrupt changes in surface conditions that were consistent with the changes in sea surface temperature. Much of these surface condition changes were due to the collection of Sargassum weed in the areas unaffected by the strong current.

Working with his cousin, a whaling captain, Captain Folger, Franklin published a map (Fig. 2.1) designating the strong current as the Gulf Stream. In this map he showed the area of the Gulf Stream and advised ship captains to sail at one latitude going east to get a boost from the Stream and another latitude headed west to avoid the Gulf Stream altogether. He suggested that if they found themselves not making much progress going west they should first sail south to get out of the stream and then try going west again. It is not recorded whether or not the ship captains followed his advice.

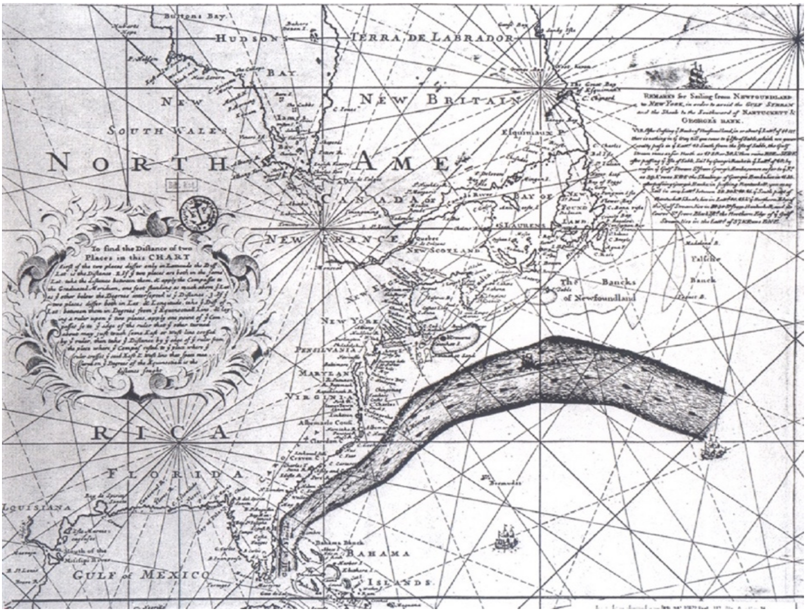

Fig. 2.1 Franklin-Folger map of the Gulf Stream. (Courtesy of Phil Richardson, WHOI)

2.2 Naturalists at Sea

Another source of early sea going scientific information was the role of "naturalists" who rode along on British exploring expeditions. One of the best known was Charles Darwin who went along on the HMS Beagle on a voyage to chart the southeast coast of South America. These naturalists were wealthy individuals interested in science and paid for their own accommodations on the ship. Fortunately, Darwin was married to a member of the Wedgewood Family who made their fortune on fine porcelain ware. So Darwin could afford to go along as the naturalist on this voyage of exploration and charting.

While we know Darwin mostly for his theory of the Origin of Species, his first paper resulting from the expedition was a paper that correctly explained the formation of coral atolls which were fringing reefs around a central land mass that had long since sunk beneath the sea surface leaving only the reefs above the surface. The development of his ideas on the origin of species stemmed from his collection of fossils of extinct species that were allied to living species on the same continent. These specimens were collected during his many trips to the South American interior while the ship continued its charting. Darwin began to wonder if species were constant or indeed evolved over time. In March 1837 ornithologist John Gould announced that Darwin's rhea (a flightless bird) was a separate species from the previously described rhea.

Darwin began speculating, in a series of notebooks, that one species does not change into another to explain these findings but rather the species evolves into the next species. Darwin began to sketch an evolutionary tree. Along the way he incorporated the idea that if a race is left to grow unchecked it will reach a point where it will struggle to survive. Darwin applied this to all life and added to his theory of evolution the principle of natural selection which is also known as survival of the fittest.

2.2.1 Naturalist Observers

There were so many naturalists traveling on British exploration ships in the early 1800's that the Royal Society in London decided to create a suite of measurement tools that these naturalists could use while at sea to collect ocean measurements. The then secretary of the Royal Society, Sir Robert Hooke, was commissioned to develop a suite of instruments that all naturalists would carry to make a uniform set of measurements at sea. One noteworthy device was an instrument to measure the depth of the ocean. It consisted of two balls, one wood and one made of iron. The pair were tossed into the sea, noting the time of deployment and when the pair hit the bottom the wooden ball would be released and float back to the surface where it would be spotted and returned to the ship. The time of transit down and up would give you an estimate of the depth of the ocean.

This system demonstrated that Hooke had spent very little time at sea. When, and if, the wooden balls hit the surface they were very hard to spot and when they were spotted nobody could say how long they had already been at the surface before being spotted. In addition the air spaces in the wood would compress at great depths and the wooden balls would lose their buoyancy and stay at the bottom. Complaints from many of the naturalists backed up by the ship captains, put an end to the use of this system for depth measurement and we had to wait till the early 20th century for the demonstration of an acoustic method to measure depth which would then become the standard method for measuring ocean depths.

Other systems were not so controversial as Hooke's depth system and many measurements of sea surface temperature and observations of wind and cloud were made by the naturalists and by the ship's officers. These measurements later became routine for any ship operating on the ocean and the observations comprise the global sea surface measurements in use even today.

2.3 Organized Expeditions

2.3.1 U.S. Exploring Expedition

In the early 19th century the U.S. Congress had the navy organize and execute the United States Exploring Expedition (1838-1842) with the intention of collecting oceanographic data all around the world. Many of the backers of this expedition saw it as a potential economic boon but others decried the lack of scientific involvement in the expedition. The leadership of the expedition was first assigned to Commodore Thomas Catesby Jones. Funding was initially requested by President John Quincy Adams in 1828 but Congress would not supply funding until 8 years later. In 1836 Congress authorized the expedition and the order was signed by then president Andrew Jackson.

The leadership had been transferred to U.S. Navy lieutenant Charles Wilkes, which is why the expedition became known as the Wilkes Expedition. The expedition was important in the U.S. for the young science of oceanography. During the expedition armed conflict broke out between the expedition and Pacific Islanders and dozens of natives were killed along with a few Americans. Unlike later expeditions this expedition used six ships, the sloops-of-war USS Vincennes (780 tons), the USS Peacock (650 tons), the brig USS Porpoise (230 tons), the fully rigged USS Relief, which served as a store ship and two schooners USS Seagull (110 tons) and the USS Flying Fish (96 tons) which served as tenders. On the afternoon of August 18, 1838, the vessels weighed anchor and set to sea under full sail. The expedition managed to circumnavigate the globe and transit the major ocean basins (Fig. 2.2.).

While the expedition is not known for dramatic scientific discoveries one unique aspect is its discovery of the Antarctic Continent. On Jan. 16, 1840 Henry Eid and William Reynolds aboard HMS Peacock sighted Eid Peak and Reynolds Peak (named after them) along the George V. Coast. On Jan. 19 Reynolds also spotted Cape Hudson and on Jan. 25 people on the Vencennes sighted the mountains behind the Cook Ice Shelf. The expedition covered 800 miles of Antarctic coastline by Feb. 12 going from 140° 30’ E to 112° 16’ E. They initially named this “Termination Land” but later referred to it as “Wilkes Land.”

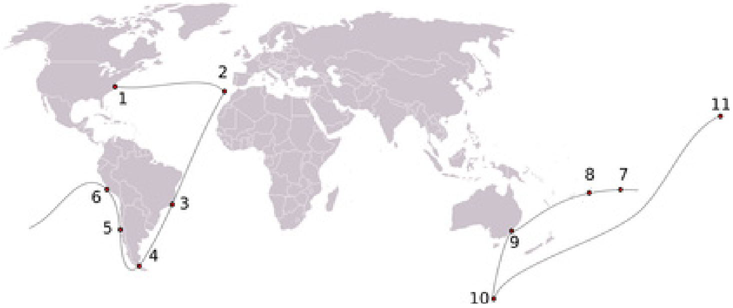

Fig. 2.2 Voyage route: 1. Hampton Roads – 2. Madeira – 3. Rio de Janeiro – 4. Tierra del Fuego – 5. Valparaíso – 6. Callao – 7. Tahiti – 8. Samoa – 9. Sydney – 10. Antarctica – 11. Sandwich Islands (via Fiji).

It was later conceded that what they had found was Antarctica which had been found earlier by international explorers. The first of these was a Russian expedition which on Jan. 27, 1820 sighted a solid ice shelf, which became known as the Fimbul Ice Shelf. This was 3 days before Edward Bransfield (a captain in the Royal Navy) sighted land and 10 months before a sealer Nathaniel Palmer (from Stonington, Connecticut) did so in Nov., 1820.

The first documented landing in Antarctica was by the American sealer John Davis at Hughes Bay near Cape Charles in West Antarctica on Feb. 7, 1821, but some historians dispute his claim. The first recorded and documented landing was at Cape Adair in 1895 by the Norwegian-Swedish whaling ship the Antarctic. On 22, Jan., 1840, 2 days after the discovery of the Antarctic coast west of the Balleny Islands, some members of the crew of the 1837-40 expedition of Jules Dumont d'Urville disembarked on the highest Islet of a group of rocky coastal islands about 4 km from Cape Geodesie on the coast of Adelie Land. As mentioned earlier the U.S. Exploring Expedition also encountered the Antarctic Continent in 1840 where they named the coast of the Antarctic Continent west of the Balleny Island "Wilkes Land," a name it retains to this day.

During a later portion of the U.S. Exploring Expedition they ran into troubles with the Gilbertese natives which led to armed conflict during which many natives and a couple of Americans were killed. A similar incident occurred a bit earlier in Samoa when the Flying Fish and the Peacock briefly bombarded the island of Upolu, Samoa following the death of an American sailor on the island. Leaving the tropical Pacific the expedition then headed north to the coast of the U.S. where the Peacock went aground when trying to enter the Columbia River and was soon lost, though with no loss of life. The crew was able to launch six boats and get everyone into Baker's Bay along with their journals, surveys, the chronometers and some of the artist's sketches.

The expedition was plagued by the poor relationships between Wilkes and his subordinate officers throughout. Wilkes's self-proclaimed status of captain and commodore, accompanied by him wearing a captain's uniform, while being commissioned only as a Lieutenant, rankled the other members of the expedition with similar rank. Wilkes's apparent mistreatment of many of his subordinates, his indulgence in punishments such as "flogging round the fleet" resulted in a major controversy upon his return to America. Wilkes was court-martialed on his return, but was acquitted on all charges except that of illegally punishing men in his squadron. In addition, the expedition's scientists were derisive called "claim diggers" and "bug catchers" by the navy crew members, which reveals a very negative relationship between the navy personnel and the scientific personnel.

In spite of this poor relationship 280 islands (mostly Pacific) were explored and more than 800 miles of the Oregon coast were charted. A total of 60,000 plant and bird specimens were collected including the seeds of 648 species, which were later planted and spread across the country. There were also 254 live plants, mostly from the home stretch of the journey, that were planted and grown in newly constructed greenhouses in the U.S. which later became the basis for the U.S. Botanical Garden. Alfred Thomas Agate, engraver and illustrator, created an enduring record of traditional Pacific island cultures. A collection of artifacts from the expedition also went to the National Institute for the Promotion of Science, a precursor of the Smithsonian Institution. From 1844 to 1961 Wilkes was engaged in the preparation of the expedition report. Twenty-eight volumes were planned but only nineteen were published. Unfortunately, the mismanagement that plagued the expedition prior to departure continued after its completion and much of these publications were lost or misplaced along with the many specimens that had been collected resigning this large expedition to the fate of being one of the least known in history.

2.3.2 The Challenger Expedition

In strong contrast the single ship British "Challenger" expedition became one of the best-known ocean expeditions which reflected the importance of science in the expedition before, during and after the three-year global expedition (1872-1876). Motivated by a desire to learn if the claim by a British naturalist (Edward Forbes) that there was no life in the ocean below 600 m, which Forbes referred to as the "azoic zone," was true or not; the University of Edinburgh biologist Charles Wyville Thomson convinced a colleague William B. Carpenter that they should mount an expedition to prove or disprove this theory in the world ocean. Carpenter was a medical doctor and an amateur biologist who strongly supported Thomson in this desire.

They managed to secure financial support from the British Royal Society in London who obtained the use of the HMS Challenger from the Royal Navy and arranged to alter the ship removing her 17 cannons and equipping her with separate laboratories for natural history and chemistry. A separate deep dredging facility was installed for sampling the very deep ocean. This ship itself was a British Naval Corvette (Fig. 2.3). The expedition was under the overall command of Captain George Nares and the ship's crew were all part of the Royal Navy. The original ship's compliment was 21 officers and 216 crew members. By the end of the voyage this had been reduced to 144 due to deaths, desertions and personnel left ashore due to illness or planned departures.

Fig. 2.3 The HMS Challenger.

The ship was a sailing vessel and steam power was used primarily to power the winch for the deep sea dredge. She was loaded with sample bottles, thermometers, microscopes, chemical apparatus, trawls, sampling bottles, sediment grabs, dredges, barometers and sounding leads. In short, it carried all of the instruments that were current with their time of operation. For sounding she carried 181 miles of Italian hemp.

The ship left Portsmouth in December of 1872 and returned in 1876 after having circumnavigated the globe. She travelled 68,890 nautical miles (79,280 mi; 127,580 km) and collected 492 deep sea soundings, 133 bottom samples, 151 open water trawls and 263 serial (vertical profiles) water temperature observations. It should be noted here that the reversing thermometers, which made it possible to lock in a temperature at depth, had not yet been invented yet so they used a min-max thermometer that would allow you to observe the minimum and maximum temperature experienced in the water column (Fig. 2.4).

From the biological samples about 4,700 new species of marine life were discovered. Thomson and Carpenter were able to clearly demonstrate that life in the ocean existed even to the greatest depths of the open ocean. The dredge used to sample life at the bottom was a simple beam attached to a bag-like net to catch the samples dislodged from the bottom (Fig. 2.5)

Water samples were collected with a bottle that trapped its sample when it rotated activated by a weighted “messenger” sent down the wire, which then released another messenger to active the next bottle on the wire (Fig. 2.6)

Bottom sediment samples were collected with a grab sampler but also with a core device (Fig. 2.7).

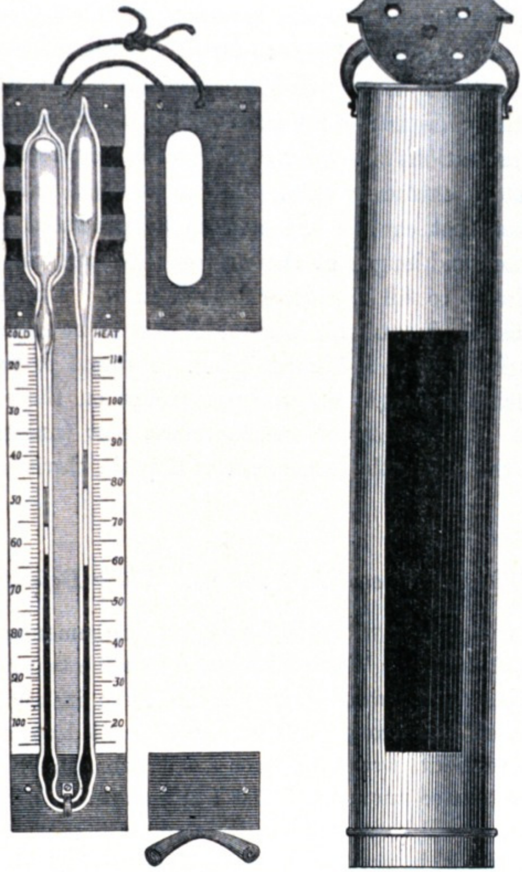

Fig. 2.4 Min-max thermometers used on the Challenger Expedition.

FIG. 17.—The Dredging and Sounding Arrangements on board the 'Challenger.'

Fig. 2.5 Dredging and sounding arrangements on board the Challenger.

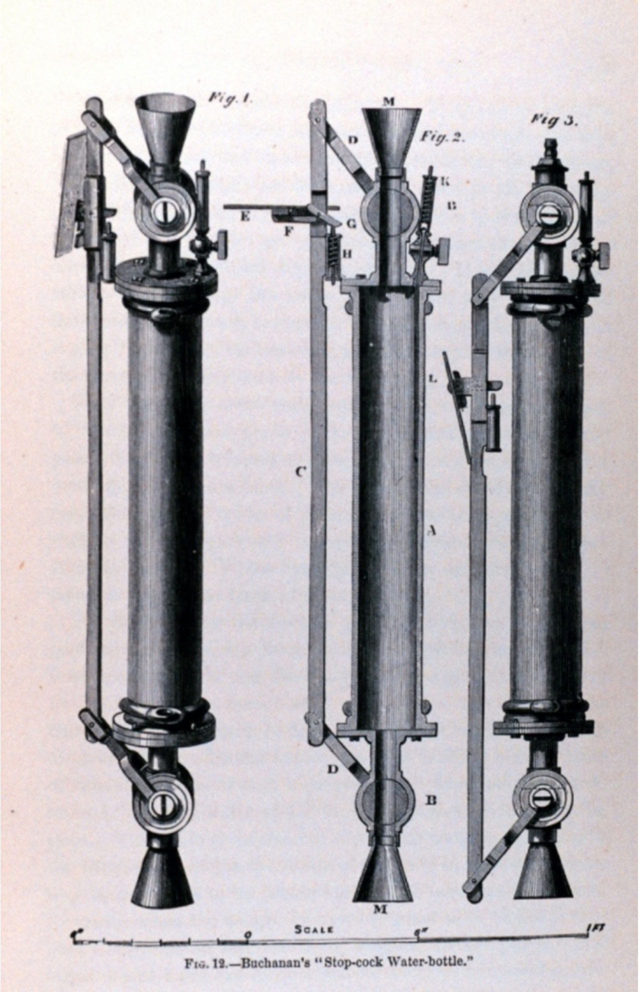

Fig. 2.6 Water sampling bottles used on the Challenger Expedition.

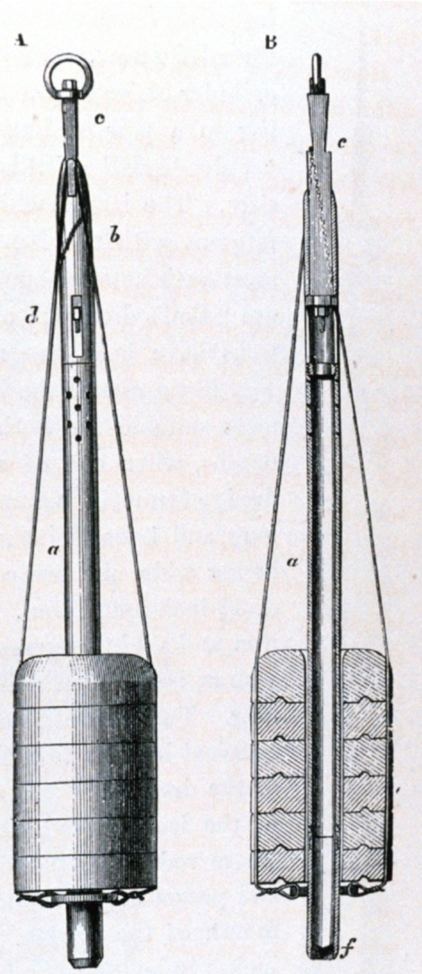

FIG. 14.—The Baillie Sounding Machine.

Fig. 2.7 The bottom sediment coring device used on the Challenger.

The six civilian staff/scientists under the direction of Wyville Thomson included the naturalists John Murray, Alphonse F. Renard, Rudolf von Willemoss-Suhm and Henry N. Mosely, the chemist/physicist John Y. Buchanan and the official artist J.J. Wild. Of course Thomson's colleague William B. Carpenter was along for the entire voyage.

The Challenger’s course of travel (Fig. 2.8) took her to all the major oceans of the world and allowed her to make repeated samples of the Atlantic.

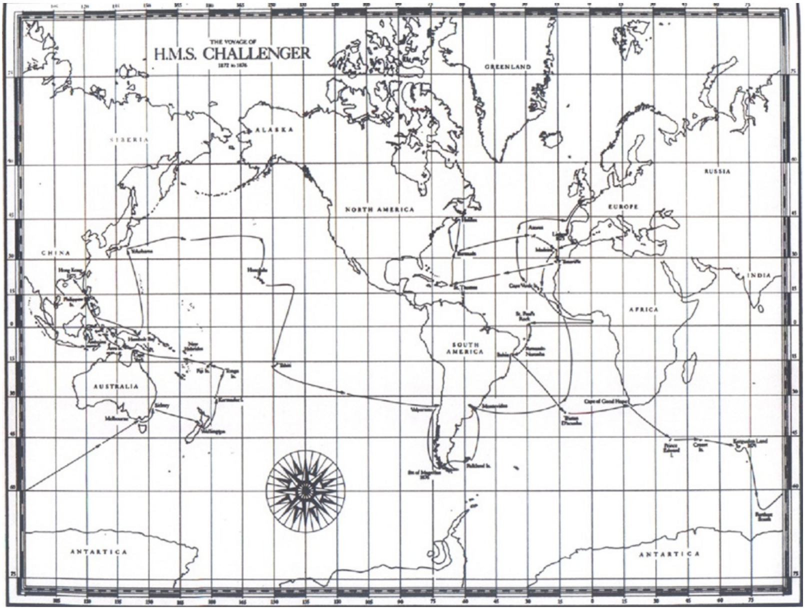

Fig. 2. 8 Cruise track of the Challenger Expedition.

The addition of John Murray, who was a Canadian student at the University of Edinburgh, was very fortuitous as he recognized the value of the phosphate that made up Christmas Island as a source of fertilizer. Claiming the island for the British crown he later returned to set up mining operations and a large part of the income from the phosphate mining was used to publish the Challenger reports as the expedition itself had run out of money. The youngest scientist was a twenty-five-year-old German naturalist Rudolf von Willemoës-Suhm who gave up a position at the University of Munich to join the expedition. Henry Nottidge Moseley was another British naturalist who had also studied both medicine and science and had just completed a government sponsored expedition to Ceylon.