# USNS *Eltanin's* 55 Cruises-Scientific Accomplishments

LUIS R. A. CAPURRO
*Intergovernmental Oceanographic Commission*
UNESCO, *Paris*

This issue of *Antarctic Journal of the United States* summarizes the scientific accomplishments of one ship's antarctic oceanic research. USNS *Eltanin* spent the 10½ years between July 5, 1962, and December 29, 1972, in a systematic, multidisciplinary survey of some 80 percent of the southern ocean between 35°S. and the antarctic continent. The cover of this journal maps the cruises, which totaled over 400,000 miles; a table (p. 60-61) lists their dates, locations, and purposes.

The National Science Foundation sponsored these 52 cruises (plus three more northerly test cruises) as part of its United States Antarctic Research Program. As a result of new U.S. government policy, the Foundation was obliged for financial reasons to stop operating the 266-foot ship, and she was placed in ready reserve. At this writing, *Eltanin* is tied to a dock in San Francisco Bay. Her future is uncertain, but ways are being sought to send her back to sea.

The significant contributions of *Eltanin* to our knowledge of the oceanography and marine biology of the southern ocean are recorded in 14 of the 20 volumes of the *Antarctic Research Series,* in five of the 16 folios of the *Antarctic Map Folio Series,* and in the numerous papers published in scientific journals and periodicals. These publications provide valuable new information on the physical oceanography, marine geology and geophysics, marine biology, chemistry, solar radiation, and meteorology of the waters surrounding Antarctica. These contributions are discussed in the succeeding articles.

To understand the full impact of *Eltanin's* appearance on the antarctic scene, one must take into account the opportunities the ship has offered the scientific community in advancing our understanding of the antarctic seas. The year-round presence of such a well equipped research ship in southern polar waters marked a new era in antarctic oceanography.

Dr. Capurro is assistant secretary for long-term and expanded programs of oceanic exploration and research (LEPOR). Formerly he was Professor of Oceanography, Texas A & M University. He also has been Director of the Argentine Hydrographic Office.

Although scientific exploration of the antarctic seas dates to the 1839-1843 *Erebus* and *Terror* expeditions under Sir James Clark Ross, it was the *Discovery* investigations, which began in 1925, that ushered in a new era of research. These investigations were primarily concerned with whales and whaling, studies of practically all the factors influencing their migration, food and feeding habits, breeding cycle, but they led to an intensive program of physical, chemical, and biological oceanography. Other expeditions followed, such as those of the *Meteor* and the *Gauss,* but the credit goes to *Discovery* for initiating a continuous program. When the *Discovery* investigations terminated before the outbreak of World War II, systematic study of the southern ocean came to an end. Subsequent scientific programs were carred out on a lower priority by supply vessels calling at antarctic stations during the austral summer.

Initiation of the *Eltanin* programs was a landmark in the scientific exploration of the southern ocean of no less significance than that of the *Discovery.* While the *Discovery* whale investigations were misson-oriented, the *Eltanin* programs encompassed every facet of research of the circumpolar waters and their relationship to the world ocean. The principal features in the United States Antarctic Research Program strategy with regard to the investigations of the antarctic ocean are—

(1) *Eltanin,* being a national research facility, was to be made available to any institution in the United States wishing to undertake oceanographic work in the southern ocean within the objectives established by the National Science Foundation.

(2) The ship was to circumnavigate the Antarctic continent.

(3) Scientific programs were required to be long range in scope and, desirably, comprehensive. Special short-term scientific programs also were to be supported.

In the papers that follow, many of the principal investigators whose work has been closely associated with *Eltanin* review the significant accomplishments made in physical oceanography, marine biology, geology and geophysics, paleontology, and meteorology. Support facilities for specimen storage and bottom photography also are reviewed.

### Physical oceanography

A main objective of the physical oceanography programs aboard *Eltanin* was to improve our understanding of the circulation of the southern ocean. Studies were conducted on the physical and chemical characteristics of the water masses with emphasis on the influence of bottom topography on current patterns and direction. The *Eltanin* array of modern oceanographic data has enabled physical oceanographers to expand earlier concepts and to develop many new concepts dealing with antarctic waters. Throughout many of her cruises, *Eltanin* has provided valuable oceanographic data for the region extending westward from the Scotia Sea to the Kerguelen Islands. The remaining area of the southwest Indian and southwest Atlantic sectors of the Antarctic is known only in very general terms. Here are some of the recent advances in our knowledge of antarctic oceanography made possible through *Eltanin* data.

- Antarctic Bottom Water (ABW) is produced in the Ross Sea, the Adélie Coast region, and the Weddell Sea; it is produced by escaping shelf water in short periods of time, not necessarily during winter.
- ABW enters the Scotia Sea and southern Drake Passage via a passage at 40°W. in the Scotia Ridge east of the South Orkney Islands.
- The Polar Front (Antarctic Convergence) varies in intensity and structure to depths up to 1,000 meters.
- The front extends to the south of 60°S., south of the Campbell Plateau.
- The Antarctic Circumpolar Current (ACC) is composed of a variety of currents, some narrow with well defined axes, some broad with ill defined structure.
- ACC has a volume transport in excess of 2 x $10^{18}$ $m^3$/sec.

Other major oceanographic accomplishments are discussed by Gordon below and were published in Volumes 15 and 19 of the *Antarctic Research Series.*

### Marine geology and geophysics

This research consisted of continuous surveys of bathymetry, sediment thickness, and magnetic and gravity fields. The field observations taken were: precise depth recording, continuous reflection seismic profiling, seismic refraction with sonobuoys, total intensity magnetic field with nuclear precision magnetometer, continuous gravity measurements, heat-flow determination, rock dredging, deep-sea cores, bottom photographs, and nepheloid layer measurements.

*Eltanin* has been responsible for the majority of the data on marine geology and geophysics for the oceanic areas south of about 35°S. Although the southern ocean was one of the last to be systematically explored, the findings in the South Pacific were instrumental in firmly establishing the reality of sea floor spreading and plate tectonics. These concepts have led to a revolution within the earth sciences that is unparalleled in its 200-year history. Further, the South Pacific was the first large oceanic area where magnetic anomalies could be recognized, correlated, and related to records of terrestrial magnetic reversals and models of sea floor spreading. This work was done almost exclusively on the strength of the *Eltanin* magnetic and topographic data. The discovery of such major features of the sea floor as the Chile Ridge, the Eltanin Fracture Zone-Louisville Ridge, the Southward structural continuation of the Peru-Chile Trench, the complex tectonic expression of the Scotia Area region, were all significant in formulating the early concepts of plate tectonics. More recently, major new discoveries have been reported for the area of the southeast Indian Ocean (Hayes, personal communication). These findings are summarized in volume 19 of the *Antarctic Research Series.* More information on *Eltanin's* marine geology and geophysics programs is presented below in articles by Watkins, Hayes, and Bandy.

### Marine biology

Biological investigations of the seas surrounding Antarctica were accepted as a major task in the planning and developing of the U. S. national antarctic research program. The expensive conversion of the *Eltanin* for antarctic work in 1960 and 1961 included a specially designed laboratory for experimental biological studies at sea as well as provisions for overside fishing and dredging. The basic goals of the biological programs on the *Eltanin* can be summarized as follows:

- Gathering of quantitative data on primary organic production of antarctic and subantarctic waters.
- Assessing of the standing stock of all ecologically important trophic levels, ranging from bacterial cells through the largest fish and mammals.
- Understanding the rate of flow of organic carbon (or energy) throughout all levels of the food chain.
- Assessing of respiratory and excretary losses of organic materials in each trophic level.
- Understanding the trophodynamics of the entire food chain in antarctic waters.

- Evaluating the mineralization processes occurring in antarctic waters.
- Describing the distribution of organic materials throughout the entire water column.
- Understanding the basic physiology and biochemistry of organisms growing in unique antarctic conditions.

As shown in El-Sayed's article below, these goals and objectives have changed during the decade of 1962 to 1972, having begun with the collecting and exploratory stage and culminated with more sophisticated and highly integrated programs designed to study the total antarctic ecosystem. Notable among these programs are those pertaining to physiology and biochemistry (discussed by McWhinnie). Of the estimated 511 new species compiled below by Hedgpeth (a little over 11 percent of the number of species discovered by HMS *Challenger* a hundred years ago) 15 species were named for *Eltanin*.

### Meteorology and solar radiation programs

Shipboard meteorological programs focused on collecting precise measurements near the sea surface and in the upper atmosphere. These observations were carried out on almost all the 55 cruises, in which daily radiosonde flights were made. During some of the cruises carbon-dioxide samples were obtained for the National Bureau of Standards and hourly surface observations were made during selected frontal passages for the International Antarctic Meteorological Research Center in Melbourne. Commencing with Cruise 35, a unique cooperative program between Australia and the U. S. National Weather Service has resulted in an agreement whereby Australian personnel would operate the shipboard meteorological program. Below, Zillman and Dingle discuss this program.

Another area of cooperation also developed between the meteorological and the marine biologists. Since primary organic production in the sea is, in part, a function of the radiant energy, a knowledge of the spectral distribution of solar radiation that is made available to the water mass is basic to an understanding of organic production. In keeping with the integrated approach of the biological studies conducted aboard the *Eltanin,* a program to measure the quantity and quality of solar radiation entering the water was initiated during Cruise 46. Below, Franceschini discusses this program.

### An efficient platform

During the last decade, *Eltanin* has served as a very efficient platform for a wide spectrum of biological, geological, geophysical, chemical, physical, and meteorological studies. In spite of the considerable work already done by this ship, much work still lies ahead. It appears that the task of the scientific investigations of the southern ocean cannot be accomplished by only one ship, no matter how sophisticated her equipment and instruments


**The *Eltanin* in Washington, D.C., prior to her shakedown cruise and departure for Antarctica.**

*NSF*

may be. The advent of remote sensing (manned and unmanned) from aircraft and satellites may be of substantial help in this respect. In the meantime, as Watkins states in his article below, "The cruises have ceased, but the scientific returns will continue for decades to come, so, in this very real sense, *Eltanin* will continue to live and serve the scientific community."

---

## The 55 oceanographic cruises of USNS *Eltanin*

This is a listing of every *Eltanin* cruise from February 27, 1962, to December 29, 1972. The cruise number is followed by the dates of departure and arrival at port, the area covered, the length of the cruise track, the purpose of the cruise, and the principal investigator or U.S. Antarctic Research Program on-board representative.

Cruise 1. 2/27-3/9/62. Off eastern United States. Shakedown. Albert P. Crary and John T. Crowell.

Cruse 2. 3/15-4/16/62. North Atlantic and Labrador Sea. Second shakedown. A. P. Crary and John T. Crowell.

Cruise 3. 5/23-6/27/62. New York to Valparaíso via Panama Canal. United States and Chile. 3,799 nautical miles.* Continued testing, trawling. George R. Toney.

Cruise 4. 7/5-9/1/62. Valparaíso to Valparaíso. Drake Passage. 7,594 nautical miles.* Trawling, coring, bottom camera stations, current-meter buoy stations. George R. Toney.

Cruise 5. 9/10-11/15/62. Valparaíso to Valparaíso. Drake Passage. Bacteriology, hydrography, bathythermography, coring, rock dredging. George R. Toney.

Cruise 6. 11/24/62-1/23/63. Valparaíso to Punta Arenas. Drake Passage. Marine biology. George A. Llano.

Cruise 7. 2/4-3/19/63. Punta Arenas to Montevideo. Scotia Sea. 3,916 nautical miles.* Marine biology. George A. Llano.

Cruise 8. 4/1-6/19/63. Montevideo to Talcahuano. Scotia Sea. South Sandwich Trench investigation. Walter R. Seelig.

Cruise 9. 8/1-9/27/63. Talcahuano to Valparaíso. Argentine Basin and Scotia Sea. 9,364 nautical miles. Bathymetry and hydrography. John G. Colson, Jr.

Cruise 10. 10/6-12/6/63. Valparaíso to Valparaíso. Southeast Pacific. 7,770 nautical miles. Hydrography and plankton sampling. Robert W. Mason.

Cruise 11. 12/17/63-2/21/64. Valparaíso to Valparaíso. Southeast Pacific and Bellingshausen Sea. 9,143 nautical miles. Marine biology and coring. Philip M. Smith.

Cruise 12. 3/3-4/30/64. Valparaíso to Valparaíso. Weddell and Scotia Seas. 8,199 nautical miles. Hydrography and coring. Kendall N. Moulton.

Cruise 13. 5/13-7/13/64. Valparaíso to Wellington. Trans-Pacific. 7,286 nautical miles. Hydrography and coring. Kendall N. Moulton.

Cruise 14. 7/29-9/19/64. Wellington to Valaparíso. Trans-Pacific. 7,880 nautical miles. Bottom profiles. Robert W. Mason.

Cruise 15. 10/1-12/4/64. Valparaíso to Auckland. Trans-Pacific. 7,101 nautical miles. Trawling, sampling of waters, ocean bottom, and marine life, bottom topography. George R. Toney.

Cruise 16. 1/28-2/25/65. Auckland to Wellington. Tasman Sea. 4,572 nautical miles. Test submarine geophysical equipment. Philip M. Smith.

Cruise 17. 3/12-5/13/65. Wellington to Valparaíso. Trans-Pacific. 7,671 nautical miles. Hydrography and bathymetry. Merle R. Dawson.

Cruise 18. 5/24-6/16/65. Valparaíso to Talcahuano. Southeast Pacific. 4,065 nautical miles. Ocean stations and marine biological collecting. Merle R. Dawson.

Cruise 19. 7/6-9/3/65. Talchuano to Auckland. Trans-Pacific. 7,587 nautical miles. Marine biology, meteorology, physical oceanography, bottom photography, marine geology, cosmic radiation, vlf recording. Merle R. Dawson.

Cruise 20. 9/13-11/12/65. Auckland to Valparaíso. Trans-Pacific. 8,574 nautical miles. Hydrography, submarine geophysics. Albert P. Crary.

Cruise 21. 11/23/65-1/7/66. Valparaíso to Punta Arenas. Southeast Pacific. 5,796 nautical miles. Regular, sediment-core, and heat-flow stations. George R. Toney.

Cruise 22. 1/19-3/16/66. Punta Arenas to Punta Arenas. Scotia Sea. 6,508 nautical miles. Hydrography, trawling, coring. Harry W. Wells.

Cruise 23. 3/31-5/28/66. Punta Arenas to Auckland. Trans-Pacific. 7,330 nautical miles. Hydrography, marine geology and biology, ornithology, upper-atmosphere physics, meteorology, seismic and magnetic profiling. Charles L. Roberts, Jr.

Cruise 24. 7/9-9/9/66. Auckland to Valparaíso. Trans-Pacific. 7,150 nautical miles. Biology, marine geology, seismic profiling, hydrography, meteorology. USARP Representative: William T. Austin.

Cruise 25. 9/24-11/20/66. Valparaíso to Wellington. Trans-Pacific. 7,905 nautical miles. Marine biology and geology, hydrography, seismic profiling, meteorology, magnetics. USARP Representative: Albert P. Crary.

Cruise 26. 11/29-12/19/66. Wellington to Wellington. Tasman Sea. 2,345 nautical miles. Biology, oceanography, geology, geophysics. USARP Representative: Nicholas Vartzikos

Cruise 27. 12/31/66-3/1/67. Wellington to Melbourne. Ross Sea. 5,510 nautical miles. Seismic profiling, hydrography biological collecting. George A. Llano.

Cruise 28. 3/10-5/28/67. Melbourne to Valparaíso. Trans-Pacific. 9,112 nautical miles. Profiling. Bruce A. Warren.

Cruise 29. 6/1-8/2/67. Valparaíso to Brisbane. Trans-Pacific 8,692 nautical miles. Physical oceanography. Bruce A. Warren.

Cruise 30. 8/12-9/21/67. Brisbane to San Francisco. Trans-Pacific. 6,608 nautical miles. Hydrography, meteorology, surface-water sampling. Sayed Z. El-Sayed.

Cruise 31. 11/15-12/19/67. San Francisco to Dunedin. Trans-Pacific. 8,086 nautical miles. Mid-water trawling, geophysics, hydrography. Melvin L. Fields.

Cruise 32. 12/30/67-2/29/68. Dunedin to Wellington. Ross Sea. 8,864 nautical miles. Biological collecting, geophysics, hydrography, marine geology, meteorology. Kendall N. Moulton.

Cruise 33. 3/22-5/19/68. Wellington to Auckland. Southwest Pacific Basin. 6,869 nautical miles. Physical oceanography, plankton and bird collecting, geophysics, meteorology. T. B. Armstrong.

Cruise 34. 5/28-7/31/68. Auckland to Adelaide. Southwest Pacific. 8,044 nautical miles. Physical oceanography, geophysics, survey of benthic and pelagic vertebrates and invertebrates, distribution of plankton and birds, marine geology, meteorology. John R. Twiss, Jr.

* Based on possibly inaccurate pit log data.

Cruise 35. 8/12-10/8/68. Adelaide to Adelaide. Southwest Indian Ocean. 7,314 nautical miles. Marine geology, primary productivity, hydrography, trawling. Melvin L. Fields.

Cruise 36. 10/18-12/18/68. Adelaide to Wellington. Southeast Indian Ocean. 6,368 nautical miles. Primary productivity, zooplankton and phytoplankton studies, meteorology, geophysics, hydrography, marine geology. Walter Seelig.

Cruise 37. 1/10/69-3/3/69. Wellington to Melbourne. Southwest Pacific. 7,040 nautical miles. Physical oceanography, marine geology and geophysics. Arnold L. Gordon.

Cruise 38. 3/20-5/13/69. Melbourne to Melbourne. Southeast Indian Ocean. 5,237 nautical miles. Study of total metabolic processes of living organisms in the southern oceans. L. R. Pomeroy.

Cruise 39. 6/8-8/5/69. Melbourne to Auckland. Indian-Antarctic Ridge. 7,356 nautical miles. Marine geology and biology. USARP Representative: Merle R. Dawson.

Cruise 40. 9/15-11/21/69. Auckland to Lyttelton. Pacific Ocean. 10,600 nautical miles. Hydrography. Bruce A. Warren.

Cruise 41. 12/20/69-2/16/70. Adelaide to Adelaide. South Indian Ocean. 9,581 nautical miles. Deep-sea tides. Frank E. Snodgrass.

Cruise 42. 2/28-4/11/70. Adelaide to Punta Arenas. Trans-Pacific. 8,391 nautical miles. Geophysics, meteorology. Robert E. Houtz.

Cruise 43. 4/20-6/4/70. Punta Arenas to Wellington. South Pacific. 8,218 nautical miles. Geophysics, meteorology, hydrography. Dennis E. Hayes.

Cruise 44. 6/24-8/18/70. Wellington to Fremantle. South Pacific. 8,431 nautical miles. Hydrography, bottom coring, geophysics, meteorology, bathythermography. Arnold L. Gordon.

Cruise 45. 9/9-10/28/70. Fremantle to Fremantle. Southern ocean between Western Australia and Wilkes Land. 6,459 nautical miles. Marine geology and geophysics; physical oceanography; meteorology. Lawrence A. Frakes.

Cruise 46. 11/20/70-1/20/71. Fremantle to Fremantle. Southern ocean between Western Australia and Wilkes Land. 7,200 nautical miles. Biological oceanography. Sayed Z. El-Sayed.

Cruise 47. 2/3-4/13/71. Fremantle to Melbourne. Indian Ocean. 10,899 nautical miles. Geophysics, physical oceanography and geochemistry, bottom sampling. USARP Representative: Robert Houtz.

Cruise 48. 6/28-8/19/71. Newcastle to Fremantle. Mid-Indian Ridge, 7,838 nautical miles. Hydrology, geophysics, meteorology. Norman D. Watkins.

Cruise 49. 8/31-10/27/71. Fremantle to Fremantle. South and west of Australia. 7,399 nautical miles. Geophysics, hydrography, coring. Kenneth L. Griffiths, Jr.

Cruise 50. 11/7-1/3/72. Fremantle to Lyttelton. Tasman and Ross Seas. 7,447 nautical miles. Physical oceanography, geophysics, coring. Arnold L. Gordon.

Cruise 51. 1/17-2/25/72. Lyttelton to McMurdo Station. Ross Sea. 4,550 nautical miles. Biology. Mary Alice McWhinnie.

Cruise 52. 2/28-3/27/72. McMurdo to Lyttelton. Ross Sea shelf. 5,395 nautical miles. Geophysical surveying. Robert Houtz.

Cruise 53. 4/10-6/9/72. Lyttelton to Fremantle. Southeastern Indian Ocean. 11,400 nautical miles. Geophysics. Thomas D. Aitken.

Cruise 54. 6/20-9/7/72. Fremantle to Newcastle. Southeastern Indian Ocean. 12,300 nautical miles. Geophysics, physical oceanography, and sediment coring. Rude G. Markl.

Cruise 55. 10/27-12/27/72. Newcastle to Port Lewis. Southern Indian Ocean. 6,745 nautical miles. Submarine geology, physical oceanography, marine geophysics. Bruce C. Heezen.

# Physical Oceanography

ARNOLD L. GORDON
*Lamont-Doherty Geological Observatory*
*Columbia University*

The divergent Ekman drift and thermohaline alterations of the circumpolar waters, fostered by the compact landmass of Antarctica, sets up a meridional circulation pattern that reaches far to the north, below the main thermocline. This pattern has two basic components: the transformation of upwelling deep water to Antarctic Surface Water and ultimately into Antarctic Intermediate Water and Antarctic Bottom Water. For the intermediate water the formation region is believed to be the Polar Front Zone (Antarctic Convergence), and for the bottom water the formation zone appears to be within the continental margins. Estimates of heat and salt balances suggest that the northward flowing bottom water contributes nearly 40 million cubic meters per second to the world ocean, and the intermediate water supplies perhaps as much as 20 million cubic meters per second (Gordon 1973a).

The meridional velocity field is superimposed on a strong zonal flow that probably extends to the sea floor with relatively small attenuation. The zonal flow is directed eastward north of the low atmospheric pressure trough surrounding Antarctica and westward between the trough and Antarctica. The eastward flow, called the Antarctic Circumpolar Current (ACC) or West Wind Drift, is by far the stronger and most probably accomplishes the largest transport of water of the ocean's currents, over 200 million cubic meters per second (Gordon 1967a, Reid and Nowlin 1971, Callahan 1971). The effect of bottom topography is clearly observed in the path and structure of the deep reaching circumpolar current (Gordon and Bye 1972), which is more diffuse over basins and very well defined as it transverses passages. In places the current may be multi-axial.

The asymmetry of Antarctica to the earth's spin axis and the bottom morphology create large variations in the circulation pattern with longitude and permit development of large cyclonic gyres within the Weddell Basin and southeast Pacific basins (northeast of the Ross Sea). Within these gyres may occur the bulk of the upwelling of the Circumpolar Deep Water (Gordon 1971a), though some upwelling probably occurs all about Antarctica.

The scientific importance of antarctic oceanog-

Lamont-Doherty contribution number 1996.