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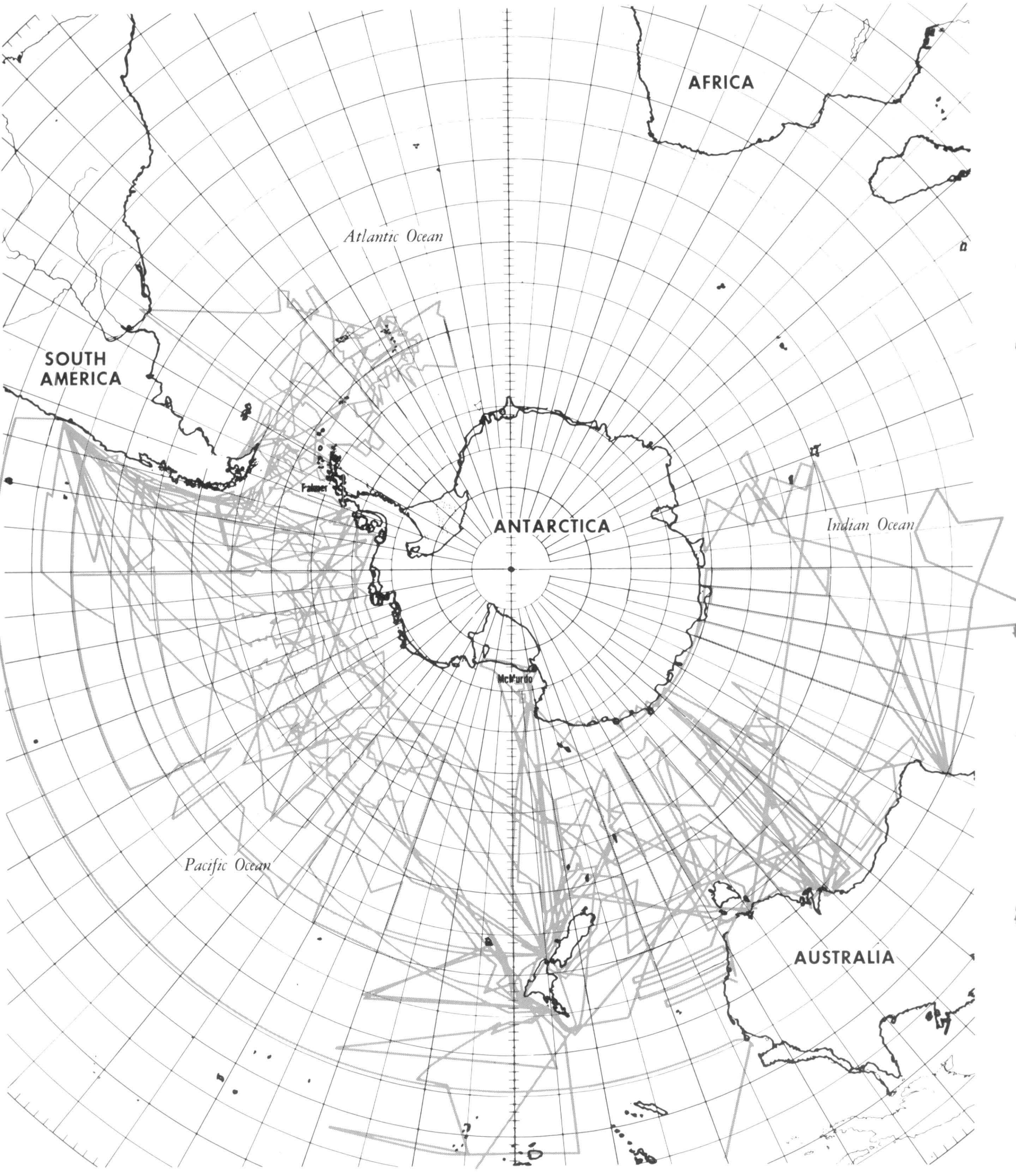

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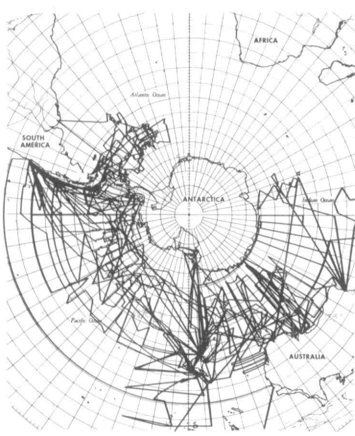

COVER

Tracks of the USNS *Eltanin's* 55 cruises for the U.S. Antarctic Research Program, between July 5, 1962, and December 29, 1972.

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Contents

USNS *Eltanin's* 55 Cruises-Scientific Accomplishments

LUIS R. A. CAPURRO
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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 end 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.

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* Based on possibly inaccurate pit log data.

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.

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

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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.

raphy coupled with the problems of working in the vast area of the polar and subpolar regions, where storms and ice present real hazards, has led to the expedition style of oceanography, *i.e.,* commitment of scientists and a well-equipped ship for extended periods. Where regional oceanography is fairly well known, short cruises can be fruitful, but our knowledge of antarctic waters at the beginning of the 1960s was quite general. Most data and ideas had been generated by the *Discovery* expeditions, mainly during the 1930s; the basic physical oceanographic findings were reported in the *Discovery Reports* (Deacon 1933, 1937, 1963; Mackintosh 1946, and many others). During the IGY period, many nations collected much new data in antarctic waters (see Capurro, 1964) and somewhat refined our understanding, but big gaps remained. These gaps were not confined to the obvious lack of winter continental margin data and other regions and times of ice, but to winter and summer measurements in the open sea in areas where ice was not a great problem.

Eltanin in 1962 began a major year-round United States antarctic oceanographic expedition to fill the data gaps in the open sea and fringes of the pack ice fields. As this was accomplished for the Pacific sector, more cruises were devoted to special problems, as Antarctic Bottom Water (AABW) production, ACC path, and polar front studies. While the beginning cruises employed quite classical instrumentation, eventually the equipment became more modern with the advent of the *in situ* electronic salinity-temperature-depth (STD) systems, timed release bottom-moored current meters, nephlometers, expendable bathythermographs (XBTS), and in addition to the Nansen casts, mechanical bathythermography and surface temperature recorders. The deck equipment was improved with the auto-analyser for nutrient determinations and Carpenter modification of the Winkler titration method for oxygen determination, with data processing and equipment monitoring facilitated by an onboard computer system. On many cruises the physical oceanographic data array was expanded to include sampling for trace metals and radioisotope concentrations. The station physical oceanographic data collected aboard *Eltanin* from Cruises 7 through 55 are reported in Jacobs (1965, 1966), Jacobs and Amos (1967), and Jacobs *et al.* (1972). The information of Cruises 4 to 6 is in Friedman (1964). Cruises 28 and 29 (the Scorpio Expedition) were in subtropical waters and are reported in Scripps Institution of Oceanography *et al.* (1969).

The hydrographic station array, with a high percentage reaching near the deep sea floor, extends from the Scotia Sea and northern Weddell Sea westward to the longitude of Kerguelen Island. When the program was terminated, in 1972, about 100° of longitude in the southwestern Indian and southeastern Atlantic Oceans had not been covered by the *Eltanin* data network. The antarctic oceanographic data of *Eltanin* has already contributed much to our understanding in each of the major processes with Antarctic waters: Antarctic Circumpolar Current (ACC), Antarctic Bottom Water (AABW) production and spreading, structure of the polar front zone and other antarctic frontal zones, structure and spreading of the thick layer of Circumpolar Deep Water (CDW), and the fine vertical structure and horizontal distribution in the temperate and salinity fields, including details of the temperature-minimum layer. The *Eltanin* data array will no doubt contribute much more as more oceanographers look at it more closely in the coming years. Analysis already completed is likely a small percentage of what is either in progress or probable for the future.

Within each of the following discussions, I include areas for further field studies. Many of these suggestions are in *Southern Ocean Dynamics, a Strategy for Scientific Exploration,* a report on antarctic oceanography recently completed by an *ad hoc* working group, Committee on Polar Programs, National Academy of Sciences.

Antarctic Circumpolar Current

The transport of water of the ACC has vexed oceanographers for a long time. Problems in transport estimation arise from an apparent lack of a zero reference level needed for geostrophic determinations and the difficulties of obtaining long-period current measurements for either direct determination of transport or for a reference value for geostrophic flow. The transport determined for the Drake Passage using direct current measurements for a reference (Reid and Nowlin, 1971) and an equivalent barotropic model (Gordon, 1967a) lead to values from 220 to 240 million cubic meters per second. Callahan (1971), using *Eltanin* hydrographic stations and bottom current meter data for reference (Cruise 41) along 132°E. determined a transport of 235 million cubic meters per second. The comforting agreement with the Drake Passage values was short-lived, as current and hydrographic measurements made in the Drake Passage by the Canadian *Hudson* expedition only 1 month after the *Eltanin* Cruise 41 measurements, indicated a transport towards the west of 15 million cubic meters per second. McKee's (1971) treatment of the sea level records on either side of the Drake Passage would indicate only a 40 to 50 percent variation in the transport, if it were near 200 million cubic meters per second, *i.e.* not a reversal. Gordon and Bye (1972) show that much of the observed changes in sea level could be accounted for by variations in the baroclinicity between the sea surface and 2,500 meters. Therefore the *Hudson* observations are difficult to explain. Gordon (1973a) has suggested a possible control of the Drake Passage flow by a blocking action initiated by the position of the northern boundary of the Weddell gyre marked by the Weddell-Scotia confluence. This confluence varies greatly in position within the upper few hundred meters (Gordon 1967b) but appears steady at deeper levels.

The ACC is some 21,000 kilometers long, and it varies in latitude by nearly 20°, mainly in response to the bottom topography. It passes through narrow passages in places, parallels ridges for long distances in others, crosses broad flat basins, and is deflected by submarine ridges. Its dynamics may change from regime to regime; certainly its structure changes, and perhaps the term Antarctic Circumpolar Currents is more appropriate. *Eltanin* has obtained many hydrographic sections across the ACC (and the polar front zone, which can be thought of as the thermohaline base for the ACC) that define the temperature and salinity distribution and permit the definition of the sea surface dynamic topography relative to a deep reference layer (Gordon 1967a,b, 1972a,b, Gordon and Goldberg, 1970, Gordon and Bye 1972; Callahan 1971, 1972).

The striking features of the ACC in the Indian and Pacific sectors are the relationship of the structure to bottom topography. In the region south of Australia where the current parallels the midocean ridge the axis is found over the northern flank of the ridge, with a weak current over the southern flank, often flowing toward the west. The ACC on reaching the Macquarie Ridge is divided into filaments, two passing through the narrow gaps in the ridge, at 54° and 56°S., one curling around the southern end of the ridge. However, the bulk of the cold water appears to continue to follow the northern flank of the midocean ridge. The northern filaments appear to coalesce into a jet-like current over the southern flank of the Campbell Plateau, where they then shift sharply northward and may initiate a series of standing Rossby waves in the Southwest Pacific Basin.

An *Eltanin* current meter placed 100 meters off the sea floor at the base of the Campbell Plateau (56°S. 170°E.) for 3 days recorded a relatively steady flow of 28 centimeters per second towards 067°. Using this value for reference, the surface geostrophic flow is 70 centimeters per second (1.4 knots). The southern filament continues to flow along the midocean ridge, which turns northward in the region north of the Ross Sea. All filaments combine to pass through the deep Usarp Fracture Zone in the mid ocean ridge at 145°W. 57°S. Therefore, from Macquarie Ridge to the Usarp Fracture Zone the ACC is multi-axial. East of the fracture zone the ACC has a poorly defined axis and does not redevelop a real axis until reaching the Drake Passage, where a major northward shift takes place.

There is little doubt that what is needed to further the study of the ACC are long term measurements of the currents and pressure fields, in association with measurement of the thermohaline fields. Such work should be carried out in a number of distinct regimes of the ACC.

Antarctic Bottom Water

Eltanin data showed that the most concentrated (highest concentration of shelf water) AABW emanating from the Weddell Sea flows clockwise along the periphery of the Weddell Basin, following the 3,000- to 4,000-meter isobath (Gordon 1966, 1967a,b; Hollister and Elder, 1969). This contour-following flow contains water in the northwestern Weddell Basin with potential temperature below —1°C., oxygen above 6 millimeters per liter, and silicate below 90 microgram-atoms per liter. It flows eastward in the northern Weddell Basin with an important arm penetrating the western Atlantic Ocean, and a small amount entering the Scotia Sea by way of a passage in the South Scotia Ridge at 40°W. Some of this water appears to enter the Pacific by a route along the southern extreme of the Drake Passage. It also fills the deeper portions

Characteristics of observed Antarctic Bottom Water

Variety	Location	Potential temperature °C	Salinity °/oo	Oxygen ml/l	Silicate ug.at/l
Low salinity	1. Western periphery of Weddell basin	—1.4	34.634 to 34.674	6.7	87
	2. Deepest parts of Weddell basin	—0.7	34.634 to 34.674	5.9	110
	3. Adélie Coast	—0.7	34.650	5.9	110
High salinity	4. Deep ocean adjacent to the Ross Sea	—0.5	34.738 to 34.754	5.6	104

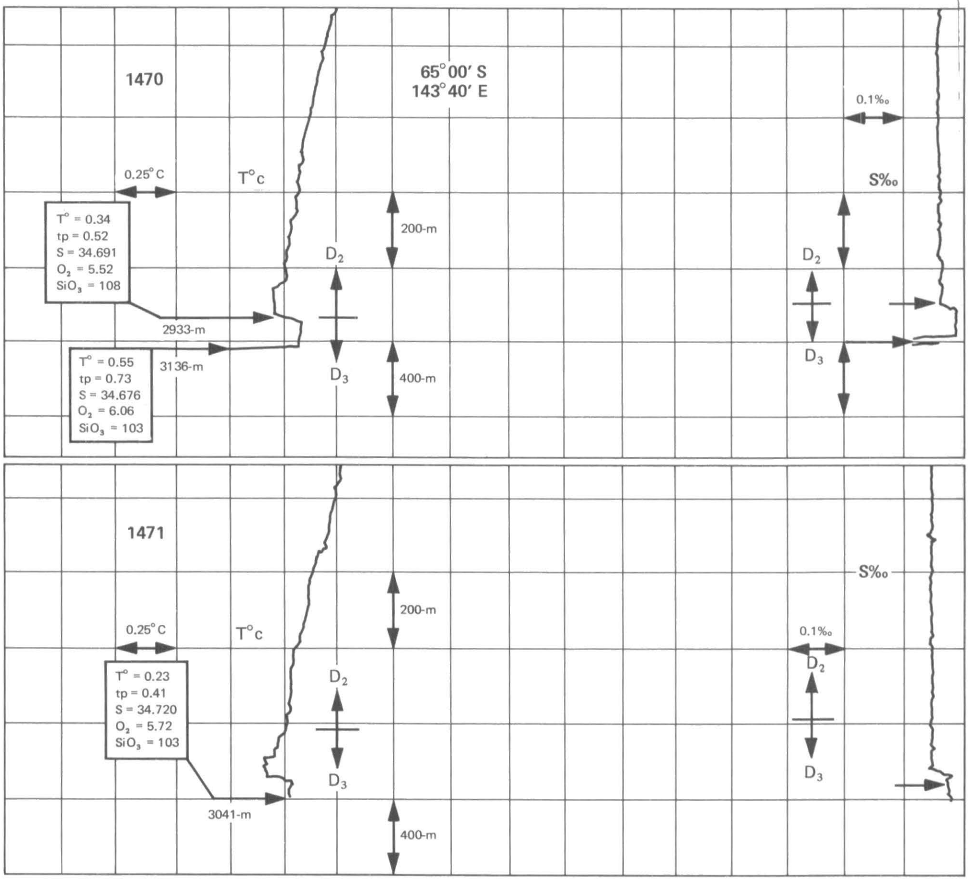

Figure 1.
The lower portion of 2 STD stations (the down and up traces of a single lowering), taken over the continental rise of the Adélie Coast during Cruise 50. Values given in the large boxes (at left) are of water samples taken simultaneous to the STD data's collection.

of the southern and eastern Scotia Sea with a dense water that must play a role in the northward deflection of the ACC in this region.

The major contribution of the *Eltanin* data relative to AABW is the continental margin work of Cruises 27, 32, 37, 50 and 52. These data show that AABW is formed within the Ross Sea (Jacobs *et al.*, 1970b; Gordon, 1971a, 1972b) and the Adélie coastal region near 140°E. (Gordon and Tchernia, 1972; Gordon 1973b). Before these cruises, bottom water formation in these areas was suggested (Ivanenkov and Gebin, 1960; Gordon, 1966; Lynn and Reid, 1968; Tchernia, 1951) but not conclusively shown.

Pre-*Eltanin* data on the continental shelf show that shelf water at the freezing point with salinity sufficiently high to produce bottom water if it were to escape from the shelf is also found near the Shackleton and Amery Ice Shelves. *Eltanin* Cruise 56 was to investigate these areas. Another margin area of some interest is west of the Amery region where ice shelves extend nearly to the shelf break, leaving very little shallow region exposed to sea ice production.

Types of AABW can be classified according to their characteristics; Gordon (1973b) has done this (table). The high salinity variety formed in the Ross Sea flows in part over the continental rise off the Adélie coast, where its dilution with the low salinity bottom water formed there is clearly evident (Gordon and Tchernia, 1972). The blending of these two AABW types yields an apparent low concentration bottom water (low concentration in the sense of low amount of shelf water), but on inspection of bottom oxygen and silicate its freshness or high concentration is seen.

In November-December 1971 (Cruise 50), a unique STD station on the continental rise off the Adélie coast showed a strong thermohaline layering near the sea floor with the low-salinity, locally produced bottom water forming a distinct bottom layer of 80 meters thick and lifting above it the saline Ross Sea bottom water (fig. 1). The *in situ* density nearly matches, although the sigma-t values show instability of 0.02. Gordon (1973b) suggests that this stratification represents a recent injection of the Adélie water and eventually a more uniform blend (as found on Cruise 37 in January-February 1969 in the same area) would form.

The abrupt termination of the warm deep water all about Antarctica immediately north of the slope (Sir George Deacon, personal communication, 1973) may be taken as evidence of active continental margin processes at all longitudes. We need more data in the vicinity of the continental margins at all longitudes, especially near the expected centers of AABW production and in the winter. However, AABW may form in the summer months, even if the salt input is a winter process, since the formation of AABW is associated with the escape of water from the shelf rather than with the actual generation of shelf water. Naturally, the two may be closely tied together, if AABW is being produced faster than the continental shelf can accommodate, but summer formation has been observed (Gordon and Tchernia, 1972; Seabrooke *et al.,* 1971).

Another aspect of AABW production to which *Eltanin* data has relevance is the role of the ice shelves. Extensive layers of water at depths of hundreds of meters within the Ross Sea have temperatures well below the 1-atmospheric-pressure freezing point; also, Lusquinos (1963) has noted this phenomenon for the Weddell area. A role of the ice shelves is expected, since the freezing point at the contact of the sea water with the bottom boundary of the glacial ice is well below —2°C. Probably the cold, saline shelf waters of the open Ross Sea, which are probably the product of sea ice formation, flow below the ice shelf and there, exposed to melting and refreezing, become colder and perhaps saltier. The resulting increased density may enable AABW production or perhaps more AABW production than previously thought possible. The greater compressibility of the colder water may have a role in the "sinking potential" of the shelf water (Lynn and Reid, 1968; Gill, 1973). Sampling below the shelf ice to determine the thermohaline alteration of this water and the exchange of this water with the open sea would have direct relevance to AABW production.

The *Eltanin* bottom data array is well suited to study of bottom circulation away from the continental margins (Gordon 1966, 1972b). The bottom water, heavily laden with suspended material (Eittreim *et al.,* 1972), generally flows westward until it meets a blocking submarine feature that diverts the flow toward the north and eventually eastward. The midocean ridge that nearly encircles Antarctica is breached in a number of regions where fracture zones occur.

Polar Front and other frontal zones

The antarctic water column, with its temperature-minimum layer in the upper 300 meters and a deeper temperature-maximum layer, is separated from the subantarctic water column with its deep isohaline surface layer by the region of complex thermohaline structure marking the polar front zone (or Antarctic Convergence, a term some oceanographers prefer). The zone has been described by Mackintosh (1946), based mostly on the *Discovery* observations. The *Eltanin* data show that the position of the zone is very similar to that given by Mackintosh, with perhaps a more southern position near the 180° meridian. The data also indicate that the intensity of the zone varies with time

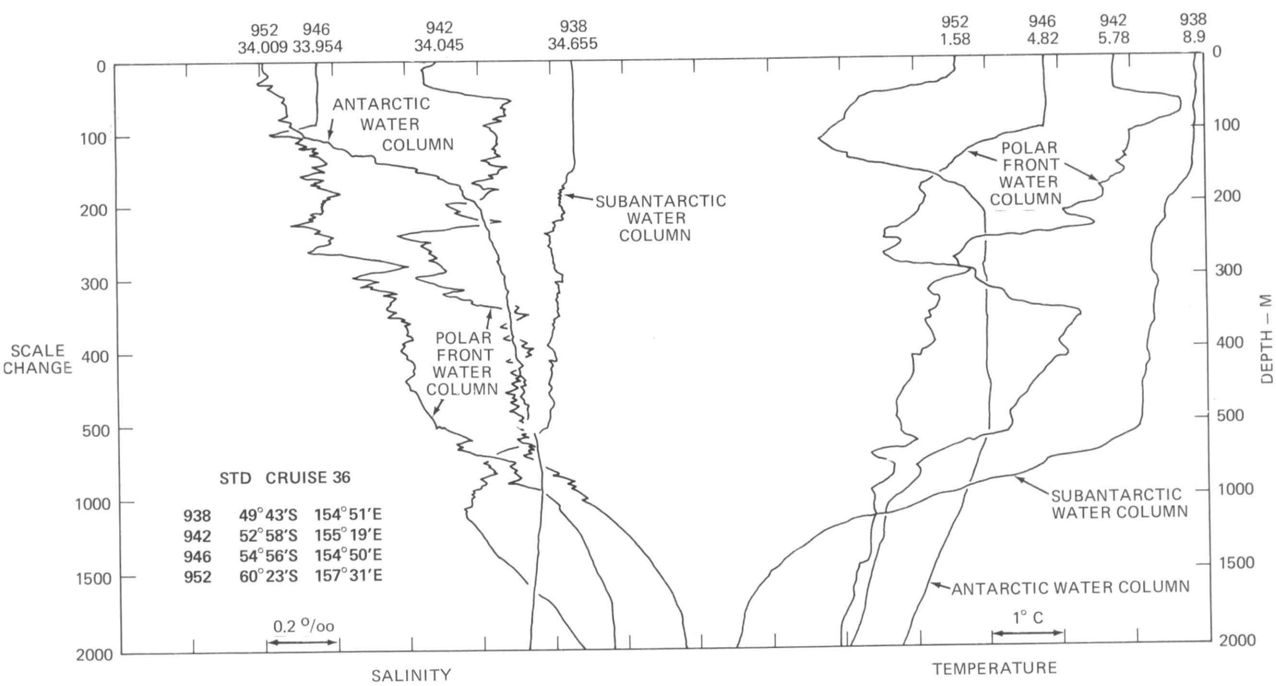

Figure 2. STD profiles north, within, and south of the Polar Front Zone.

and position, although it stays within a belt of 2° to 4° of latitude (Gordon 1967b, 1971b). This belt appears to bear some relation to the general bottom morphology.

Interesting aspects of the polar front zone brought out with the *Eltanin* data are (1) the double front structure east of Macquarie Ridge, (2) the highly complex nature of the thermohaline vertical profiles in the zone, and (3) its movement. Wexler (1959), who first discussed the double front, related it to an upwelling or divergent process. The *Eltanin* data, however, show that the warm zone that separates the cold water into the main southern body and an isolated northern cell appears to be warmed antarctic surface water. No explicit signs of upwelling of the deep water are found. Gordon (1971b) gave various hypotheses for the formation of the double front. One was later supported: the double front may be generated at the southern tip of the Macquarie Ridge, where warm water, riding over the ridge crest, eddies into the colder surface water (Gordon, 1972a). There are two bases for this model. First, a "steady state" double front occurs across the southern tip of the ridge; if it shed eddies, this front would produce the observed feature in the Pacific, which is transient. Second, the double front has not been observed west (upstream) of the ridge. A model study by Boyer and Guala (1972) indicates the possibility of shedding eddies in this region. Because they heat the lower atmosphere faster than the ambient antarctic water, the warm-water eddies may significantly affect the weather and perhaps climate of the southern South Pacific. The magnitude of this effect depends on the frequency of the eddies, not known but expected to be at least one a week.

The advent of salinity-temperature-depth (STD) instrumentation has contributed much to oceanography. *Eltanin* has had an STD system since 1966. The data appears in the *Eltanin* data reports (see references) and have been used in numerous publications.

The STD profiles indicate that as the polar front is approached the degree of structure on a scale of

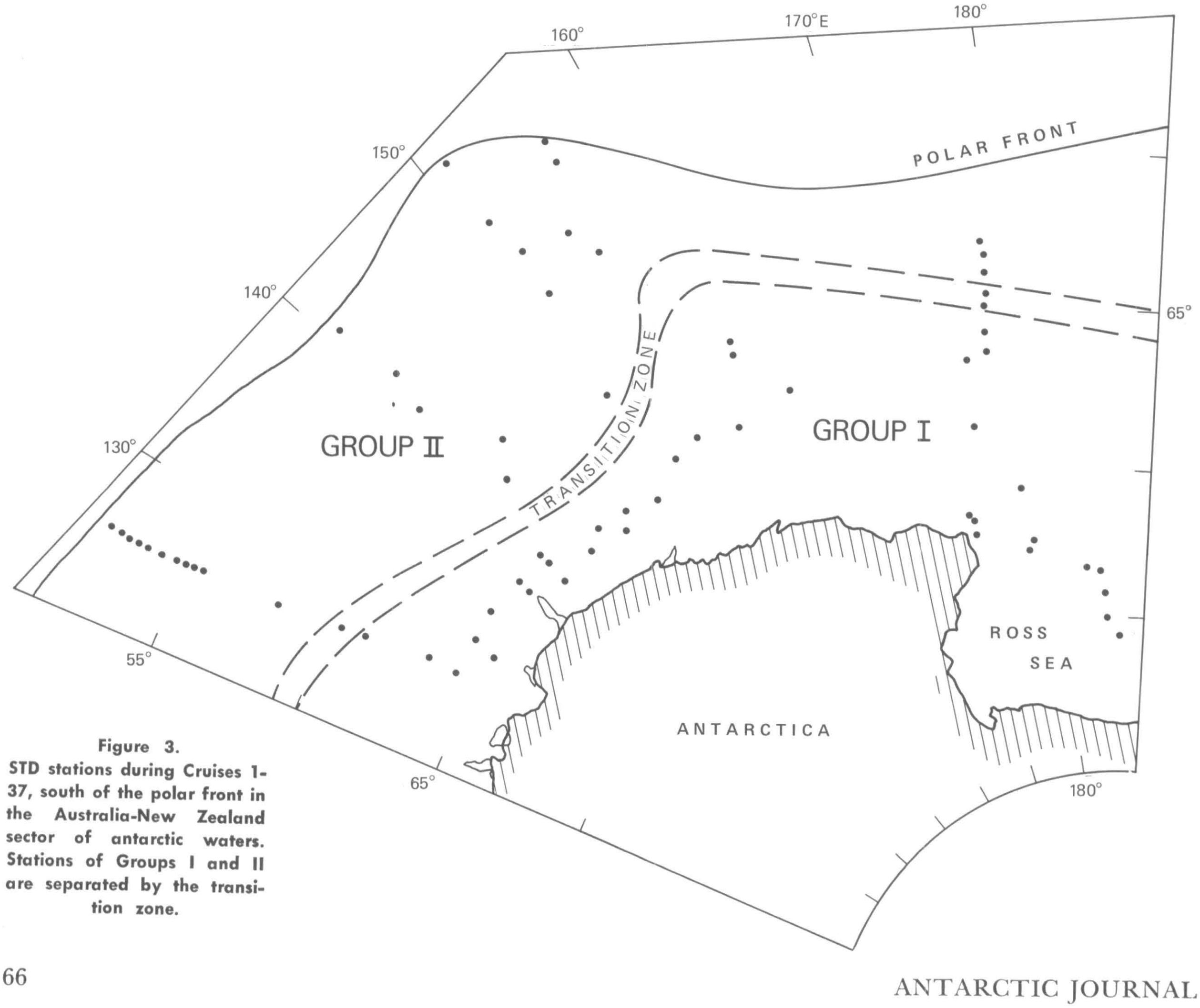

Figure 3.
STD stations during Cruises 1-37, south of the polar front in the Australia-New Zealand sector of antarctic waters. Stations of Groups I and II are separated by the transition zone.

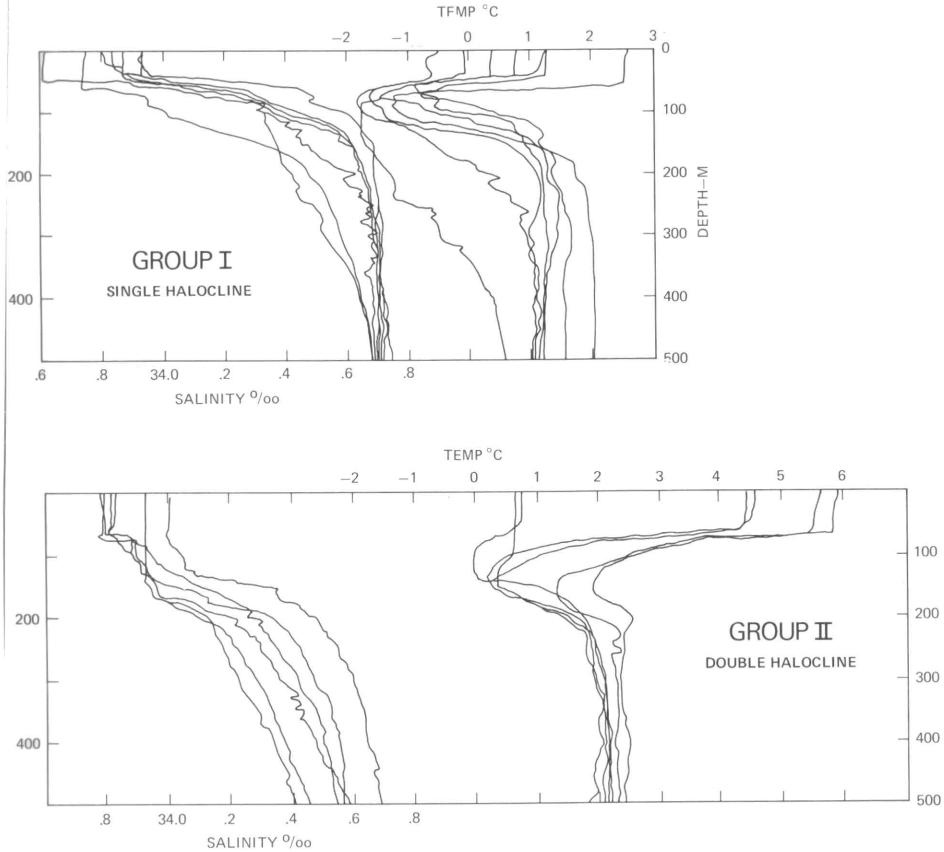

Figure 4.
STD profiles of Group I (left) and Group II (below). The strong halocline of Group I is directly above a strong T-min layer. Group II's halocline is weaker and generally below the broader T-min layer, with a small halocline above the T-min layer.

tens to hundreds of meters increases greatly (fig. 2). Since the inversions are stably stratified, they are probably the result of large-scale horizontal eddies acting on a mean thermohaline field that possesses significant slope of isopleths. These structures would decay in time by the action of smaller scale turbulence and molecular processes. One wonders if the ultimate fate of at least part of these structures is Antarctic Intermediate Water. Study of these STD records promises to be rewarding.

The *Eltanin* STD data reveal that the polar front is not the only distinct front. The Australasian Subantarctic Front, first described by Burling (1961) for the area south of New Zealand, extends far to the west, perhaps to the southwest Indian Ocean (Gordon and Goldberg, 1970).

Another frontal zone exists about halfway between the polar front and Antarctica. It has not been discussed in the literature and in fact is not obvious in serial casts, but it does appear on the STD profiles. Fig. 3a shows the distribution of STD stations south of New Zealand and Australia obtained through Cruise 37. On fig. 3b, stations south of the transition zone are group I; those north, group II.

Stations in group I display a strong halocline immediately above the very sharply defined temperature-minimum layer. Most of the water within the temperature-minimum layer is colder than −1.0°C. and saltier than 34.3 parts per thousand. Group II shows a broad, warmer (over 0°C.) temperature-minimum layer with a double halocline, one above and one below the temperature-minimum layer. The salinity of the temperature-minimum layer is near 34.0 parts per thousand. The transition from group I to group II is abrupt. The process at the transition zone is open to speculation; the similarity of the group-II isohaline cold layer to the 18°C. water of the North Atlantic suggests its formation at the transition.

The transition is near the climatic position of the Antarctic Divergence, and some role in the conversion of deep to surface water may be present.

Circumpolar Deep Water

The mass of Circumpolar Deep Water (CDW) flows eastward around Antarctica. Part of this huge volume flows into the Atlantic, Indian, and Pacific Oceans via the deep western boundary and appears to return to antarctic regions at slightly shallower levels in a modified form. The Atlantic has the additional effect of incorporating into the return flow the salty North Atlantic Deep Water (NADW).

On reaching antarctic waters, North Atlantic Deep Water flows eastward to mix with CDW that has passed through the Drake Passage (Gordon, 1971c) by the longitude 70°E. This mixing transfers much salt into antarctic waters, offsetting the fresh water inflow by precipitation and from the antarctic ice.

In addition to its eastward flow, CDW slowly spirals southward and to shallower depths to upwell and be converted to an antarctic water mass. The *Eltanin* data have allowed more detailed tracing of the CDW in the Indian and Pacific Oceans by the general station array and more importantly by the greater accuracy in the salinity determinations than technically feasible on the earlier expeditions.

Conclusion

An array of modern hydrographic and STD stations extending to the sea floor is needed in the important regions of the southwestern Indian and southeastern Atlantic Oceans. In this region is found the eastern boundary of the Weddell Gyre, where AABW somehow spreads into the Indian Ocean, where the ACC flows over complex topography, where the NADW and CDW are discernible water masses, where the polar front zone shifts southward.

The Weddell Gyre represents a large volume of cold, relatively fresh water extending from the Antarctic Peninsula to 20° or 30°E. Along its southern boundaries are some of the most extensive ice shelves of Antarctica, many reaching the outer continental shelf. The northern boundary appears to be subject to position variability, especially in the upper few hundred meters. This variability affects the northern extent of the cold surface water and may account for the highly variable sea ice conditions of the Scotia Sea region (Fletcher, 1968). This shifting may also influence the flow through the Drake Passage. The eastern margins of the gyre are not well known. The water within the gyre on recirculation becomes colder and fresher throughout its depth. However, the CDW reaches its shallowest levels within the center of the gyre, making the surface water more susceptible to AABW formation during sea ice growth. The CDW at 400 meters is very similar to that found at 3,000 to 4,000 meters in the northern Drake Passage, suggesting that within the gyre is a major zone of CDW upwelling. The variation of the position and size of the Weddell Gyre may be of significance to production of AABW and to the weather and climate of the southern hemisphere. Paleoclimates may also be better understood by the study of submarine sediments at the fringes of the Weddell Gyre.

The above discussion gives a brief account of the contributions of the *Eltanin* to our knowledge of antarctic physical oceanography; perhaps some of the speculations will not hold up under closer study. The *Eltanin* data will give food for thought for oceanographers for a long time and will play a major role in the planning of future more specialized field programs. The significance of the antarctic region in governing the condition of the world ocean and atmosphere strongly suggests that we not abandon our study of antarctic waters.

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Marine Geology

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Ten years ago, when the *Eltanin* program began, marine geology was a simpler science than it is today. At that time it was, in general terms, concerned with the physiography, tectonics, and genesis of the sea floor; the distribution and variation of sediments; and an understanding of the associated roles of organic and inorganic materials and dynamic factors modifying the distribution of these sediments. While this description is still largely valid, it has become virtually impossible to satisfactorily isolate marine geology from marine geophysics, micropaleontology, and (to an increasing extent) some aspects of physical oceanography. Knowledge of sea floor genesis, tectonics, and overlying sediment thickness and distribution results from geophysical means; micropaleontology is the discipline required to understand sediment origin and variation in time and space; and physical oceanography can provide limits on the water mass dynamics and boundaries, critically effecting sediment type and broad accumulation patterns. This essential broadening of the science during the last decade has been paralleled by the so-called revolution in the earth sciences, which is based almost completely on the recognition of mobility in sea floor and continental configuration.

The contribution of the *Eltanin* marine geology program as summarized here must therefore overlap somewhat with the geophysics and micropaleontology programs in particular as presented elsewhere in this issue. It is still too early to evaluate most of the contributions from the last series of cruises in the southeastern Indian Ocean (between 39 and 55) since they have not yet been published.

Background

The relative advance in knowledge of the marine geology of the southern ocean provided by the *Eltanin* program compares favorably with resulting advances in other scientific activities. For example, several hundred hydrological stations had been occupied by the end of the 1950s (Deacon, 1964), whereas according to Ewing and Heezen (1956) only four piston cores with any observable stratigraphic variation had been recovered. Nevertheless, using grab samples or gravity cores, Phillipi (1910), Schott (1939), and Hough (1950, 1956) had described marine sediments from the subantarctic sea floor and had recognized the paleoclimatic significance of intercalated silicious ooze, carbonates, and glacial-marine sediment, but no age control was available. As early as 1937, Deacon (1937) had pointed out that the region between the pack ice and the Subantarctic Convergence was biologically the world's most productive marine environment, with a corresponding sedimentary significance. The most important contribution during the period immediately preceding the *Eltanin* program was Litizen's (1960) description of bottom sediments including some submarine moraines in the subantarctic of the Indian Ocean.

The broad physiographic framework of the southern ocean sea floor was well known by the late 1950s, particularly as the result of cruises of *Discovery,* as summarized by Heardman (1948).

In the early 1960s the glacial history of Antarctica was, with only rare exceptions, considered to be closely related to the Arctic events. Initiation of the present antarctic glaciation was envisaged as occurring during the last 1 to 2 million years. Thus little advance had been made on the ideas of early 20th century geologists.

Further and wider evaluation of the status of marine geological and geophysical problems in the subantarctic region, as of the mid 1950s, was published by Ewing and Heezen (1956). Thus the stage was set for the *Eltanin* cruises to begin in 1963.

Contributions from the *Eltanin* program

Physiography. The *Eltanin* program has been instrumental in providing much fine detail in the physiography of the Scotia Sea, South Pacific, and southeast Indian Ocean.

Heezen and Johnson (1965) refined earlier surveys of the South Sandwich Trench, during cruise 8. The detailed physiography was supplemented by seismic profiling which revealed, when compared to other trenches, an unexpectedly thin sediment cover. Cruises through 22 enabled Heezen *et al.*

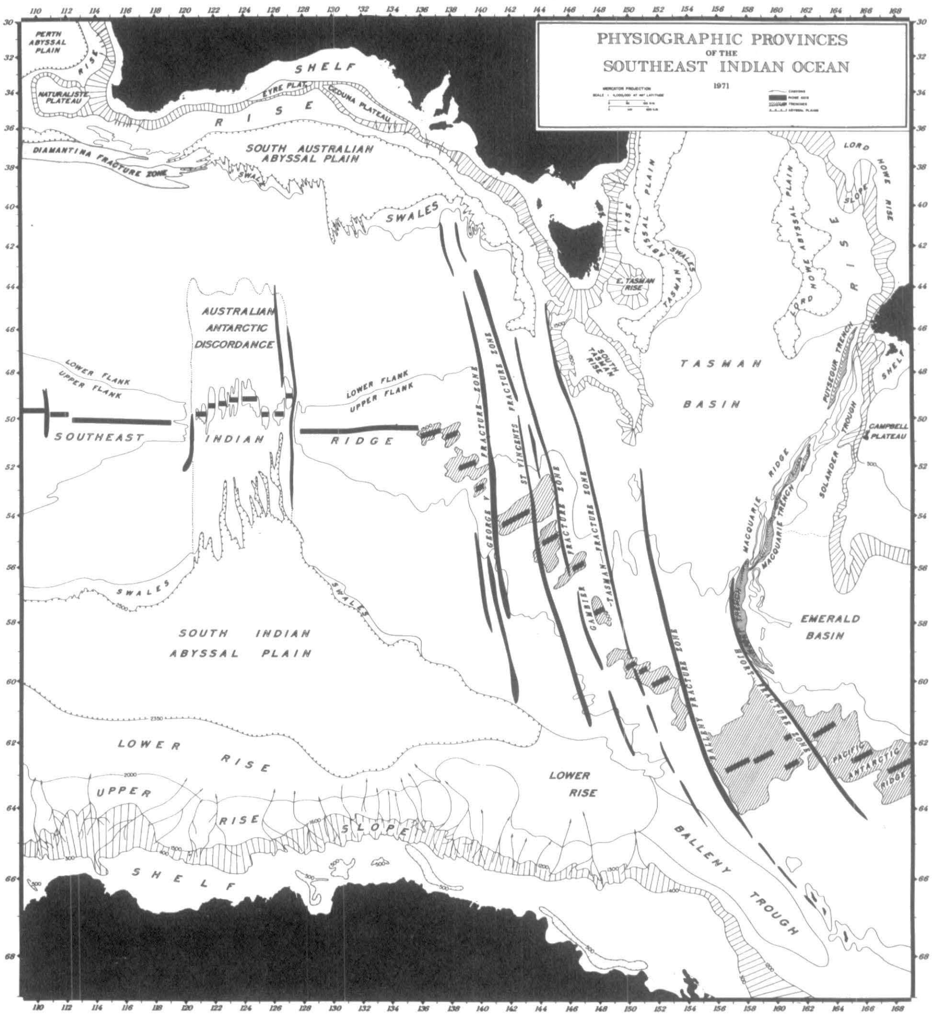

Figure 1. Physiographic map of the southeast Indian Ocean (Hayes and Conolly, 1972).

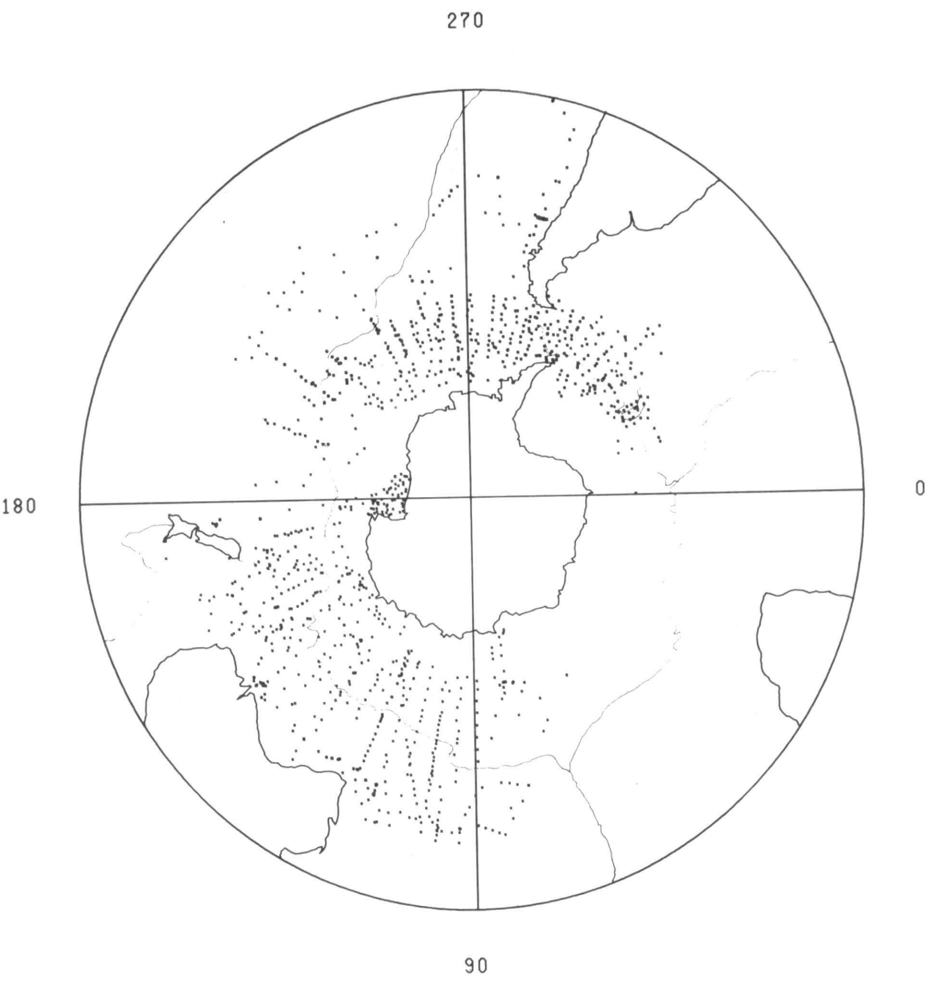

Figure 2.
***Eltanin* core locations.**

(1966) to present details of the Scotia Sea physiography. When cruises began in the South Pacific, perhaps the world's longest fracture zone was discovered: the Eltanin Fracture Zone offsets the East Pacific Rise by about 1000 km. During cruise 29 a possible extension of the fracture zone to the northeast, in the form of the Louisville Ridge, was detected by Hayes and Ewing (1971). Another feature named after the vessel is the *Eltanin* Seamount, on the Chile Ridge.

Not surprisingly the South Pacific cruises have shown that earlier concepts of the form of the Bellinghausen Basin were oversimplified (Heezen *et al.*, 1966; Hollister and Heezen, 1967).

The major contribution to southern ocean physiography from *Eltanin* cruises is for the region south of Australia and New Zealand. Hayes and Conolly (1972) identified a possibly unique mid-ocean ridge feature, which they call the Australian-Antarctic discordance (fig. 1): otherwise relatively subdued ridge topography is interrupted by a 400 km. wide zone of very irregular features. To the east of this, but west of the Macquarie Ridge, a series of five or six major offsets in the midoceanic ridge system are now well-defined (fig. 1). Data from this same series of cruises has been added to many results from the U.S. Naval Oceanographic Office and the Australian and New Zealand Hydrographic Office to provide fine definition of the Antarctic continental shelf south of Australia, to the extent that several glacial troughs up to 2000 meters deep were identified.

Bottom Photography. Extensive contributions and innovations have resulted from the very large *Eltanin* bottom photograph collection (Simmons and Landrum, 1973). The early cruises enabled Heezen and Johnson (1965), Heezen *et al.* (1966), and Hollister and Elder (1969) to detect the effects of bottom currents on sediments in the Scotia Sea, the South Sandwich Trench, and the northern part of the Weddell Sea. Contour currents were identified flowing from the Weddell Sea into the South Sandwich Trench. Heezen and Hollister (1967) extended this form of analysis to the Bellingshausen Basin, providing unambiguous evidence of the dynamic effect of the circumantarctic current on the surface sedimentary structures. The concepts developed as the result of these studies assisted Watkins and Kennett (1971, 1972) in confirming the existence of an extensive and unique region of scour in the South Tasman Basin, identified originally by dating of the *Eltanin* core collection. Conolly and Payne (1972) used the same photographs to assist in their interpretation of sedimentological data, which also enabled them to detect this scour zone.

Sedimentology. The bottom sediments of the sub-antarctic can be expected to reflect the huge biological productivity of these waters (Deacon, 1937) as well as dynamic processes such as turbidite emplacement and redistribution by bottom currents and the effects of atmospherically transported particulate matter.

The earlier U.S.S.R. marine geology program led to the production of a map of the bottom sediment type of the southern ocean by Bakayev (1966). Similar results from the *Eltanin* core collection (fig. 2) were compiled by Goodell (1964, 1965, 1968) for the Scotia Sea and South Pacific; Monastero (1973) for the Tasman Basin; and Conolly and Payne (1972) for the region south of Australia and New Zealand. In general, the *Eltanin* maps show

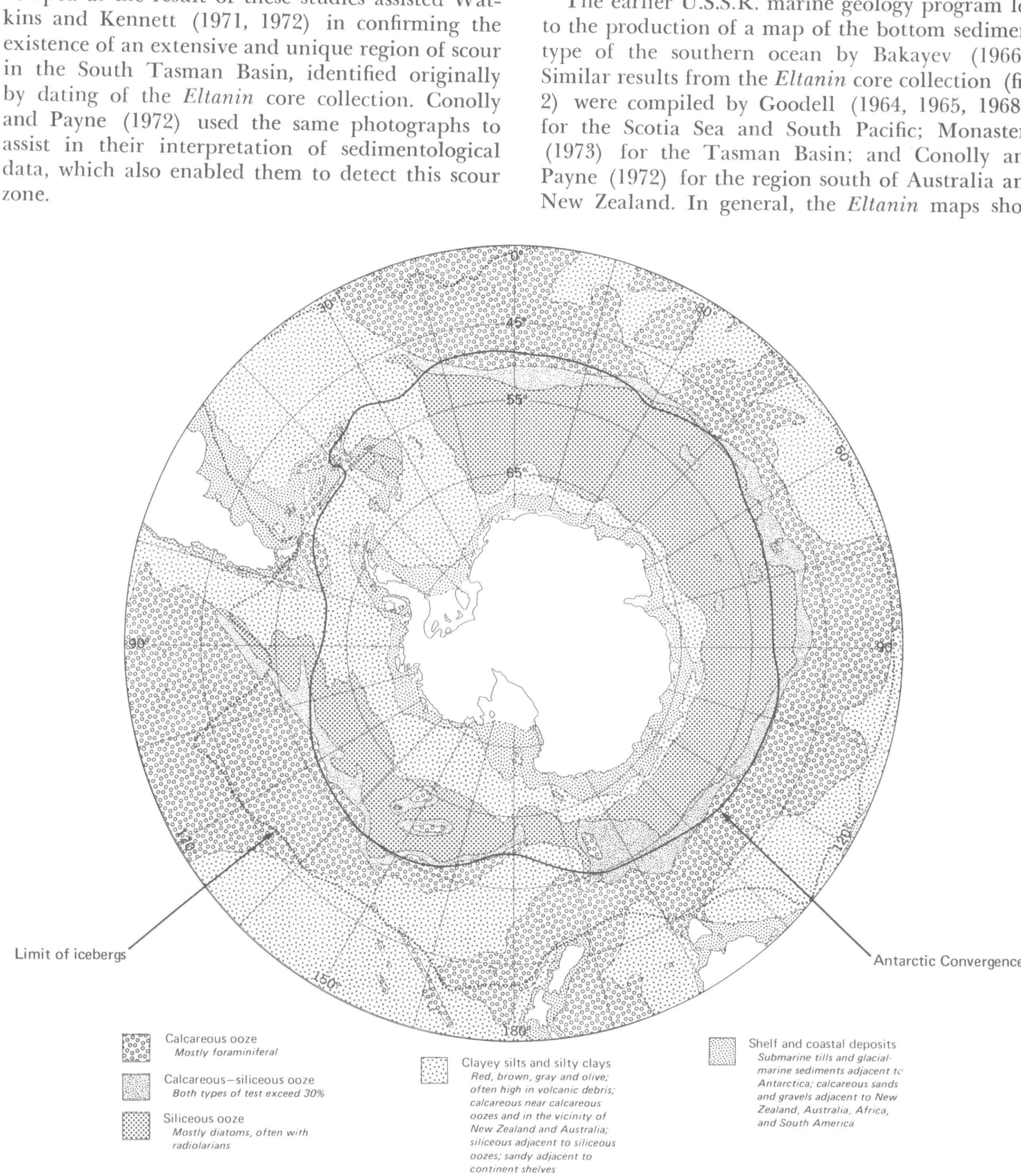

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Figure 3. Bottom sediments of the circumantarctic (Goodell, 1973).

that the present Antarctic Convergence coincides with the separation of silicious ooze to the south from calcareous oozes to the north, with a zone of intermixing up to 600 kilometers wide south of Australia (Conolly and Payne, 1972). These data have formed the dominate source for the entire circumantarctic sediment map published by Goodell (1973) as reproduced in fig. 3. Chemical and petrographic analyses of core tops from Cruises 13 through 33 by Nayudu (1971) showed that submarine volcanism may be an important contributor to the sedimentary geochemistry of the southwest Pacific segment of the southern ocean. Fisher (1968) reported on the clay mineralogy from the South Pacific: he interprets the dominance of illite to be related to erosion of New Zealand sediments. Glauconite in some *Eltanin* cores from the Scotia Sea was analysed by Bell and Goodell (1967), who showed that the mineral is authigenic in this region.

The sediment distribution is clearly a dominant function of the independently derived tectonic history of the southern ocean, which since 1968 has been understood to be a result of the formation of new crust at the axes of ridges. The sediment cover is less than 100 meters over the ridges, but 2 kilometers or more adjacent to the antarctic continent (Conolly and Payne, 1972), with the Macquarie Ridge forming a distinct tectonic control of sediment accumulation according to results from Cruises 16 and 27 (Houtz *et al.*, 1971). The locations of the early and middle Tertiary cores in the *Eltanin* collection are quite consistent with the required increase of maximum age of sediment away from the spreading ridge axis (Margolis and Kennett, 1970). Seismic reflectors in the Bellingshausen Basin, particularly well-defined during Cruise 17, were interpreted to represent turbidites from the continent, but analogy with Atlantic data would suggest that perhaps these reflectors are chert layers. Weaver and Wise (1972) have used sediments collected during Cruise 47 to demonstrate that chert was originally organic silica. Chert was recently recovered during drilling of Broken Ridge in the southeast Indian Ocean (Luyendyk *et al.*, 1973), the Cretaceous age of which was earlier suggested as the result of *Eltanin* Cruise 48 seismic reflection data and sedimentation rate estimates (Watkins, 1971). True turbidites were sampled in the *Eltanin* cores south of Australia (Payne and Conolly, 1972).

During the early phases of the *Eltanin* program, the only method available to measure sedimentation rates in deep-sea sediments was radiometric, which could be used on sediments younger than about 0.3 million years. The ionium-thorium disequilibrium method (using alpha particle spectrometry) was applied to *Eltanin* cores from the Scotia Sea (Holmes, 1965), and gamma ray spectroscopy was also applied to the *Eltanin* cores (Osmond and Pollard, 1967). Such analyses are, for reasons discussed below, now proving much more useful as a means to investigate sediment genesis and post-depositional processes. For example, Scott *et al.* (1972) have shown for some *Eltanin* cores south of Australia that thorium-230 is removed from sea water in association with iron and manganese colloids and that clay accumulation is not greatly different between ridge and continental margin. Similarly, Osmond and Pollard (1967) have attributed a variation in the thorium-230 excess at the top of some *Eltanin* cores to be caused by diffusion of intermediate daughter products.

Since 1966, the paleomagnetic method has superceded radiometric methods for large-scale sedimentation rate determinations for cores that exceed 0.7 million years in age. The *Eltanin* core collection (fig. 2) has been dated systematically using paleomagnetism and related micropaleontological criteria. This approach has yielded new insights into marine sedimentology. For example, in limited portions of the *Eltanin* core collection Watkins and Goodell (1967a) showed a strong correlation between microfaunal extinction and geomagnetic polarity reversal; Hays and Opdyke (1967) showed the same relationship in three of the longest *Eltanin* cores, taken from the Bellingshausen Basin; Watkins and Goodell (1967b) used *Eltanin* cores to confirm details of the geomagnetic polarity history during the past 2.5 million years; Kennett and Watkins (1970) detected a possible relationship between geomagnetic polarity change and volcanic maxima, as recorded in seven cores north of the Ross Sea; and Watkins (1968) used eight cores to exhibit the magnetically distorting effects of faunal redeposition, as well as the possible occurrence of two short-period polarity reversals at 0.81 and 1.07 million years ago. Paleomagnetically dated *Eltanin* cores have been used to assist delineation of the Australian tektite field (Gentner *et al.*, 1970); for the detection of very fine volcanic dust that has been transported atmospherically across much of the South Pacific (Huang *et al.*, 1973a); and for investigation of a possible relationship between microfaunal diversity and volcanic activity (Huang *et al.*, 1973b).

On a much larger scale, paleomagnetic dating of the entire *Eltanin* collection revealed the existence of the unique South Tasman Basin disconformity (Watkins and Kennett, 1971, 1972), as shown in fig. 4, and a related scour zone in the Ross Sea (Fillon, 1972) and the Bellingshausen Basin and Scotia Sea (Goodell and Watkins, 1968). This

Figure 4.
Second-order trend surface on the paleomagnetically determined age of sediment at the tops of *Eltanin* cores taken south of Australia (Watkins and Kennett, 1972). Shown is a region centered on the south Tasman Basin, where a modern disconformity exists because of bottom current sediment scouring.

feature is caused by the action of the circum-antarctic current on bottom sediments. Fluctuation of the current can result from several causes, including variation in the production of Antarctic Bottom Water. These *Eltanin* data have stimulated speculation about the early Tertiary sedimentary history of the region south of Australia (Watkins and Kennett, 1973). Fisher (1970) used paleomagnetically dated cores in an attempt to detect movements of the regional sediment patterns between the present and 0.7 million years ago. He concluded that the southern limit of the belt of silicious ooze has moved southwards 5° of latitude during that period, consistent with warming since that time, although Hays (1965) and others have opposite views.

Dredged rocks. Both as a by product of the *Eltanin* biological dredge hauls and less frequent rock dredging, one of the world's largest deep-sea rock collections (fig. 5a) has been accumulated and is now stored at Florida State University.

Because of the unique size of the collection, Watkins and Self (1971, 1972) were able to employ trend surface analyses on the distribution of the various rock types recovered (example in fig. 5b). These studies reveal a dominant ice-rafted origin except for recoveries from parts of the Macquarie Ridge and the East Pacific Rise. The former were subjected to chemical and magnetic analysis (Watkins and Gunn, 1971) to provide a 400-kilometer northward extension of the known outcrops of harzburgite-peridotite on Macquarie Island. The configuration of the trend surfaces shows that the Ross Sea glaciers probably provided most of the ice-rafted deposits dredged from the South Pacific, and that the Scotia Sea receives most of its ice-rafted debris from the Weddell Sea, as independently proposed by Edwards and Goodell (1969) using heavy mineral analysis of selected *Eltanin* core tops.

Paster (1971) selected fragments of nine definite *in situ* basalt pillow fragments, collected during Cruises 5 through 24, for a study of petrographic and geochemical variations within single samples. He concluded that iron loss is characteristic of pillows, providing perhaps a major source material for ferromanganese concretions. Watkins *et al.* (1970) and Watkins and Paster (1971) used the same specimens to help provide an understanding of the factors controlling magnetic properties of submarine basalts, which are relevant to interpreting the very important linear magnetic anomalies defined at sea level. They concluded that quenching strongly affects the magnetic properties, inferring that analysis of materials dredged from the outer skin of large volcanic bodies is inapplicable to the whole bodies. A concentration of sulphides in the outer parts of these submarine pillows also was noted, explained as being due to inhibition of degassing by the quenching process.

Glacial history of Antarctica. The *Eltanin* core collection has provided definitive evidence of extensive continental glaciation (in the form of ice-rafted sediments) since at least the upper Miocene (Opdyke and Hays, 1967; Goodell *et al.,* 1968), and conceivably as early as the Eocene (Geitzenaur *et al.,* 1968; Margolis and Kennett, 1970, 1971) although palynological evidence from *Eltanin* cores (Kemp, 1972) is consistent with substantial forest cover of Antarctica during that period, as earlier suspected by Dodonov and Markov (1966). The age of the initiation of the extensive ice cover of the continent has yet to be determined. Another problem involves interpretation of the meaning of glacial-marine sediments: despite a coincidence of micropaleontological evidence of colder climate and glacial debris in some *Eltanin* cores (Margolis and Kennett, 1972), it is far from certain, as Warnke (1970) and Anderson (1972) have emphasized, that fluctuations in the ice-rafted sedimentary fraction is a simple function of changes from interglacial to glacial conditions.

Manganese nodules. The only sea floor materials of potential commercial value are manganese nodules, although, as Potter (1969) has summarized, "the exploitation of nodules in such deep, stormy, and fast flowing waters is a remote prospect."

A definitive and comprehensive study of the extensive *Eltanin* collection of dredged manganese nodules collected through Cruise 27 has been published by Goodell *et al.* (1971), who supplemented the 122 separate dredge hauls with specimens from 83 piston cores and information from several hundred bottom photographs. A resulting map of the

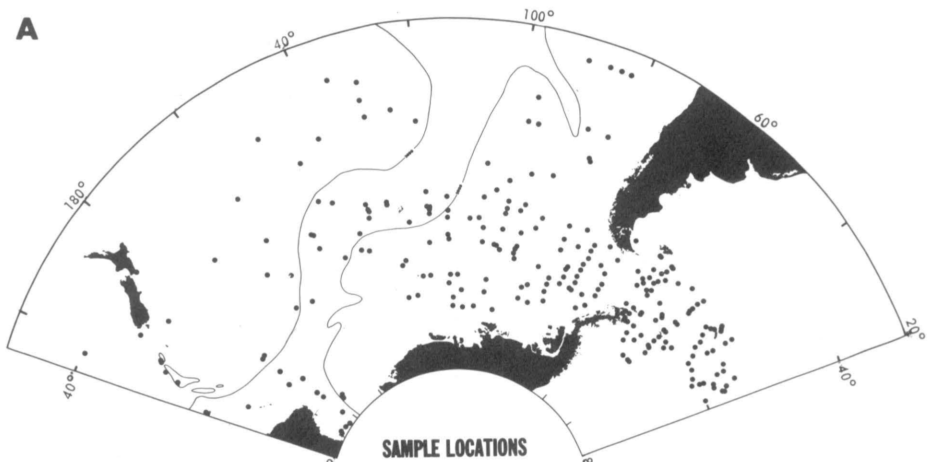


Figure 5A.
Locations of *Eltanin* dredge hauls, Cruises 5-27.

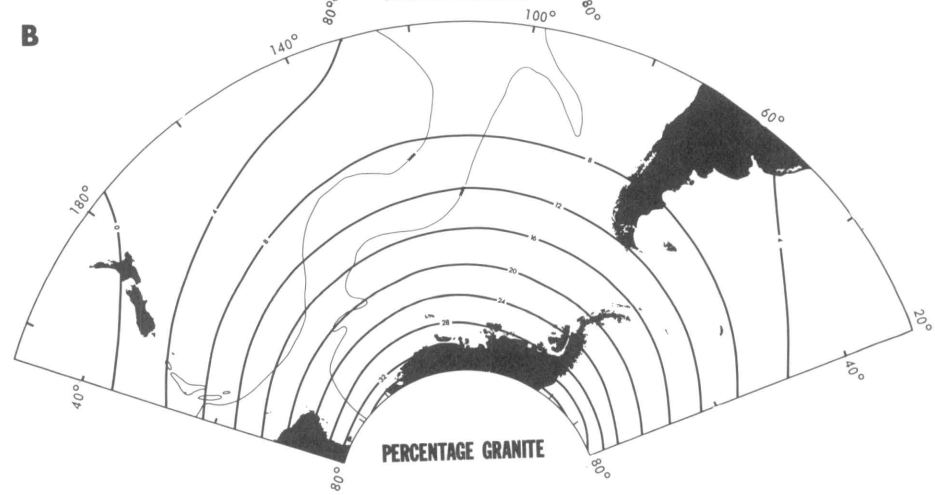


Figure 5B.
Second-order trend surface map showing granite percentage of each haul (Watkins and Self, 1971-1972). Amounts of granite decrease with each latitude away from the continent, consistent with ice-rafted origin.

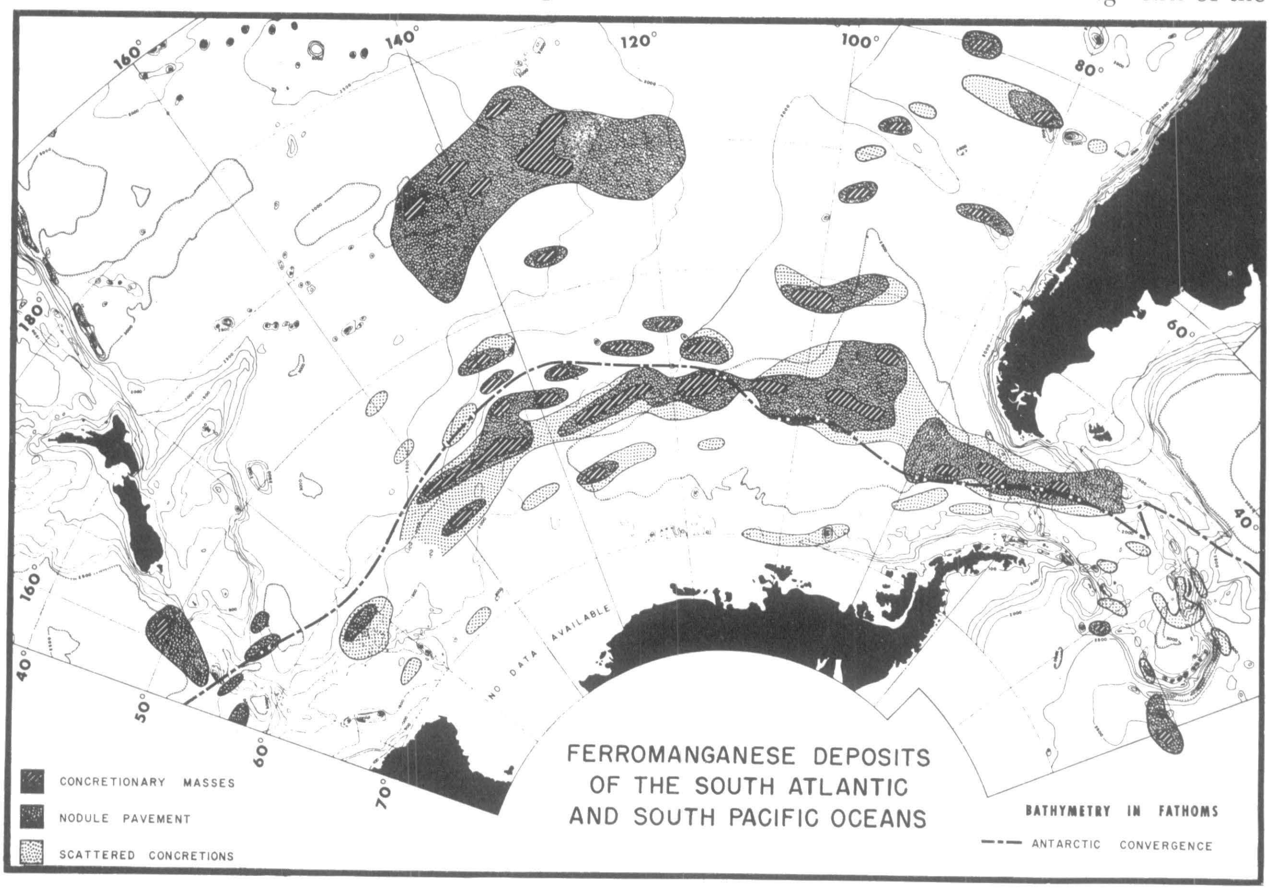
distribution of manganese nodules is shown in figure 6. One of the world's major manganese fields lies roughly along the position of the present Antarctic Convergence at about 60°S., without any relationship to underlying sediment type or water depth variation below 3,000 meters (Watkins and Self, 1972, fig. 9). According to Goodell *et al.* (1971), the nodules of the southwest Pacific basin are characterized as chalcophile (nickel, copper, cobalt, tin), whereas the East Pacific Rise is dominated by lithophile elements (titanium, vanadium, zinc, cobalt, barium, and strontium). Detrital minerals incorporated into the nodules are mainly quartz, feldspar, ferromagnesian and clay minerals, increasing in concentration southward towards the continent.

The origin and configuration of the nodule field is related to both source materials and sedimentation dynamics. It coincides closely with a scour zone defined, using both sedimentation rate measurements (Goodell and Watkins, 1968) and inferences from bottom photography (Hollister and Heezen, 1967). This demonstrates that the circumantarctic current has, through its sediment scouring capabilities, enhanced the growth of the nodule field. The same explanation applies to the other manganese field defined by the *Eltanin* program: the South Tasman Basin manganese "pavement" (Watkins and Kennett, 1971; Conolly and Payne, 1972), coincides with a zone of nondeposition (figure 4). The position of the Eltanin Fracture Zone suggests that it may have acted as a source region for much of the manganese field in the Bellingshausen Basin, and similarly tectonic activity in the Australian-Antarctic discordance (Hayes and Conolly, 1972) may have released those elements necessary for growth of the South Tasman Basin nodule field.

Cronan (1973) incorporated some *Eltanin* manganese nodules from the Scotia Sea into a comparative chemical study of Atlantic and Pacific nodules. He showed that the Atlantic materials have higher iron/manganese ratios, perhaps because of a higher fraction of continentally derived materials, in the Atlantic suite.

Summary and future prospects

Although the *Eltanin* materials and data have been only partially analyzed, the marine geology of the Scotia Sea and the subantarctic segments of the



Antarctic Research Series

Figure 6. Manganese nodule distribution in the circumantartic (Goodell, 1968).

South Pacific and southeast Indian Ocean is now as well known (and perhaps better understood) as any part of the world's deep ocean floors. The program, unprecedented in the scale, station density (figs. 2 and 5a), and rate of activity, has yielded in only 10 years an indefinitely greater scientific harvest than all other high latitude marine geology programs combined.

The intimate relationship between sediment type and distribution, climatic change, bottom current activity, manganese nodule development, and glacial history has been uniquely demonstrated by study of the core collection using diverse methods, and by use of bottom photographs and physical oceanographic results. This practice of the bringing together of various disciplines and methods is likely to produce further insights in the near future.

Because of the global importance of the circum-antarctic current, it is virtually certain that its changes in intensity and direction have been recorded in the sediments of all oceans. It follows that if a comprehensive understanding of the Pleistocene and Pliocene sedimentary history of the world's ocean basins is to be arrived at, results of study of the *Eltanin* core collection will play a key role.

Probably the major potential contribution that the *Eltanin* marine geology program can offer to polar science is a finely detailed chronology of the waxing and waning of the antarctic ice cap for the past two to three million years. This must rank as one of the most significant of all problems in geology, marine or otherwise. Although cores recovered during the Deep Sea Drilling Project are expected to provide the best means to delineate early to mid-Tertiary continental glaciation, it is only with the coring station density provided by the *Eltanin* program that such problems as the fluctuation of preferred iceberg track directions, intensity of iceberg production, and the long-term change in velocity and production of Antarctic Bottom Water can be studied.

Consideration of the advances made in marine geology since the beginning of the *Eltanin* program together with a modest extrapolation into the future suggests that emerging new techniques and refinement of present methods certainly will take place in the marine sciences. As this happens, the availability of the *Eltanin* materials and data means that the critical, most expensive, and most difficult to obtain components—the cores—will be on hand.

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.

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Marine Geophysics

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The research program aboard the *Eltanin* has resulted in the collection of the vast majority of existing marine geological and geophysical data for the area south of 35°S. Although the southern ocean has been one of the last to be systematically explored, the geophysical discoveries from the South Pacific and southeast Indian Ocean have been instrumental in establishing the credibility of the hypothesis of seafloor spreading and plate tectonics and in defining areas and topics for future research. In the last 10 years, the concepts of plate tectonics have led to a revolution in the earth sciences that is unparalleled in its 200-year history. The broad geographic scope and the comprehensive nature of the geophysical data collected aboard *Eltanin* soon demanded that the controversial theories of seafloor spreading and continental drift be critically rather than cynically examined.

During the first nine cruises of *Eltanin* the geophysical program consisted only of precision echo sounding and total intensity magnetic measurements (Kroenke and Woollard, 1968). The areas of concentration in this early phase of operations were the southwest margin of Chile, the Drake Passage, and the Scotia Sea. These *Eltanin* data were later supplemented by data collected by the British Antarctic Survey and led to the production of detailed bathymetric maps of the Scotia Sea (Heezen and Johnson, 1964; Barker, 1972). Further, patterns of magnetic lineations have been identified as part of the Cenozoic pattern of seafloor spreading (Barker, 1972a; 1972b).

Between *Eltanin* Cruises 10 and 16 the modest geophysical program gave way to programs with greater emphasis on physical oceanography and marine biology. However, commencing with Cruise 16 a seismic reflection profiling system (SPARKER) was installed on board the ship to complement the precision depth and magnetometer measurements. It was at this time (1965) that workers from Lamont-Doherty Geological Observatory became responsible for conducting the marine geophysical program aboard *Eltanin*. The scope of geophysical measurements has expanded gradually since that time and has included the upgrading and refinement of the existing instrumentation. At the beginning of Cruise 28 a Graf-Askania sea gravimeter was installed (Talwani, 1970; Talwani and Meijer, 1972). Before Cruise 39, a radio receiver for use with expendable sonobuoys was acquired to measure the velocity profile of deep sea sediments by wide angle reflection and refraction techniques. A 3.5 kilohertz sounding probe for use in examining the fine structure of the near surface sediments was installed just before Cruise 48. The reliability and value of most of the geophysical observations was greatly inhanced by the acquisition of a precision Navy satellite navigation system in late 1965.

Measurement of gravity at sea is a relatively difficult task (Talwani, 1970), and only a few investigators have attempted it. Consequently, the *Eltanin* gravity data provide the major source of information regarding the earth's field at high southern latitudes. The detailed knowledge of the earth's gravity field not only has been used in the analysis of local and regional structural problems, but it is also crucial in studies of the geoid and the shape of the earth. These latter studies are required, in part, to improve and expand our system of navigation and communications satellites. Since the southern hemisphere is predominantly an ocean hemisphere, the only means of obtaining a knowledge of the distribution of short and intermediate wavelength gravity anomalies (which cannot be detected by orbiting satellites) is through the use of ships.

One of the most important discoveries that resulted from the *Eltanin* program was presented by Pitman and Heirtzler (1966) and by Pitman *et al.* (1968). They analyzed bathymetric and magnetic profiles over the Pacific-Antarctic Ridge and unequivocally demonstrated that (1) magnetic lineations are present and are parallel to the topographic axis of the ridge, (2) the magnetic lineations are distributed in a bilaterally symmetric fashion about the ridge axis, (3) a model of normal and reverse polarity magnetic blocks, consistent with that proposed by Vine and Matthews (1963), could account for the observed anomalies near the ridge crest. In addition, they were able to show that a similar model of magnetic blocks could likewise account for the magnetic lineation pattern associated with other mid-oceanic ridges. The Cruise 19 magnetic and topographic profiles shown in fig. 1 demonstrate both the extraordinary bilateral symmetry of the lineation pattern and the close correspond-

Lamont-Doherty Geological Observatory contribution no. 1985.

ence of the observed magnetic profile to the theoretical one. Because this *Eltanin* profile has been reproduced in many publications, one sometimes hears the comment that it is the only profile in existence that clearly demonstrates these phenomena. This is not true; numerous profiles recorded by *Eltanin* throughout the southwest Pacific and the southeast Indian Ocean convincingly demonstrate the presence of the magnetic lineation pattern and bathymetry (*e.g.*, Cruise 39 profile, fig. 1).

This is not to say that complications do not exist. Fig. 2 illustrates the need to consider both morphologic and magnetic data simultaneously in evaluating the character of the mid-oceanic ridge system at any particular locale. The morphology at ridge crest axes varies from the Mid-Atlantic Ridge type where a rift valley is present to the East Pacific Rise type where the crest has no rift valley. It also is commonly known that the mid-oceanic ridge system is offset in a transcurrent fashion by amounts ranging from a few kilometers to hundreds of kilometers. Fig. 2 shows a recent crossing (Cruise 43) of the Pacific-Antarctic Ridge in the southwest Pacific in which a small fracture zone was crossed very near the crest of the ridge. This configuration gives rise to an apparent rift valley. However, the simultaneous recording of magnetic anomalies shows that the axial anomaly is repeated thereby establishing that a fracture zone, rather than a rift valley, was crossed. Fortunately, this profile was not one of the first examined in the critical initial phase of testing the Vine and Matthews hypothesis, for the observed polarity of the anomaly at the apparent ridge axis is opposite to that expected, and an entirely erroneous conclusion might have been drawn.

Systematic analysis of the *Eltanin* data in the South Pacific has led to the discovery of many important features relating to the processes of seafloor spreading and plate tectonics. The South Chile Ridge, which lies between the East Pacific rise and intersects the Chilean coast at about 45°S., was shown by Herron and Hayes (1969) to be an actively spreading ridge segment. This ridge lies adjacent to the Albatross Cordillera, and both systems are actively spreading, yet there is no evidence of crustal destruction in the intervening area. These observations provide the first indications that some ridge crests must migrate. Further analysis of the distribution of actively spreading ridges and seismicity around the antarctic continent and elsewhere has substantiated this argument.

The Eltanin Fracture Zone, which defines the single most dramatic offset in the Albatross Cordillera (East Pacific Rise-Pacific-Antarctic Ridge system), was shown to extend well over 4,000 kilometers to the northwest as a continuous topographic lineament (Hayes and Ewing, 1971). It has since

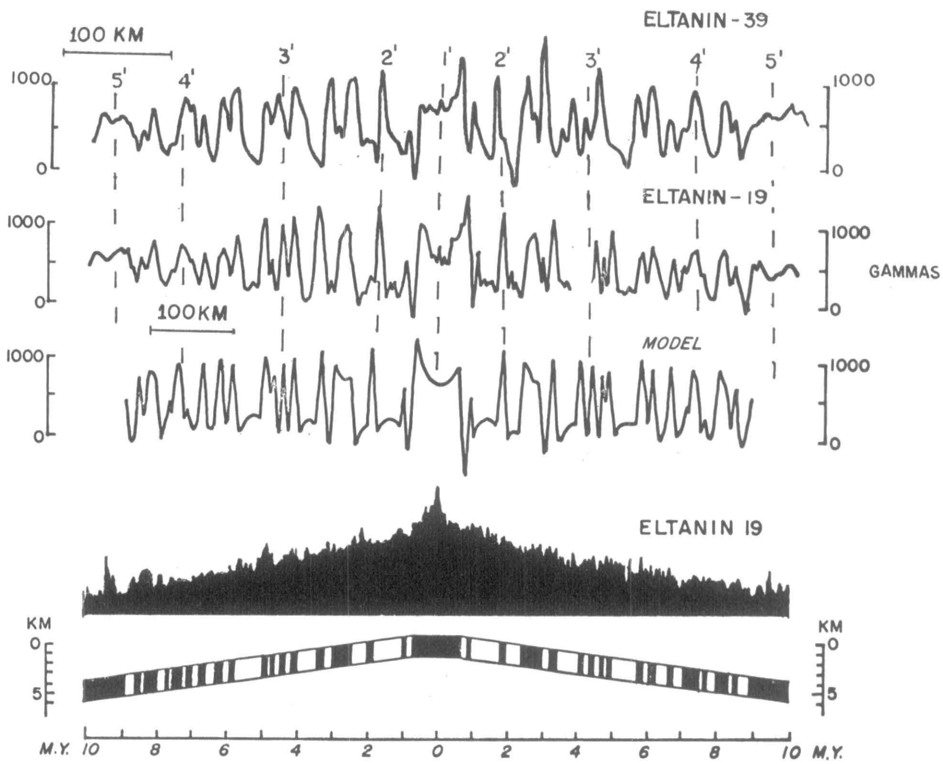

Figure 1. Observed magnetic anomalies from *Eltanin* Cruises 19-39, and ridge topography from Cruise 19. The theoretical anomaly computed from the block model (near the bottom) can be correlated with the observed profiles (Hayes and Pitman, 1970).

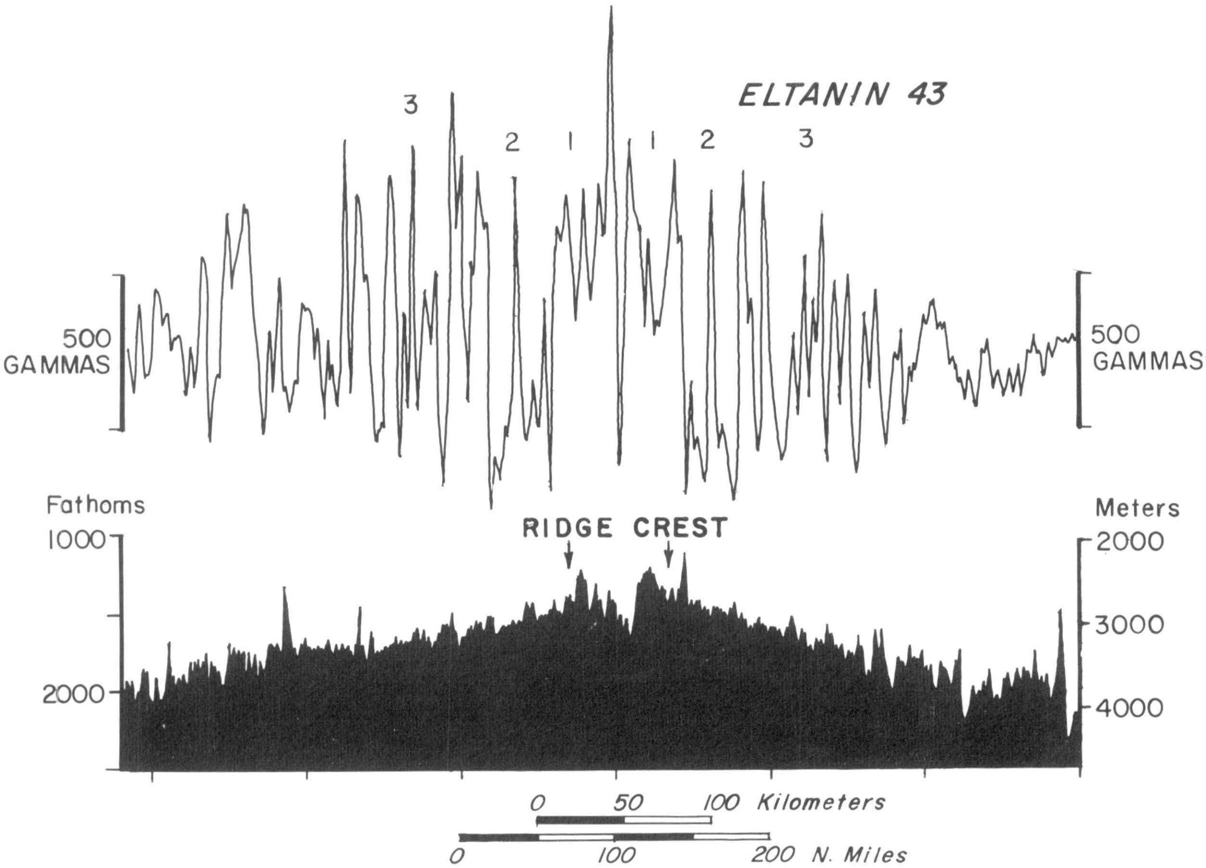

Figure 2. Magnetic anomalies and topography (compare with previous figure).

been speculated that this lineament records the migration of the Pacific crustal plate over a mantle hot spot where mantle material upwells.

The many *Eltanin* transits across the Patagonian continental margin area have confirmed the earlier suggestion of Hayes (1966) that the Peru-Chile trench continues as a structural feature well south of the latitude of the Chile Rise, where no topographic trench is evident due to its burial by terrigenous sediments (fig. 3). The region where the trench is buried corresponds to a portion of the continental margin that is essentially aseismic. Analysis of the patterns of seafloor spreading shows that crustal subduction along this margin has been dormant for a long time, thus allowing sediments to fill the older structual trench and remain relatively undisturbed.

The general pattern of sediment distribution throughout the southern ocean shows that the thickness of sediments is determined largely by the age of the underlying seafloor. Naturally, the older the seafloor, the more potential it has for accumulating thick quantities of sediment (*e.g.,* fig. 4). However, this simple pattern is modified substantially by variations in the patterns of surface and bottom currents and also the type and population of planktonic organisms that lived in the near surface waters. Further, the distribution of terrigenous sediments is largely controlled by the proximity of terrigenous source areas and the effectiveness of topographic barriers in limiting downslope transport of detritus. Fig. 5 shows a highly simplified version of a sediment isopach map for the southern ocean (Houtz *et al.,* 1973). Information synthesized in this isopach map has come largely from the seismic reflection profiles and sonobuoy data collected aboard *Eltanin.* Much additional work needs to be done in analyzing the role of deep sea topographic barriers in affecting sediment distribution and also in examining the nature of the continental margin of Antarctica. Continental margins are difficult areas to work in, and the antarctic continental margin especially so because of ice and severe storms.

Recently, several major discoveries have been reported for the southeast Indian Ocean, *Eltanin's* area of concentration during the last several years. These findings are summarized in a comprehensive volume (Hayes, 1972). Many of the geophysical studies presented in this volume consider some new aspects of seafloor spreading and resulting complications; these complications must be taken into account in refining the existing theories. The ability to define new problems and to recognize the need for refinement of these theories has only been possible because of the dense data coverage in this area.

Among the more significant findings for the southeast Indian Ocean is the Australian-Antarctic Discordance, a highly disrupted segment of the Southeast Indian Rise. This disrupted segment is unlike any other known portion of the mid-ocean ridge system. It is bounded on both sides by relatively simple ridge segments. Within the Australian-Antarctic Discordance the ridge crest cannot be recognized convincingly, and the regional depths are several hundred meters greater here than in adjacent areas. Within the disturbed portion of the ridge the typical magnetic anomaly pattern cannot be identified easily. The geological processes responsible for this unique segment of the seafloor are still a matter of conjecture (Weissel and Hayes, in prep.).

A high degree of bilateral symmetry has generally been observed in the development of new ocean crust and the generation of magnetic anomalies, and it is often assumed that this symmetry is an essential condition in the seafloor spreading process. Weissel and Hayes (1971, 1972) provided the first evidence that some large areas of the seafloor have been generated through processes of seafloor spreading in a systematic asymmetric fashion. The observed asymmetry was large, with about 40 percent more material generated on the north flank of the ridge than on the south flank. This asymmetric generation of seafloor, occurring over long periods of time and with the fidelity at the scale of 5 kilometers or less, imposes serious problems to existing models of crustal accretion (Hayes, 1971).

The detailed mapping of the magnetic, morphologic, and fracture zone patterns between Australia and Antarctica by Weissel and Hayes (1972) and Hayes and Conolly (1972) has provided the information necessary for uniquely determining the position of Australia with respect to Antarctica in the pre-rifted Gondwanaland puzzle. Further extension of this history of the southern ocean has come about through the recognition that the Tasman Sea, a major marginal sea, was generated by processes of seafloor spreading that have been dormant for about 60 million years (Hayes and Ringis, 1972, 1973). Within the Tasman Sea, magnetic anomalies are bilaterally symmetric about an ancient, buried ridge crest. Without the joint analysis of magnetic and seismic reflection information, the evolutionary history of this basin could not have been recognized. The definition of the timing and direction of motion of New Zealand (and associated submerged continental plateaus) with respect to Australia has allowed further conclusions to be drawn regarding the paleogeographic reconstruction of Gondwanaland.

The distribution of sediments on the seafloor of

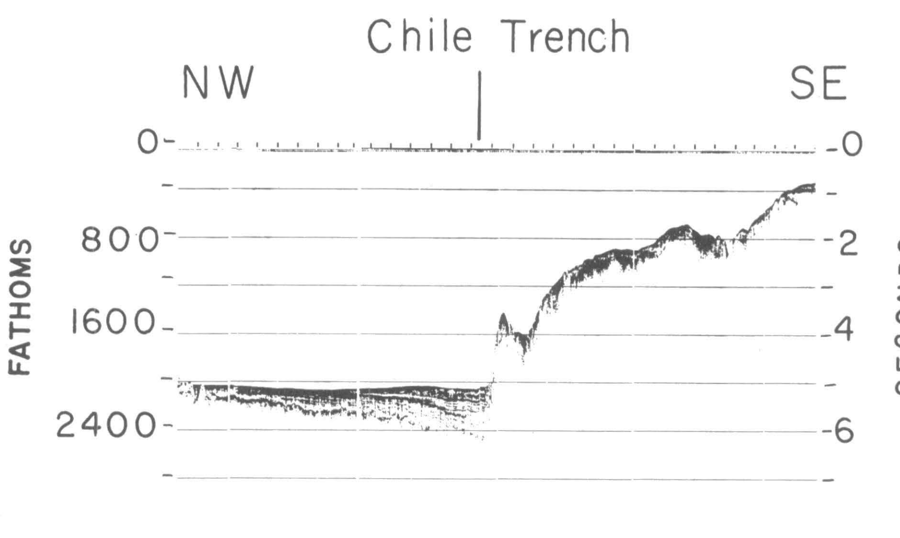

Figure 3. Seismic reflection profile across the sediment-filled segment of the Peru-Chile Trench.

the southeast Indian Ocean was mapped by Houtz and Markl (1972), and this general pattern is also included in fig. 5. The South Indian abyssal plain lying south of the ridge is built up to a level approximately 1 kilometer higher than its counterpart to the north. The continental rise and adjacent abyssal plain next to the antarctic continent are believed to be composed dominantly of terrigeneous sediments. If we assume that the presence of a thick ice cap inhibits the extent to which terrigeneous material can be derived from the antarctic continent, how can so much sediment have been derived from the antarctic continent during the short period following continental rifting and prior to the formation of the glacial ice? This is especially puzzling when one contrasts the relatively long history of erosion and transportation of terrigeneous material from the Australian continent and the resulting thin blanket of terrigeneous sediments deposited on the seafloor to the south.

The tectonic evolution of the Macquarie Ridge complex southwest of New Zealand has long been an area of controversy. Many *Eltanin* cruises, (*e.g.* 16, 27, 37, 44 and 53) concentrated on surveys of this region. It has now been shown that the Macquarie Ridge complex cannot simply be related to crustal extension, crustal subduction, or transcurrent faulting, but that different segments of the complex are probably represented by all three of these tectonic regimes (Hayes and Talwani, 1972; Hayes *et al.*, 1972; Christoffel, 1971). The history and nature of this tectonically complex region can be understood as a natural consequence of the interaction of crustal plates moving about as a result of the seafloor spreading processes. The *Eltanin* Deep Sea Drilling Project. Houtz and Meijer (1970) and Houtz and Davey (in press) have mapped the major geophysical parameters of the continental shelf lying north of the Ross Ice Shelf. They have shown that the area can be divided into two distinct geological provinces separated by a major structural discontinuity trending approximately north-south and lying close to the 180° meridian. Their studies constitute the only comprehensive geophysical survey of the antarctic continental shelf. Many shallow water regions, such as the continental shelves of the Antarctic Peninsula and the Weddell Sea, are now "accessible" in terms of our present technological ability to exploit buried resources. The question of the economic potential and exploitation of the antarctic continent and the surrounding seafloor is being addressed. The United States, through the *Eltanin* program, is the only country that has accumulated adequate data to evaluate the potential of offshore areas and to provide informed scientific guidelines to other Antarctic Treaty countries.

The Kerguelen Plateau has been an area of intense investigation for *Eltanin* Cruises 46, 47 and 54. The origin and nature of this submerged plateau is not clearly understood. However, it seems likely that it is a foundered microcontinent that was previously attached to the antarctic continent, or at least lay closer to it than at present. A complete magnetic lineation pattern representing the Present out to anomaly 18 (about 45 million years ago) has been recognized along the northeast flank of the Kerguelen Plateau and along the southwest flank of the Naturaliste Plateau and Broken Ridge, and these two features were thus once contiguous.

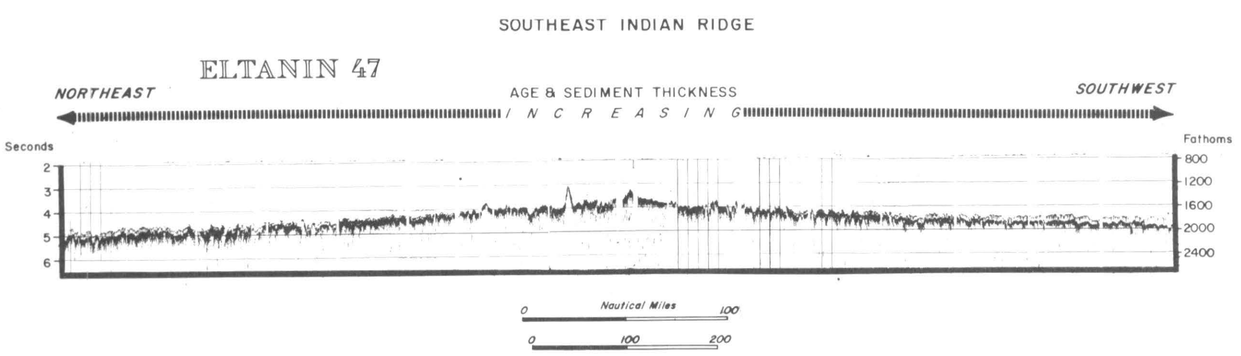

Figure 4.

Seismic profile across the Southeast Indian Ridge, showing a uniform increase in the thickness of pelagic sediments with the increasing age of underlying crystalline rock.

marine geophysical data have been used in attempts to explain the nature and timing of movement along the Alpine Fault of New Zealand (Christoffel, 1971; Hayes and Talwani, 1972).

The Ross continental shelf has been the target of recent *Eltanin* geophysical exploration and the However, south of Australia and north of Wilkes Land, magnetic anomalies are recognized that extend as far back as anomaly 22, about 55 million years ago (fig. 6). One possible explanation for this distribution of anomalies is that an ancient locus of crustal accretion jumped (about 45 million years

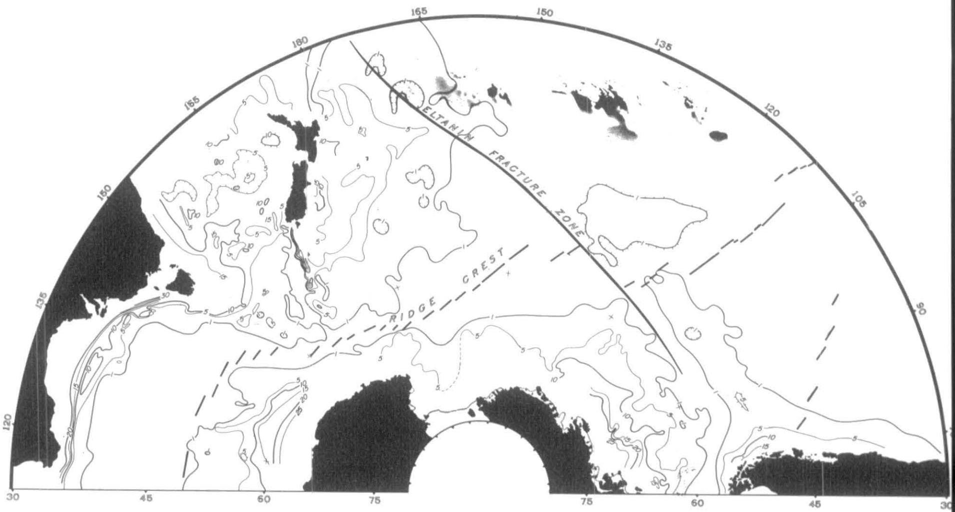

Figure 5.
Sediment isopach map (stereographic polar projection simplified from Houtz *et al.*, in press). Contours are in tenths of a second of reflection time (0.1 sec.=100 meters of sediment). The ridge crest usually defines the areas of minimum cover.

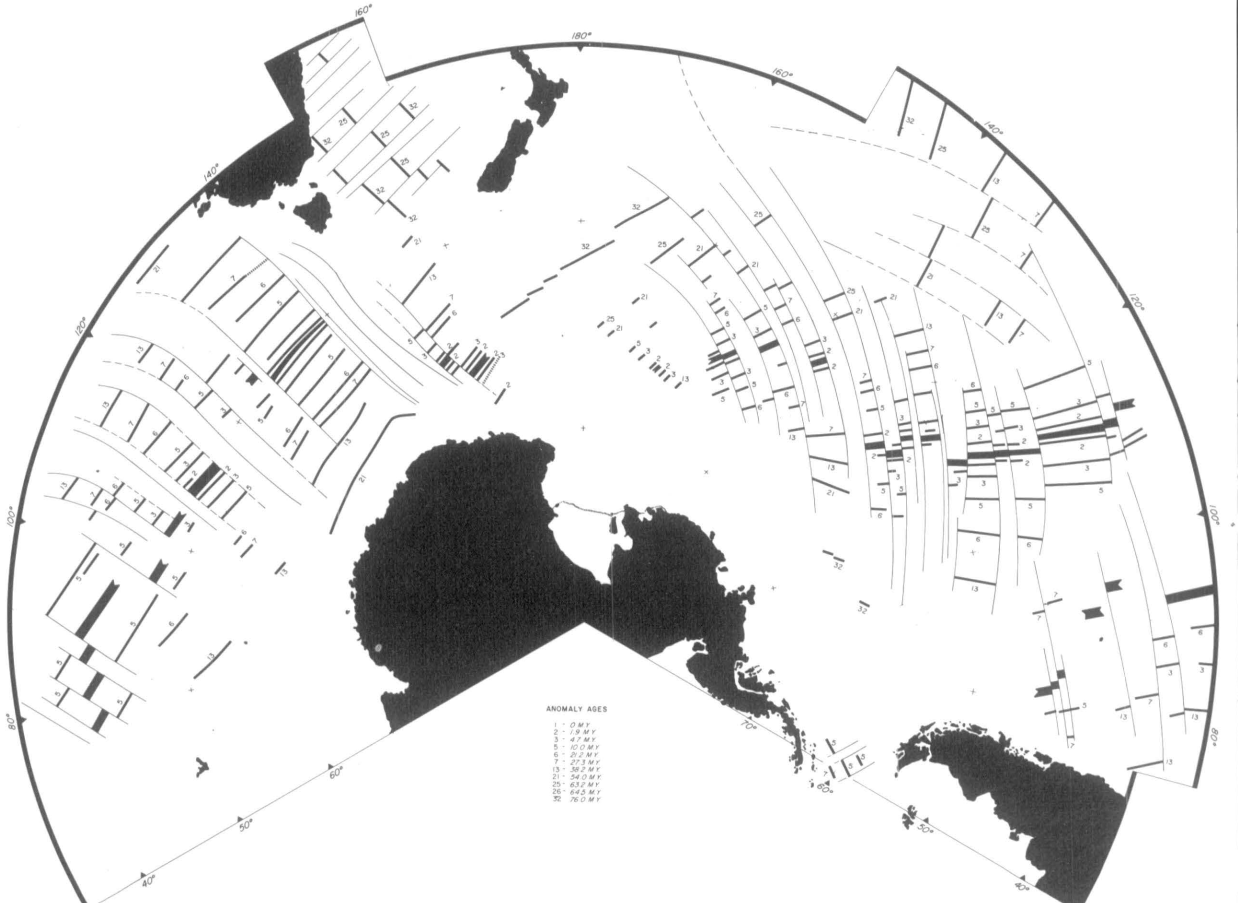

Figure 6. Magnetic lineations and inferred basement ages (modified from Pitman *et al.*, press). Stereographic polar projection.

ago) from an area southwest of Kerguelen Plateau to its northeastern flank. To test this hypothesis it is necessary to conduct surveys in the unknown region southwest of the Kerguelen Plateau to look for symmetrically distributed anomalies corresponding to anomalies 22 through 19 and an extinct ridge axis. If such anomalies are not present, indicating that the Kerguelen Plateau has always been in its present position with respect to Antarctica, a major shear zone must have existed that extended south from western Australia to the Antarctic continent, and which was active from about 55 to 45 million years ago (Ewing *et al.,* 1972).

In addition to the studies cited above, the *Eltanin* geophysical data have contributed heavily, although often not obviously, toward the success of many other scientific studies. Such studies include nearly circumpolar bathymetry and physiography (*e.g.* Heezen and Bentley, 1973; Heezen and Tharp, 1969) and similar studies of the South Pacific now in preparation by J. Mammerickx and others at Scripps Institution of Oceanography. Also aided are empirical curves of ridge elevation and crustal age (*e.g.* Sclater *et al.,* 1971), a synthesis of magnetic anomalies and crustal ages (fig. 6 and Pitman *et al.,* 1973), and global continental drift and plate tectonics (*e.g.* LePichon, 1968).

Glomar Challenger's first leg of deep sea drilling in the Antarctic has recently been completed and was very successful. It is *Eltanin* geophysical information that has allowed drilling in antarctic waters to become a reality and that has helped give high scientific priority to additional proposed drilling there.

The sector of the southern ocean between 80°E. and 30°W. is the only major oceanic area on this planet that has not yet been examined in at least a cursory reconnaissance fashion. This is the area that is the most enigmatic and controversial in terms of Gondwanaland reconstructions. In addition, our knowledge of the continental geology of Antarctica corresponding to this sector is poor. Outcrops on the continent are confined to narrow bands near the coast, and it is unlikely that much additional knowledge of this sector will be obtained using existing methods of geological survey. It is more likely that the key to greater knowledge of the Enderby Land and Queen Maud Land sectors can best be realized by analyzing the sediments and geophysical properties of the southwest Indian and southeast Atlantic Oceans.

Although the southwest branch of the Mid-Indian Ridge is defined roughly by earthquake epicenters and by the regional morphology, there is still considerable ambiguity regarding the true trends of the ridge and associated fracture zone segments. Further, no seafloor spreading magnetic lineations have been recognized in this area.

The *Eltanin* research program was by no means perfect, but the resultant scientific accomplishments are impressive. The significance of the science and the associated cost can withstand a rigorous, critical evaluation. There appears to be no alternative means to complete the research designated for *Eltanin*. A major scientific goal, that of the southern ocean circumpolar survey, has been left uncompleted, and marine science studies everywhere will suffer as a consequence.

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Paleontology

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The expansion of the United States Antarctic Research Program in 1961-1962, by adding the USNS *Eltanin* to its program, contributed greatly to the impetus of multidisciplinary programs in the southern ocean. One phase of these involved the study of the paleontology of deep-sea cores combined with paleomagnetic stratigraphy of those same cores. Other phases involved the study of population gradients, the definition of paleoclimatic indices, the study of depth zonation of species in waters with essentially no temperature gradient, and the employment of paleontological criteria in defining deep-sea unconformities or hiatuses.

Paleontological highlights of the first 55 cruises of *Eltanin* are those involving largely the microfossil groups of radiolarians and foraminiferans, with less attention given to groups such as diatoms and silicoflagellates.

Benthic foraminiferal distribution

At the outset of the *Eltanin* programs, studies were made of distributions of recent foraminiferans to establish an improved depth zonation (McKnight, 1962; Bandy and Echols, 1964). With the sampling program of the *Eltanin* operation, studies were made of the depth zonation of foraminiferans in the area of the Peru-Chile Trench from samples taken during Cruise 3 (Bandy and Rodolfo, 1964; Theyer, 1971a). Distributions of foraminiferans in Drake Passage have been determined from samples taken largely during Cruises 4, 5, and 6 (Herb, 1971). Cruises 7, 8, and 9 in 1963 and Cruise 12 in 1964 provided cores used in determining the benthic foraminiferal patterns in the Scotia Sea area (Echols, 1971). Benthic foraminiferal trends in the Pacific-Antarctic Basin were made possible by samples taken on Cruises 7 to 17 of *Eltanin* (Theyer, 1971b). Pflum (1966) reported on four profiles distributed between the Ross Sea and the Bellingshausen Sea. These and other studies have provided a basis for evaluating the depth zonation of benthic foraminiferans in much of the antarctic waters, an important aspect assisting in the paleoenvironmental interpretations of fossil assemblages.

An important discovery in benthic foraminiferal studies is the generally isobathyal nature of a number of important species common to the Antarctic and to lower latitudes (Bandy and Echols, 1964). For example, *Bulimina aculeata* d'Orbigny has similar distribution patterns in low and high latitudes; *Epistominella exigua* (Brady) has a similar depth distribution in the Antarctic, the Gulf of Mexico, and the Gulf of California. Of equal importance is the definition of depth zonation of benthic species in antarctic waters in the absence of an important temperature gradient. Both depth distribution and the provinciality of benthic populations were defined by Herb (1971) for Drake Passage and by Echols (1971) for the Scotia Sea area.

Planktonic zonation

One of the major problems in the studies of radiolarians has been the contrast between the tests accumulating on the sea floor and those of living populations in the water column (Hays, 1965). Studies of living foraminiferal populations such as those by Be (1969) compared with the work of Blair (1965) show this as well. Cruises 8 through 19 provided planktonic tows for studies of the living foraminifera of the Antarctic in Be's study. Hays (1965) pointed out that the boundary between antarctic and subantarctic radiolarians is 3° to 10° north of the mean position of the Antarctic Convergence. It was suggested that this implies a recent warming period during the past few thousand years. Two other factors contribute to this disparity (Bandy, 1972a): (1) there is a northward movement of antarctic surface water as descending subantarctic intermediate water to the north of the polar front, transporting antarctic populations to the north of the Antarctic Convergence before they are deposited on the sea floor, and (2) many of the cores from Cruises 39 and 45 are known to have Pleistocene or older sediments exposed near the surface of the sea floor. Clearly, deep tows are needed to establish the degree of northward movement of planktonic groups at depth in the water column in order to evaluate properly the first factor.

The major initial work on late Tertiary and Quaternary history of antarctic seas was that by Hays (1965) in which the radiolarian zonation was defined, based upon many core analyses including those from Cruises 4 and 8 of *Eltanin*. Subsequent verification of this together with modifications resulted from his studies of cores from Cruise 11 (Hays, 1967) and from Cruises 13 and 14 (Hays and Opdyke, 1967). The latter study related the radiolarian zonation directly to the paleomagnetic scale. This basic zonation of Hays (1965) and Hays and Opdyke (1967) was modified slightly by Bandy *et al.* (1971) with letter subdivisions (table) based on studies of cores from *Eltanin* Cruises 13 and 14.

Planktonic foraminiferal zonation for the southern oceans is that being developed for cores largely north of the polar front owing to the lack of carbonate biofacies to the south. In his study of *Eltanin* cores from Cruises 4, 11, 15, 20, and 21, Kennett (1970a) defined a *Globorotalia puncticulata* zone in the lower Pleistocene with an upper limit near the Brunhes-Matuyama boundary; a *Globorotalia inflata* zone was defined for the Brunhes from about 650,000 years to about 300,000 years in northern subantarctic waters and about 200,000 years in southern subantarctic waters; a *Globorotalia truncatulinoides* zone was defined above this diachronous boundary in the uppermost Brunhes. These zonal indices were thought to have appeared much later in time than in low latitudes as a result of adaptation rather than reflecting paleoceanographic changes (Kennett, 1970a).

In contrast, Theyer (1972, 1973) has evidence in cores from Cruise 39 that *Globorotalia truncatulinoides* made its first appearance in the Gauss in several cores near southern Australia where it occurs together with diagnostic radiolarians such as *Prunopyle titan* and *Lychnocanium grande*. Watkins *et al.* (in press) disagree with the findings of Theyer; however, there is no question but that there is an overlapping set of ranges for the critical species mentioned above in the cores studied by Theyer. A comparison of zonations by various authors is given in fig. 1. Note that studies of *Eltanin* cores by different investigators using somewhat different techniques are providing what appear to be conflicting sets of data, highlighting problems that need resolution. From the extensive analyses of Theyer (1972, 1973), it is clear that there is a much more extensive area of Gauss-age sediments exposed on the sea floor south of Australia than was discovered earlier by Watkins and Kennett (1971, 1972).

Based in part on Cruise 11 cores of the *Eltanin,* Donahue (1967) developed a late Pliocene-Pleistocene zonation for diatoms. The evidence suggests that the latest Pliocene was warm, there was some cooling in the lower Pleistocene (Chi Zone), and the later Pleistocene (equivalent to the Brunhes) contains cold water forms. Thus, the zonation developed is essentially based on paleoceanographic changes. Precise correlation is possible with diatoms, as is nicely illustrated in studies of *Eltanin* cores from Cruises 39 and 44 (Abbott, 1971; Payne *et al.,* 1971).

Paleoclimatology and paleoceanography

Using data from various sources together with that from *Eltanin* cores from Cruises 13, 21, 23, and 24, Margolis and Kennett (1970, 1971) determined that there has been low planktonic foraminiferal diversity during much of Cenozoic time, suggesting relatively cool temperatures throughout this long time interval. Ice-rafted sand grains support the conclusions that glaciation must have prevailed throughout much of the Cenozoic. Mandra and Mandra (1970) in studying antarctic silicoflagellates discovered evidence of a warmer climate during the Late Eocene and indicate that the Paleocene-Eocene climates of coastal Antarctic were at least as warm as the modern climates of South Island, New Zealand. Correspondence of paleoclimatic data from silicoflagellates and planktonic foraminiferans was demonstrated by Jendrzejewski and Zarillo (1972) in a study of late Pleistocene samples from a core taken on *Eltanin* Cruise 33.

A series of paleoclimatic cycles has been illustrated in the studies of late Cenozoic core segments of the *Eltanin* program. Cores 11-2, 4-5, and 11-3 were studied by Hays (1965, 1967) and by Kennett (1970a). The presence of temperate radio-

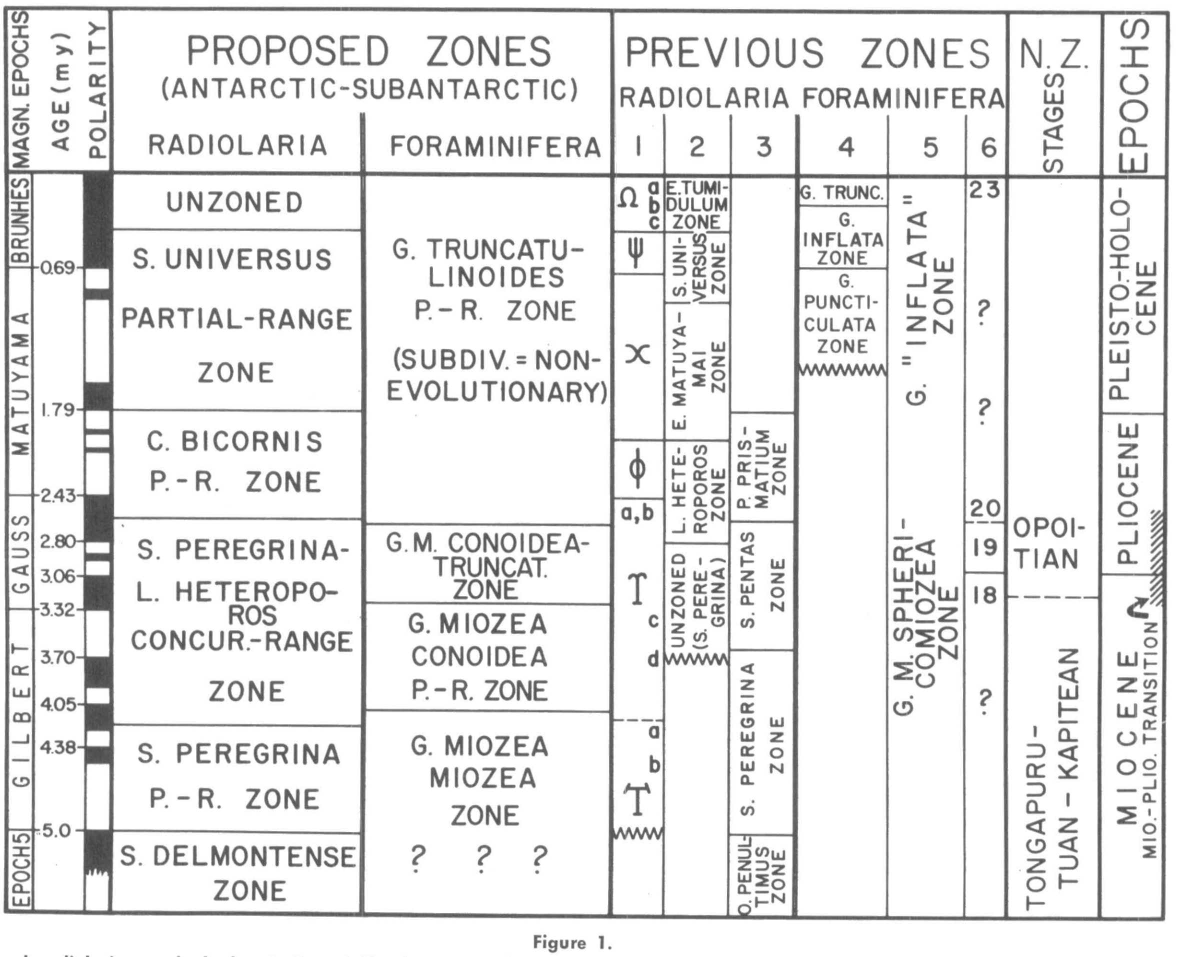

Figure 1.
Proposed radiolarian and planktonic foraminiferal zones and correlation with previous work (Theyer, 1972). References are: (1) Antarctic, Hayes and Opdyke, 1967, Bandy *et al*., 1971; (2) North Pacific, Hayes. 1970; (3) tropics, Riedel and Sanfilippo, 1970, 1971; (4) Antarctic-Subantarctic, Kennett, 1969, 1970; (4) New Zealand, Jenkins, 1971; (6) tropics, Blow, 1969. Correlation of 3, 5, and 6, completed with the magnetic scale inferred from the present work. Number 4 was indirectly correlated with the scale by Kennett; 1 and 2 are results of direct correlations.

larians in the Chi zone, now correlated with much of the middle and upper Matuyama Magnetic Epoch, suggests this zone is somewhat warmer than the Brunhes above; conversely, Kennett (1970a) and Keany and Kennett (1972) conclude from their study of foraminiferal data that the Matuyama was cooler than the Brunhes. Since the temperate radiolarian *Saturnulus planetes* occurs together with other warm water indices in the lower Gilbert, in the Matuyama, and again at the top of the Brunhes as reported by Bandy *et al.* (1971) in *Eltanin* cores (Cruises 13 and 14), it is unlikely that it changed its environmental tolerance at the base of the Brunhes. Similarly, *Globigerina antarctica* (Keany and Kennett, 1972) is the modern warm water planktonic foraminifer often referred to incorrectly as *Globigerina falconensis* Blow, a Miocene species; this warm water form occurs in the Matuyama and disappears in the Brunhes in antarctic waters although it continues living today in warmer waters to the north. *Eltanin* cores from Cruises 13 and 14 provided the samples used in showing that the colder paleoclimatic cycles in the Brunhes were less than 0°C., whereas the minimum values for cool cycles in the Matuyama Magnetic Epoch were about 5°C. (Bandy and Casey, 1970; Bandy *et al.* 1971).

Regardless of the differences of interpretation of paleoclimatic data for core studies, clearly, climatic cycles are being defined in high latitudes of the Antarctic by various techniques, showing perhaps 10 warm cycles in the Matuyama and at least four, perhaps six, in the Brunhes Normal Magnetic Epoch. Variations in sampling intervals, variations in the preservation of faunas, and variations in depositional hiatuses contribute to many of the discrepancies in data from core to core. This is particularly true in cases involving the definition of minor paleoclimatic cycles.

Eltanin Cruises 27, 34, 36, 37, 38, and 39 provided core data that enabled Watkins and Kennett (1971, 1972) to define an extensive area of erosion centered in the south Tasman Basin between Australia and Antarctica. This major sedimentary disconformity, defined by employing paleomagnetic methods and micropaleontology, is thought to have been produced by a substantial increase in the velocity of Antarctic Bottom Water associated with late Cenozoic cooling and a corresponding increase in glaciation of Antarctica.

Planktonic species serve as important indices of water masses; *Eltanin* collections have contributed much to the knowledge of these and to their utilization in defining important changes in water mass boundaries in geologic time. Hays (1965) reported important changes in the skeletal structure of radiolarians across the polar front; those to the south have thick shell walls and those to the north have thin shell walls, even within the same species; *Eltanin* Cruises 4 and 8 provided some of the data for this study. Herb (1968) defined important changes in planktonic foraminiferans across the Antarctic Convergence in Drake Passage from collections taken during *Eltanin* Cruises 4, 5, and 6. Significant changes in forms of *Globigerina bulloides* d'Orbigny were defined across water mass boundaries principally in the area of *Eltanin* Cruise 45, in the southeastern Indian Ocean (Bandy, 1972a).

The most significant planktonic foraminifer in the southern oceans is *Globorotalia* (*Turborotalia*) *pachyderma* (Ehrenberg). In early studies it was discovered that left-coiling populations of this species occur in both north and south polar waters whereas right-coiling populations are characteristic of temperate waters (Bandy, 1960). Kennett (1968) and Malmgren and Kennett (1972) defined a latitudinal variation in *G. pachyderma,* from thick-walled, four chambered (final whorl) forms in antarctic waters, to 4½ to 5- chambered forms in a band roughly between the Antarctic and Subtropical Convergences, and then to thin-walled four-chambered forms to the north. Arctic and antarctic forms of this species were shown to be somewhat different (Kennett, 1970b).

In analyses of cores from *Eltanin* Cruises 4, 5, 6, and 39, and samples from other sources, a comparison was made of specimens of *G. pachyderma* from both the water column and the bottom sediments in the antarctic and arctic areas (Bandy and Theyer, 1971; Bandy 1972b). The very globose forms with a highly thickened wall are quite unique antarctic forms of the species, and it has been found that the northward expansions of this type occurred during major cold cycles of the late Cenozoic. The origin and development of this critical form and its variations have served to establish a bipolar paleoclimatic model for the late Cenozoic, cold cycles being marked by expansions into lower latitudes of these variations or subspecies and warm cycles being marked conversely by the retreat of these indices toward higher latitudes (Bandy, 1972b). Such intrusions of colder water masses into lower latitudes provide important information about paleoceanographic changes and also serve as significant events for geochronology.

Faunal extinctions and magnetic-field reversals

Studies of radiolarians in cores from antarctic seas, including *Eltanin* cores from Cruises 13 and 14, have contributed evidence that six of the eight

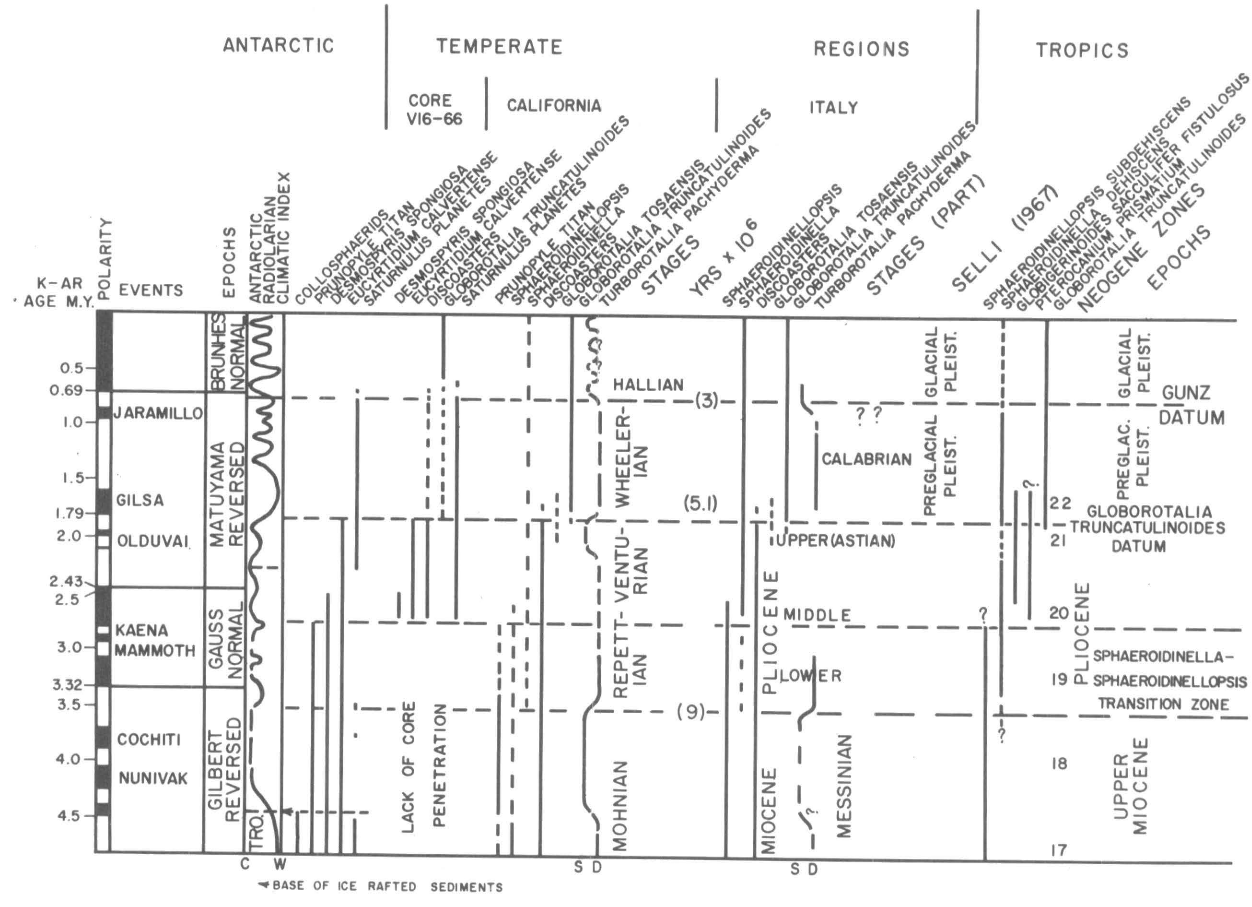

Figure 2.
Major late Neogene planktonic datum planes (revised from Bandy, Casey, and Wright, 1971). The upper limit of the Miocene in the Antarctic (at 3.5 million years) is approximately at the extinction level of *Cyrtocapsella tetrapera* and *Theocyrtis redondoensis*. The paleomagnetic scale is from Cox (1969).

species that have become extinct in the past 2.5 million years disappeared near magnetic reversals (Opdyke *et al.* 1966; Hays and Opdyke, 1967; Hays, 1971). Hays indicates that the data gathered so far do not support the correlation of extinctions with reversals for most radiolarians and foraminiferans (Hays, 1971); however, there is a good correlation for some species.

Kennett and Watkins (1970), in studies of cores from *Eltanin* Cruises 27, 32, and 33, show that some volcanic maxima occurred when geomagnetic polarity was changing. They conclude that upper mantle activity and geomagnetic polarity change may be related and that the coincidences of faunal extinction and polarity reversals may be related to volcanically induced climatic changes.

Interestingly, Crain (1971) points out that experimental data suggest that very low magnetic fields have serious deleterious effects on many organisms. He suggests that the low magnetic field itself during reversals, rather than increased cosmic radiation, may have produced mass extinctions.

Discussion

Paleontological discoveries of many kinds stem from the *Eltanin* program. Many of these are complementary to programs under way by other ship programs in lower latitudes, extending those in an important way. In paleontology, one of the most significant results has been the development of planktonic zonation on a background of the paleomagnetic scale and its radiometric base. These relationships led to the construction of a correlation model for major Neogene planktonic events from the Antarctic to the tropics (Bandy and Casey, 1969; Bandy *et al.*, 1971). The base of the Pleistocene was correlated with the base of the Gilsa event at about 1.79 million years; the base of the Pliocene was placed at about 3 million years based on the correlation of the first appearance of *Sphaeroidinella dehiscens* at this point by Glass *et al.* (1967), an event that marks the base of the classic lower Pliocene in Italy.

A revised model is presented here for the correlation of major Neogene planktonic datum planes from the Antarctic to the tropics (fig. 2). The major revision is in the placing of the Miocene-Pliocene boundary at about 3.5 million years. The basis for this change is that the classic lower Pliocene of Italy shows a transition zone in which there is the co-occurrence of *Sphaeroidinella dehiscens* and ancestral forms of *Sphaeroidinellopsis;* a restudy of V20-163 in the Indian Ocean shows this zone to correlate with the interval from about 3.5 to about 3 million years or slightly less (Bandy, in press). Further, the upper Miocene type sections of Italy exhibit an assemblage of planktonics of the *Globorotalia miozea* group; this same group occurs in the Gilbert Reversed Magnetic Epoch of V20-163 restricted below a level corresponding with 3.5 million years. In cores from the southern oceans, south of the polar front, this upper Miocene boundary is represented by the upper limits of the radiolarians *Cyrtocapsella tetrapera* and *Theocyrtis redondoensis,* which is the upper limit of Upsilon *d* of Bandy *et al.* (1971).

Radiolarian zones of Hays (1965), Hays and Opdyke (1967), with letter subdivisions added by Bandy et al. (1971).

QUATERNARY	Omega Zone	a. Modern *Spongoplegma antarctica* complex with warm water forms such as *Theoconus zancleus* and *Saturnulus planetes.* b. Modern *Spongoplegma antarctica* complex without a warmer water influence.
QUATERNARY	Psi Zone	*Acanthosphaera* sp. group (middle Brunhes, with its upper boundary at about 400,000 years) (Hays, 1967).
QUATERNARY	Chi Zone	*Saturnulus planetes* and *Pterocanium trilobum,* upper limit approximates the upper boundary of the Matuyama Reversed Magnetic Epoch, at about 690,000 years.
QUATERNARY	Phi Zone	*Eucyrtidium calvertense* upper limit approximates Gilsa event, the base of the Quaternary, 1.79 million years.
PLIOCENE	Upsilon Zone	a. *Desmospyris spongiosa* and *Helotholus vema* upper limits, in the lower Matuyama. b. *Prunopyle titan* and *Lychnocanium grande,* upper limits in upper Gauss Normal Magnetic Epoch. c. *Oroscena* (digitate) and *Oroscena carolae,* upper limits near upper boundary of the Gilbert Reversed Magnetic Epoch, perhaps at 3.32 million years.
MIOCENE		d. *Cyrtocapsella tetrapera* and *Theocyrtis redondoensis,* upper limit in the upper Gilbert at about 3.5 million years.
MIOCENE	Tau Zone	a. *Triceraspyris sp.,* upper limit at about Gilbert b, between 4.05 and 4.25 million years. b. *Ommatocampe hughesi* and *Cannartiscus marylandicus,* upper limit about Gilbert c, between 4.38 and 4.5 million years.

The productive and significant interdisciplinary and cooperative programs stemming from the work of the first 55 cruises of the *Eltanin* are highly meritorious. Many significant results have been achieved, and many problems have been resolved. However, about one third of the southern ocean has yet to be studied, and many critical problems remain to be resolved. Population gradients of planktonic species in high latitudes of the southern ocean need attention, time-transgressive aspects of planktonic zonal indices need resolution, and the use of planktonic and benthic microfossil groups are needed in learning more about the history of the basins bordering Antarctica.

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Biological Oceanography

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When *Eltanin* made her maiden voyage to the icy waters of the Antarctic during Cruise 4 in July 1962, the main objective of the marine biological program was to increase the knowledge of the biology and ecology of the seas surrounding Antarctica. In this respect, the ship's mission did not differ much from those of her celebrated predecessors *Belgica, Pourquoi Pas?, Meteor, Gaus,* and *Discovery.*

Any reviewer of *Eltanin's* accomplishments in biological oceanography between 1962 and 1972 certainly must be impressed by the rapid evolution from exploratory studies to more sophisticated and highly integrated programs designed to study the total antarctic ecosystem. In fact, there were two distinct phases. The first began with Cruise 4 in the Drake Passage and ended with Cruise 36, more than halfway around the antarctic continent in the Tasman Sea, in November 1968. This period is characterized by (a) accumulation of comprehensive and representative collections of marine fauna and flora, (b) study of distribution and biogeography of the antarctic and subantarctic flora and fauna with emphasis on relationships of the biota to nonantarctic regions, (c) use of physical and chemical oceanographic data in the study of the ecology of the marine organisms, (d) initiation of studies on the physiological mechanisms of adaptation in antarctic invertebrates (mainly crustacea) to persisting low temperatures, and (e) systematic study of the biological productivity of the waters surrounding Antarctica.

During that phase, the biological investigations were but one aspect of *Eltanin's* numerous and broad scientific programs, which included marine geology and geophysics, physical oceanography, marine chemistry, upper atmospherics, and meteorology. These multidisciplinary programs typified the early cruises.

The conflicting interests of the biological and physical programs, together with the urgency of studying the structure and function of the ecosystem, ushered in *Eltanin's* second phase of biological investigation. The phase began with Cruise 38 (March to May 1969). Together with two other biological cruises (46 and 51), this phase was a landmark in the history of biological exploration of the seas surrounding Antarctica. The latest cruise in this trilogy ended in February 1972 with the completion of an integrated study of the biology, chemistry, and physical oceanography of the Ross Sea. Unlike the earlier phase, with its emphasis on surveying, reconnaisance, and intensive collecting, the 1969-1972 period featured interrelated system-oriented studies of the antarctic ecosystem as a functioning unit. This phase has witnessed (a) documentation and extension of data for the standing crop and primary production of phytoplankton on a seasonal basis in the area from 10°W. to 10°E. and from 140°S. into the pack-ice, (b) assessment of the standing stocks and biomass of the secondary producers (zooplankton) together with seasonal variability, (c) description of the distribution of organic materials throughout the water column, including all dissolved and particulate materials, (d) understanding of microbial activity in the mineralization processes in antarctic waters, (e) determination of the biochemical composition of planktonic and nektonic organisms with respect to transfer of complex lipids in the antarctic food chain, (f) use of carbon-13 and -14 ratios to trace the pathways of carbon as it passes through the various trophic levels, (g) acquisition of experimental data on stress measurements of the response of phytoplankton (*in situ* and *in vitro*) to changing light and temperature, and (h) collection of data on trophic efficiency estimates and respiration, energy requirements, and energy content of zooplankton to provide baseline data on energy flow.

The following pages summarize the research in these two phases. On account of the multitude and diversity of the investigations, the accomplishments made in each of the main components of the marine ecosystem are discussed separately.

The earlier phase

Phytoplankton

During Cruises 13, 14 and 15 (May to December 1964) the late Paul Burkholder began a study of the distribution of the standing crop of phytoplankton (using chlorophyll *a* method) and primary production of the South Pacific Ocean. Wood (1967) studied the vertical distribution of the phytoplankton in the Bransfield Strait and at a series of stations between South America and New Zealand. He found that the maximum phytoplankton distribution occurred at a depth of 100 meters in the Bransfield Strait and between the surface and 30 meters in the Pacific sector.

Beginning with Cruise 18, the Texas A&M group embarked on one of the most extensive investigations of primary productivity ever undertaken in the Southern Ocean (fig. 1). This investigation included the systematic study of spatial, seasonal, and year-to-year variations of the standing crop of phytoplankton, species composition and species diversity of the phytoplankters, nutrient chemistry (including phosphates, silicates, nitrates, nitrites, particulate and dissolved organic carbon), and a study of the hydrographic conditions affecting the productivity of these waters. The results of this investigation (Balech *et al.*, 1968) underscored the conspicuous regional differences in the productivity parameters of the Southern Ocean and pointed to the striking differences between the productivity of the oceanic and neritic regions (El-Sayed, 1970). The data substantiated the hypothesis that the richness of the antarctic waters is real only with regard to the coastal and inshore regions, and not with regard to the oceanic regions. As a result of these productivity

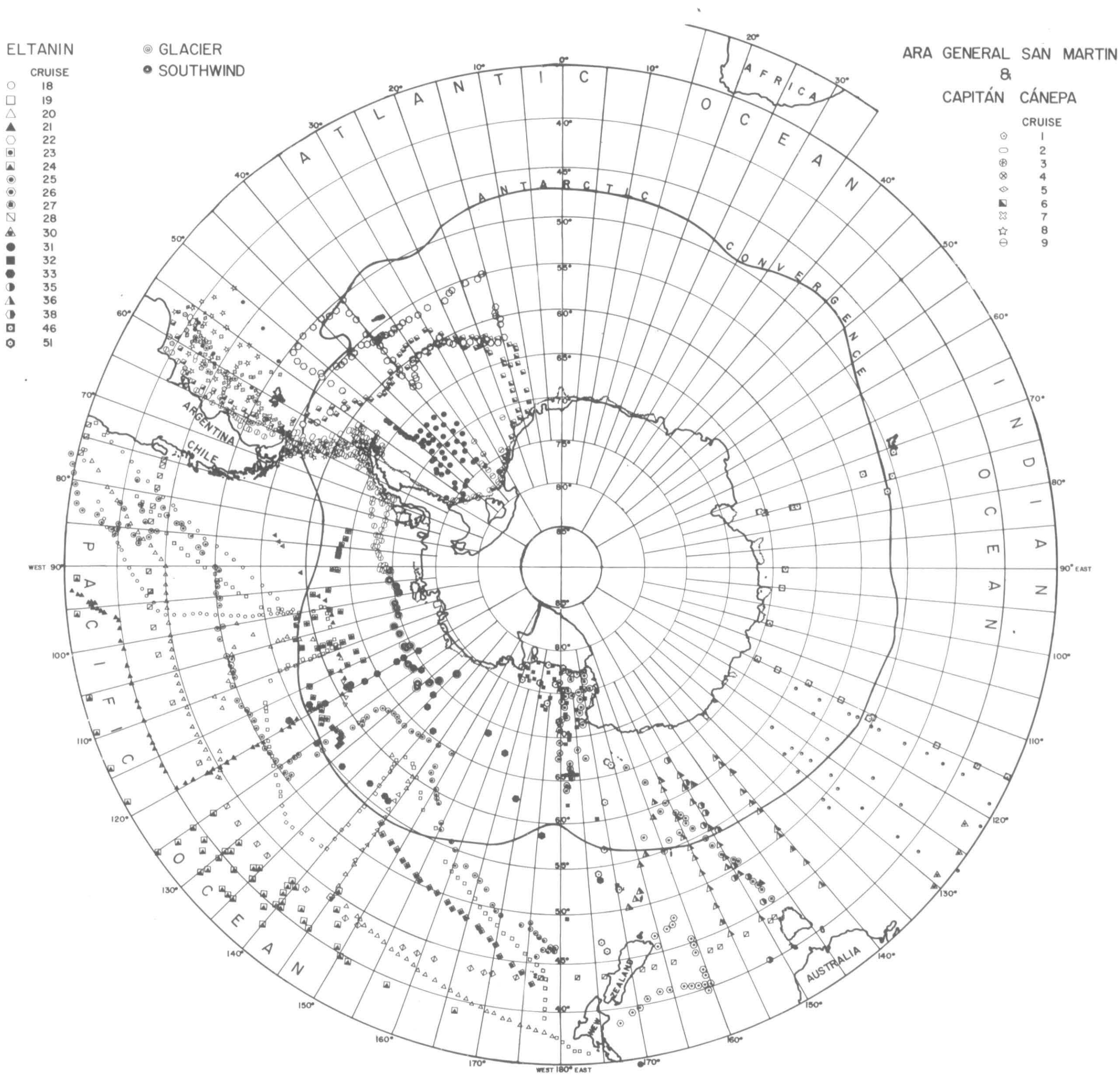

Figure 1.
Location of stations occupied in circumantarctic waters where primary productivity studies were carried out aboard the *Eltanin*, USCG *Glacier*, ARA *General San Martin*, and *Capitan Canepa* (modified from El-Sayed, 1970).

measurements, the early and persistent views regarding the proverbial fertility of the antarctic waters have given way to more realistic estimates of the productivity of that region of the world ocean. Walsh (1969) compared the phytoplankton standing crop in the Southern Ocean with that of the Strait of Florida. His data suggest that despite apparent high production during the austral summer, the overall production of the Antarctic and temperate and subtropical areas may be at least of the same order of magnitude.

Zooplankton

Extensive studies of the zooplankton populations began with the Lamont antarctic plankton program during Cruise 8. The objective was to study the distribution and abundance of the zooplankton population between the surface and 2,000 meters. Special collecting devices included (a) a multiple plankton sampler that collects at depths of 500 to 250 meters, 250 to 100 meters, and 100 meters to the surface during an oblique tow, and (b) a bathypelagic plankton sampler calibrated to sample from 1,000 to 500 meters. Since Cruise 15, a second bathypelagic plankton sampler has been collecting at depths from 2,000 to 1,000 meters. Zooplankton was collected systematically and fairly continuously during the early cruises. Portions of the samples collected were sent to the Smithsonian Oceanographic Sorting Center for sorting and distribution of the organisms among the specialists throughout the world (Fehlmann, 1971; Smithsonian Oceanographic Sorting Center, 1969).

Typical of the zooplankton studies conducted during this phase are those of Chen and Ericson (1967) who studied the vertical distribution of the major groups of holoplanktonic gastropods and correlated them with different water masses at different depths. Hillman (1969) studied the plankton samples from the Pacific sector of the Antarctic and the Scotia Sea and determined the seasonal quantitative distribution of the ostracods from 0 to 1,000 meters. Caldwell (1966) investigated the distribution of pelagic tunicates based on the material collected in the Drake Passage and adjacent areas, and Bé (1969) mapped the distribution of the planktonic foraminifera in the antarctic and subantarctic waters.

An important aspect of the zooplankton investigations during the early cruises was the estimation of the zooplankton standing crop. From the collections made in 1963 to 1965 aboard *Eltanin* between 75° and 185°W. (an area sparsely studied by *Discovery*), Hopkins (1971) assayed the standing crop of zooplankton using 202-micron closing nets in the upper 1,000 meters. He was able to show that the principal groups were copepods, chaetognaths, and euphausiids, with the copepods alone constituting 67.3, 68.8 and 70.1 percent of the biomass in the antarctic, subantarctic, and convergence zone waters, respectively. Total biomass per square meter in the upper 1,000 meters averaged 2.67, 2.58 and 2.96 grams dry weight in the antarctic, the subantarctic, and the convergence zones, respectively, with longitudinal or seasonal variability being difficult to detect. Hopkins also noted a relatively large fraction of carnivores, which generally exceeded 20 percent of the total zooplankton standing crop. His data imply that on the basis of Slobodkin's (1960) findings, standing crop cannot always be used reliably to mirror net trophic efficiency.

Fishes

Except for DeWitt (1970), the study of the ichthyofauna was limited during the early cruises. Bussing (1965) studied the collections of midwater fishes taken along the western coast of South America in the Peru-Chile Trench. He found that 83 percent of the species apparently do not cross the boundary centered at 20°S. that separates Pacific equatorial water masses from subantarctic water masses. The other 17 percent were found well on both sides of the boundary. In observing the character of the midwater fish fauna of the Ross Sea, DeWitt (1970) found that the striking decrease in the temperature of deep water in the Ross Sea is the likely explanation for the absence there of pelagic fishes of the southern ocean. DeWitt indicated that there is essentially no midwater fauna in the Ross Sea and that *Pleuragramma antarcticum* is the only species occurring in great numbers in the Ross Sea. DeWitt (1971) makes an excellent contribution to our knowledge of antarctic coastal and deep water benthic fishes; a good portion of these data were collected aboard *Eltanin*.

Benthos

Marine biologists from the University of Southern California and other institutions in the United States have filled huge gaps in our knowledge of the distribution and ecology of benthic fauna (Hartman 1964, 1966). Representative of the benthic fauna studies during the early cruises are Foster (1967), who summarizes Harvard University's brachiopods (about 10,000 specimens) taken from antarctic waters and off Antipodes and Macquarie Island, Herb's (1971) study of the distribution of recent benthic foraminifera in the Drake Passage, Kott's (1969, 1971) investigations of the ascidians, and Clark's (1970) study of the collection of asteroids made by *Eltanin* at depths from 167 to 4,686 meters off the New Zealand coast.

The fauna of the trenches bordering South America were studied by Menzies (1963). Since he was not able to show that antarctic deep-sea species were found in the trenches, he tentatively concluded that the fauna of these trenches are cosmopolitan and mostly from low latitudes. Menzies and George (1969) studied the patterns of distribution of the deep-sea antarctic isopod crustacea; they showed a tendency of the shallow-water genera to penetrate deep in the abyss and a simultaneous tendency of the abyssal genera to emerge into shallow water. These two phenomena—polar submergence and polar emergence—remain clearly distinguishable from the standpoint of taxonomic perception of the genera involved. George and Menzies (1968) provided evidence to show a seasonal breeding cycle of the abyssal isopods, with the peak breeding period limited to 4 months of the year, July to November. One of the many *Eltanin* firsts was the discovery by Rosewater (1970) in the Atlantic Ocean off southeastern South America of a small specimen belonging to the subgenera *Neopilina* collected from a depth of 1647 to 2044 meters. This discovery may indicate a widespread distribution of this abyssal group in the World Ocean.

Other research

Other research during the early cruises includes *Eltanin's* ornithological research program, which was begun by the Dominion Museum (Wellington, New Zealand) in January 1965 to study the seasonal distribution and relative abundance of seabirds in the Antarctic and subantarctic. About 45 species of seabirds were obtained. A rookery of over 10 million chinstrap penguins was found on Zavodovski Island (Harper, 1966).

Airborne insects in the Antarctic were collected by screening air while the ship was at sea. Of the 679 specimens collected, 454 were Diptera and 86 were Homoptera (Holzapfel *et al.*, 1970).

It is fitting that the earlier phase culminated in Bé *et al.* (1969), where all the marine invertebrates – planktonic foraminifera, porifera, nemertea, brachirpoda, bryozoa, sipuncula, benthic mollusca, pycnogonida, planktonic ostracoda, amphipoda, crinoidea, holothuroidea, echinoidea, asteroida, ophiuroidea, and ascdiaca – are discussed and their distributions mapped.

The later cruises

Cruise 38, which centered on study of metabolic processes in the southern ocean, blazed the trail for the two subsequent integrated biological cruises. These cruises were needed because, although we have a fairly reasonable knowledge of the composition, abundance, and distribution of the main components of the antarctic ecosystem, we still lack information about the relationship between the trophic levels and the flow of energy through that ecosystem. The time had come when studies of one component or another, which typified the *Eltanin* investigations between 1962 and 1967, could not reliably provide coherent and correlated data for computer simulation and prediction. What was needed, El-Sayed (1971) pointed out, was a team of investigators whose correlated efforts would have these objectives: (a) determination of the trophic levels and estimation of the biomass tied up in each level, (b) determination of pathways and flow of nutrient materials and energy and estimation of flow rates, and (c) measurement of the physical and chemical milieu of the community.

The accomplishments of *Eltanin* Cruise 38, whose activities centered around the study of the metabolic processes of the living organisms in antarctic and subantarctic waters, are discussed in McWhinnie (1973).

Cruise 46 (November 1970-January 1971) culminated a 3-year effort to mount balanced, integrated programs in biological and physical oceanography together with biochemical and radiation studies. These programs were designed to solve some of the outstanding problems of the antarctic marine ecosystem. Cruise 51 (January 1972-February 1972) was the second integrated biology cruise with the objective of contributing to our knowledge of the functional relationships and the energy in the trophic hierarchy of the antarctic marine ecosystem (fig. 2). The contributions made by these three cruises are summarized below.

Solar radiation available to the euphotic zone

Since photosynthesis by different species of phytoplankton is dependent on light at different parts of the spectrum, a knowledge of the spectral distribution of solar radiation received at the surface—which is a function if the altitude of the sun, the turbidity of the atmosphere, and the amount and type of clouds—is basic to a better understanding of primary productivity. During Cruises 46 and 51, efforts were directed toward determining the amount and quality of light made available in the water column (Franceschini, 1971, 1972). The approach employed two similar sets (one set measuring the downwelling stream; the other, the upwelling flux) of four hemispheric sensors to measure continuously the radiation fluxes in four wavebands a short distance above the surface. Franceschini (1972) was able to show that the quality of the energy made available for photosynthesis differs from that of the incident light. For a detailed account of studies on solar radiation, see Franceschini (1973).

Ecological studies of phytoplankton

Marine phytoplankton investigations were directed toward increasing our understanding of the ecology of the primary producers and toward a better knowledge of the dynamics of the lower trophic levels of the food chain. Such investigations are essential to the study of the functional relationships and the energy flow through the trophic levels of the ecosystem. In studying these trophic relationships, it is imperative to know the amount of carbon fixed by the phytoplankton. This was accomplished by measuring primary organic production using the *in situ* carbon-14 uptake technique instead of the simulated *in situ* methods performed during the earlier cruises (El-Sayed, 1969). In the later cruises, expanded study was made of the standing crop of phytoplankton in the upper 300 meters of the water column and of the contribution of nannoplankton to both the standing crop and primary productivity. During Cruise 51, the nannoplankton were found to contribute about 75 percent of the phytoplankton standing crop and 80 percent of the primary production. (Fay, unpublished manuscript).

Marine phycomycetes

Although studies of marine fungi began in the earlier cruises (Fell, 1968), it was not until the later cruises that concerted efforts were made to

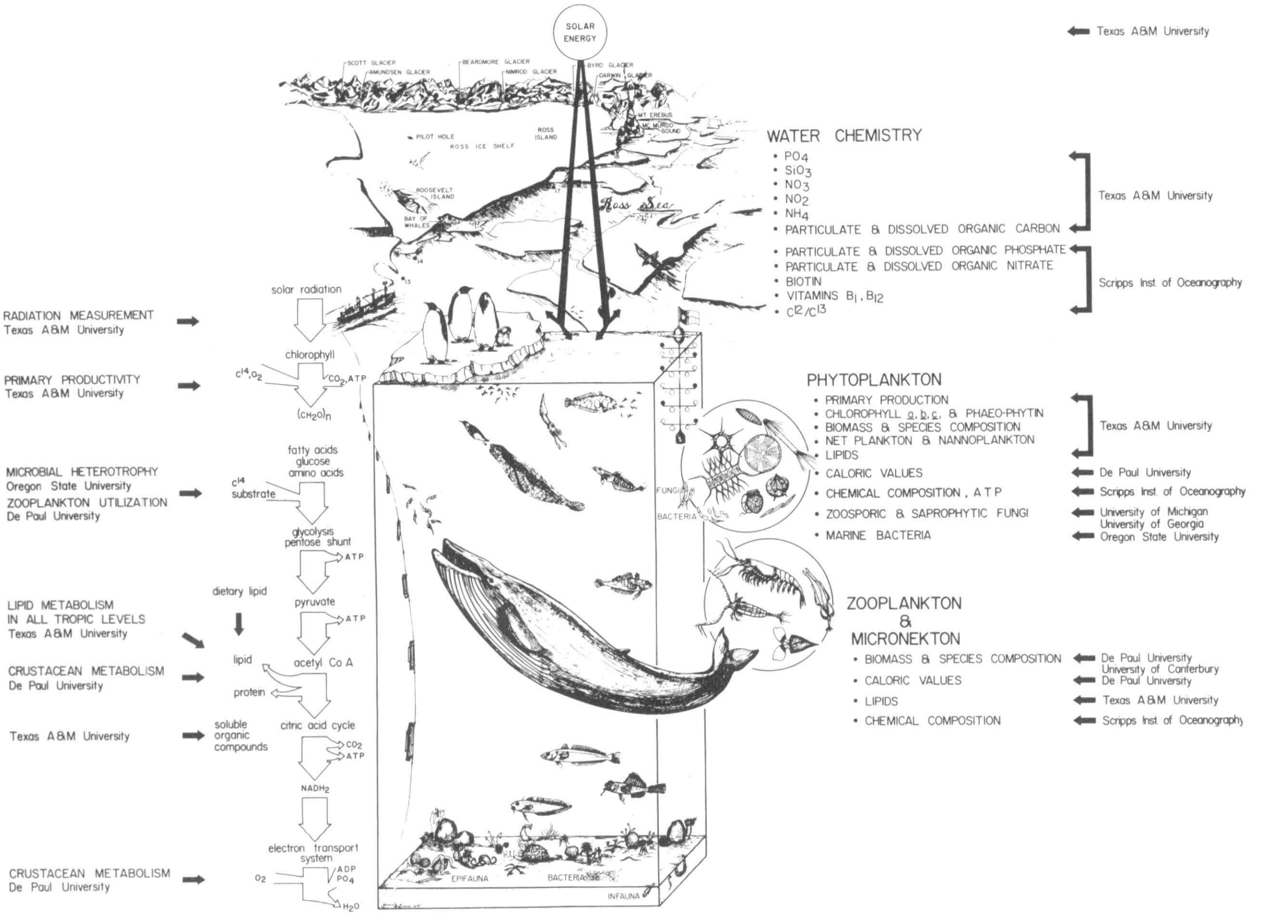

Figure 2. Aspects of the structure and function of antarctic ecosystems as studied during Cruise 51.

study their occurrence and distribution. Bahnweg and Sparrow (1972) studied the occurrence and distribution of the marine fungi from south of New Zealand and Australia to the antarctic continent. Primary emphasis was given marine phycomycetes, although the occurrence of yeasts and filamentous higher fungi (molds) also was recorded. Their preliminary results indicate that "molds" are infrequent in oceanic waters, a finding that correlates well with the results obtained by the above authors during Cruise 46 in the southern Indian Ocean. However, in contrast to the results of Cruise 46, yeasts also were rare. All of the phycomycetes found south of the polar front are somewhat similar to *Dermocystidium* sp. sensu Goldstein and Moriber (1966) in that they have neither rhizoids nor mobile zoospores.

Carbon pathways

The pathways of carbon were traced through the antarctic ecosystem using natural variations in carbon and hydrogen isotopes (Sackett and Brooks, 1972). With knowledge of carbon-13/carbon-12 and deuterium/hydrogen ratios in inorganic compounds and in marine organisms, it is possible to predict the pathways of carbon through the marine ecosystem beginning with carbon dioxide in the atmosphere and ending with the final members of the food chains.

Heterotrophic potential of marine microorganisms

The rate of heterotrophic activity was measured by kinetic analysis of the assimilation and respiration of carbon-14 labeled glucose, acetate, and various amino acids. Morita and his associates from Oregon State University are interested in measuring the extent of microbial participation in the mineralization process in antarctic waters. The rate at which this process proceeds has important implications in determining the route of energy flow through the biosphere as well as determining the potential inorganic nutrient recycling rates associated with microbial activity (Morita *et al.*, 1972).

Particulate and dissolved organic matter; plankton chemistry

During Cruises 46 and 51, detailed vertical profiles of dissolved and particulate carbon, nitrogen, and phosphorus were taken at 35 stations between Australia, New Zealand, and Antarctica. These determinations, in conjunction with inorganic nitrate, phosphate, and silicate concentrations have shown that these biologically important nutrients are not strikingly different in deep water from other oceans (Carlucci *et al.*, 1972). Thus, water sinking at the polar front does not contribute a high content of dissolved organic matter to intermediate waters of the Pacific Ocean. The investigation is important in evaluating *in situ* oxygen concentrations and rates of microbial oxidation with time in deep water. The Scripps Institute of Oceanography group also studied the distribution of particulate organic carbon (POC), nitrogen (PON), and phosphorus (POP) at the 35 stations mentioned above. The total particulate organic carbon values in the euphotic zones ranged from 30 to 200 micrograms of carbon per liter. In all profiles the particulate organic carbon decreased rapidly at depths between 200 and 500 meters, below which it ranged about 2 to 10 micrograms of carbon per liter. The carbon/nitrogen ratios of the particulate matter ranged from about 4 to 10, without any significant variation with depth. Most of the C/N ratios are close to 5.0, in sharp contrast to water of other oceans where the C/N is close to 10.0. The POC/POP ratio varies with depth from about 20 to 80; this ratio is significantly lower than those found in lower latitudes, where the ratio often is between 50 and 200.

Vitamins B_{12}, thiamine, and biotin

Although a number of reports cite the distribution of dissolved vitamin B_{12}, thiamine, and biotin in the world ocean, there was no adequate information on vitamin distribution in antarctic waters before Cruise 46. Water samples were taken at various depths during Cruise 46 and Cruise 51. Results of the earlier cruise indicate that thiamine was probably not important in the productivity of the waters since it was found in only a few samples, including those from deeper water. Biotin appeared to be produced by the phytoplankton, since it was directly correlated with high phytoplankton populations in the upper waters from most stations. The direct involvement of B_{12} in the ecology of phytoplankton is more obvious in waters of Antarctica than in most areas of the world oceans.

Also during Cruise 51 the Scripps investigators collected samples for determination of mercury and cadmium, carbon-14 and tritium content, and chlorinated hydrocarbons. These samples include water, ice, surface films, sediments, marine aerosols, and a number of organisms representing various trophic levels in the antarctic food chain (Holm-Hansen, personal communication). This work is essential in assessing variations with time of these chemical components in the Southern Ocean, with respect to rates of transfer into antarctic waters from their primary source in the northern hemisphere, as well as their flux rate through the antarctic food chains.

Physiology of antarctic zooplankton

Respirometric study of pelagic invertebrates was carried out during Cruise 51 (McWhinnie and Kirchenberg, 1972). Species studied included the euphausiids *Euphausia superba, E. crystellorophias,* and *E. triacantha;* the amphipods *Parathemisto gaudichaudii* and *Phronima* sp., the copepod *Calanoides acutus,* the chaetognath *Eukrohnia* sp. and the tunicates *Salpa* sp. and *Pyrosoma* sp. Oxygen consumption values for most animals were generally equivalent to those obtained during Cruise 46 in the southern Indian Ocean (McWhinnie and Urbanski, 1971). McWhinnie and her students also studied the use of soluble nutrients by various zooplankton. They had reported previously that antarctic amphipods, studied in the Pacific sector during Cruises 17 to 19, utilize soluble nutrients (McWhinnie and Johanneck, 1966) as do a number of species studied in the Indian Ocean sector during Cruise 46 (McWhinnie and Urbanski, 1971). The data obtained during Cruise 51 support earlier interpretations concerning a direct route of absorption of soluble organic compounds by zooplankton (McWhinnie and Kirchenberg, 1972). For a detailed account regarding the physiology and metabolism of the marine organisms in the Antarctic, see McWhinnie (1973).

Lipid metabolism

Studies since 1966 have clarified various aspects of the lipid composition and metabolism of antarctic organisms. Early investigations by Jeffrey *et al.* (1966) showed that in many of the organisms phospholipids are the most abundant lipid class. From these investigations it also was apparent that marine phospholipids are much richer than marine triacylglycerols in long-chain highly unsaturated fatty acids (HUFA). Consequently, the HUFA of marine fish and mammals seem to originate mainly from the phospholipids in organisms of the lower trophic levels rather than from the triaclyglycerols of the same organisms (Bottino, personal communication). The positional distribution of HUFA in the lipids of zooplankton, euphausiids, and fish was found to be similar in all three groups. Studies during Cruise 51 showed that whereas the fatty acids profile of a particulate species, *E. superba,* for example, is quite constant, it can differ markedly from the fatty acid profile of another species such as *E. crystallorophias.* The differences between these two euphausiids were found to be due to the presence of waxes in *E. crystallorophias* but not in *E. superba* (Bottino, 1972; also personal communication).

Clearly, synthesis of the above-mentioned studies carried out during the later cruises, namely programs of solar radiation and spectral quality of light, biological activity and chemical composition of plankton, primary productivity and phytoplankton standing crop, metabolism and energy turnover of zooplankton, role of marine fungi, pathways of carbon through the food chains, lipid metabolism, heterotrophic bacteria, should provide us with one of the most comprehensive pictures so far of the functioning of the antarctic marine ecosystem.

There is more work to do. Some of the major antarctic marine resources (*e.g.,* krill) are threatened by commercial exploitation, and marine biologists must develop guidelines, based on hard data, for the wise use of these resources within the framework of the ecosystem concept. The tragedies of overexploitation of the plaice fishery in the North Sea, the California sardine, and, lest we have forgotten, the antarctic baleen whales are glaring examples of poor management of natural resources. While marine biologists lament the layup of the ship, there is no denying that it was *Eltanin* that maintained U. S. leadership in antarctic marine biology in the 1960s. During her short service in the cause of science, *Eltanin* has earned her rightful place among the celebrated polar research vessels.

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Physiology and Biochemistry

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Eltanin has served as a complete research platform for scientific investigation of each facet of the south circumpolar marine environment. Scientific investigations have been made in meteorology, physical oceanography, marine chemistry, geology, geophysics, physical atmosphere phenomena, and biology. Precise satellite navigation has aided these studies. Study of the biological resources of polar waters has been a significant component of the broad goal to increase understanding of all elements of that little known region. Through 10 years and 55 cruises has emerged the need to elucidate functional dynamics in the antarctic aquatic biosphere and physiological mechanisms of organismic adaptation to continuous low temperature.

Background

Before the International Geophysical Year of 1957-1958, polar scientific investigations had been directed primarily to the discovery of characteristics of the biota, its density, and its species composition. Among these were the *Discovery* expeditions, which focused on the potential for exploiting of the best known south circumpolar biological resources—whales and seals. Those expeditions have contributed greatly to knowledge of the systematics and distribution of numerous species. Moreover, life cycles and many details of the biology of species have been elucidated by study of collections obtained on those expeditions. Most of these investigations centered on the Atlantic sector of antarctic waters, fewer on the Pacific sector, and very few on the other quadrants.

Upon this background antarctic marine biological programs were undertaken on 41 of 55 *Eltanin* cruises starting in 1962. Many of the programs have continued the ponderous task of surveying the southern ocean to discover further its populations, their systematics, taxonomy, and, biogeographic distributions, including relationships to vertical and seasonal variations. These studies are reviewed elsewhere in this issue (Hedgpeth, 1973).

Physiological studies of antarctic biota also were initiated early in the work of *Eltanin*, with bacteriological analyses starting on Cruise 4 (Burkholder and Hayes, 1963) and metabolic study of krill on Cruises 6 and 7 (McWhinnie and Marciniak, 1964). To explicate the biochemical and physiological basis of polar adaptation, and to define quantitative relations concerning energy-flow between trophic levels, data obtained from study of organismic metabolism are required. Energy content of organisms within consecutive trophic levels must be determined to develop broad outlines of the interrelationships of communities in this ecosystem (McWhinnie, 1972). In 1970, research in polar marine ecosystems was assessed, and the need for expanded study in population dynamics and metabolism was stressed for species which are a potential source for exploitation (National Academy of Sciences, 1970). That report emphasized the meagerness of physiological and biochemical knowledge of polar biota.

Biological processes throughout any area depend on available energy and on the photoautotrophic populations. Study of solar energy available to the circumpolar ecosystem is discussed elsewhere in this issue (Franceschini, 1973), as are the *Eltanin*-based investigations of antarctic phytoplankton and primary productivity (El-Sayed, 1973).

Role of bacteria

Among the important physiological processes in organic cycle transitions in the marine environment is the activity of heterotrophic microorganisms. In a preliminary report on bacterial populations, Walls (1967), using data from Cruise 23 and 25, showed that aerobic heterotrophs were concentrated in the surface layers with a second density peak occurring between 500 and 1,250 meters in the Pacific sector between southern Chile and New Zealand. In addition, bacteria in deep sediments were found to be facultative anaerobes capable of using a wide variety of organic substrates. However, they showed no sulfate reduction, a frequent characteristic of other deep-sediment bacteria.

On cruises 46 and 51, Morita *et al.* (1971, 1972) made more extensive investigations into heterotrophic marine microorganisms in the Indian and Pacific Ocean sectors and in the Ross Sea. They assessed the role of these organisms in mineralization and energy flow by tracing, with a carbon-14 label, the use of organic substrate. Of 14 substrates studied these natural populations showed the highest rate of uptake when incubated with the amino acids, serine, alanine, and glutamate, while ribose, sucrose and glycerol were not utilized. Incubation with Kreb's-cycle intermediates or their precursors (malate, aspartate, and glutamate) resulted in the highest respiratory percentages ($^{14}CO_2/^{14}C$-substrate absorbed) obtained with any of the substrates employed. The highest activity was obtained near the Ross Ice Shelf, indicating metabolic adaptation. Low values were found in waters north of the polar front, and a marked increase occurred at the front. Heterotrophic activity of these psychrophilic populations increased with temperature from —2.5° to 11 or 12°C., but it generally declined with higher temperatures. Population densities were greatest throughout the euphotic zone but dropped significantly below 500 meters. Data from these studies represent a basic element in the sequence of organic cycling that, when extended in space and time, will provide a quantitative value in the energy-flow equation for that ecosystem.

From these studies the south circumpolar heterotrophic population is known to show great diversity with depth and geographical location and to have a high capability to metabolize a wide range of soluble nutrients (dissolved organic carbon). With respect to adaptation, the highest rate of substrate turnover occurs at approximately 12°C., while the highest efficiency in absorption of dilute substrates occurs at the natural environmental temperatures of —2.5° to 0°C. Thus these marine bacteria contribute significantly to the mineralization processes in antarctic waters, and their heterotrophic potential exceeds the daily photosynthetic input of amino acids, completing the full cycle of organic conversion (Morita, *et al.*, in manuscript).

Unexpected was the lack of correlation between the microbial heterotrophic activity measured by those authors and (1) ATP levels studied by Carlucci *et al.* (1972) on Cruise 51, and (2) dissolved and particulate organic carbon measured by Sackett and Brooks (1972) on Cruise 51. In view of the complexity of the marine ecosystem considerably more fundamental information is required to discover the biotic, physical, chemical, and technical bases for deviations from theoretically interdependent parameters of biological activities and biochemical correlates. To provide information on biochemical aspects relating to biological energetics in high latitude southern waters, on Cruises 46 and 51 Carlucci *et al.* (1971, 1972) measured the levels of vitamins B_1, B_{12}, and biotin in water and particulates, the organic composition of particulates, of various categories of plankton and of some mesopelagic fish. Data from such studies should permit a clarification of carbon flow from surface layers to the deep waters.

Measurement of respiration

To determine the role of microorganisms in the total metabolism of the antarctic marine ecosystem, concentrates of ultraplankton were studied respirometrically using a polarigraphic electrode, on Cruises 38 and 46 (Pomeroy *et al.*, 1969), and microbial biomass was estimated by ATP analysis. The study was made to elucidate the energy required by ultraplankton adapted to low temperature. Concurrent studies at the same oceanographic stations were conducted to estimate biomass and respiration of benthic fauna (Frankenberg in Pomeroy *et al.*, 1969) and to assess the reproducibility and statistical variance in consecutive benthic sampling (Driscoll, 1969).

Knowledge of the energy required by populations throughout the water column is needed to estimate total metabolism within the antarctic ecosystem, and from which wise management of its resources can develop. Previous study at low latitudes had indicated that microorganisms account for the largest respiratory component (energy consuming) in the water column (Pomeroy and Johannes, 1968). However, technical complexities inherent in concentrating ultraplankton from large volumes of sea water, and inadvertent losses of organisms or their products on filters (Holm-Hansen *et al.*, 1970), as well as inestimable stimulation to the microbiota, combine to render this approach to total community metabolism difficult and still preliminary. Nonetheless, data from these studies did indicate a substantially smaller energy requirement for ultraplankton. Populations south of the Antarctic Convergence may have the lowest respiration rates of any oceanic region (Pomeroy, unpublished manuscript).

Some respirometric data are available for a number of antarctic organisms collected as "net plankton" and for selected benthic species; the latter, however, have been studied more extensively at land-based stations in Antarctica. On *Eltanin* Cruises 6 and 7, *Euphausia superba* (krill) collected from sea water at approximately —1°C. were shown to have a mean respiration value of 0.75 microliters oxygen per milligram dry weight per hour with a range from 0.4 to 1.1 (McWhinnie and Marciniak, 1964). The immediate past temperature and the temperature and duration of maintenance in the laboratory all influence the rate of respiration. Further, available metabolic substrate strongly influences oxygen consumption while conventional metabolic inhibitors depress it. Preliminary studies of nucleotide reduction point to high rates of substrate oxidation by both the Embden-Meyerhof and pentose pathways.

In contrast to *E. superba,* the anomuran crustacean *Munida gregaria* (grimothea) collected on the same cruises, north of the Antarctic Convergence, from waters of approximately 13°C. showed a substantially lower QO_2 ranging from 0.06 to 0.11 microliters oxygen per milligram dry weight per hour. This relationship has been found to exist for other heterothermic organisms when those that are endemic to low and high latitudes are compared. On a corresponding dry weight basis, microzooplankton collected (200 micrometer mesh net) in the euphotic zone of the Ross Sea on Cruises 51 and 52 have QO_2 values ranging from 0.3 to 0.5 microliters oxygen per milligram dry weight per hour (McWhinnie and Kirchenberg, 1972). Values obtained from samples taken from the euphotic zone (200 meters) are substantially less than those reported for low latitude ultraplankton.

Biomass

In a comprehensive study of zooplankton collections obtained between 1963 and 1965 (Cruises 10, 11, 13, 14, 15, 17, 18, 19) biomass was measured throughout the upper 2,000 meters between 75°W. and 175°W. and approximately 47°S. and 71°S. (Hopkins, 1971). Based on primary productivity data, which Burkholder and Burkholder (1967) reported in the south Pacific (Cruises 13, 14, 15), and biomass data for the same region, Hopkins computed an estimate of supportable zooplankton respiration. A minimum value was placed at 36 to 40 microliters oxygen per milligram dry weight per day. This level of respiration is considered as low relative to the actual energy requirements of organisms since it is based on the assumption of 100 percent efficiency in all physiological processes related to energy turnover in living systems.

Comparable biomass samples collected at more southern locations (to 78°S.) during Cruise 52 have been measured respirometrically (samples measured excluded euphausiids, chaetognaths, pteropods, and other relatively large net plankton). These samples yielded mean values of 9 to 10 microliters per milligram dry weight per day; some few showed maximum values to 26 to 30 microliters (in preparation). However, the samples measured excluded both ultraplankton and larger net plankton whose oxygen consumption must be added to this to arrive at a representative value for a unit volume of seawater. Thus, total productivity data obtained by the carbon-14 uptake method—when coupled with (a) utilization by heterotrophic microorganisms (Morita *et al.*, in manuscript), (b) respiration of ultraplankton (Pomeroy *et al.*, 1969), (c) net plankton (McWhinnie and Kirchenberg, 1972; in preparation), and (d) micro- and macro-nekton —do not yet offer a satisfactory energy-balance model.

Because of the high percentage of exoskeletal and other non-living elements of organism weight, more recent respiration studies of antarctic fauna have been expressed on the basis of protein weight. Larger net plankton, including three species of euphausiids, amphipods, copepods, polychaete annelids, and urochordates (salps), have been studied with use of a differential respirometer. Values obtained for the same species collected in the South Indian Ocean on Cruise 46 (McWhinnie and Urbanski, 1971) and South Pacific Ocean on Cruises 51 and 52 (McWhinnie and Kirchenberg, 1972) show similar levels of energy requirement. Values for six crustacean species vary from an average of 1.22 and 2.03 microliters oxygen per milligram protein per hour; larval *Phronima* sp. were considerably above this (10.1 microliters), while the chaetognath *Eukrohnia* sp. had a considerably lower mean value (0.45 microliters). The higher respiration levels of crustacean larvae, when compared with adults of the same species, correspond with the view that ultraplankton constitute a significant element in ecosystem respiration.

In these same studies a consistent difference was observed for euphausiid respiration. From 43°S. to 78°S., the sequentially occurring species *Euphausia triacantha, E. superba,* and *E. crystallorophias* showed mean respiration values of 2.03, 1.36, and 1.22 microliters oxygen per milligram protein per hour respectively. Whether this is a function of species differences or environmental temperature is not yet clear. Such differences may confer adaptational advantages upon these populations. Based on respiration values and on the assumption of an "average mixed diet" (R.Q.=0.85), the nutrient energy required to support these three species would be 9.89, 6.64, and 5.93 x 10^{-3} gram calories per milligram protein per hour, respectively. The energy content of available food for zooplankton (phytoplankton; microzooplankton) is unknown but is being measured (McWhinnie, in preparation). From study in this and other marine environments, it has been suggested that energy required by a large number of planktonic species may not be met by available microplankton populations. Thus, the nutrient source for the large standing crop of antarctic zooplankton remains a major unanswered question concerning their ecology as well as energy flow in the south circumpolar ecosystem.

Dissolved organic compounds

Related to this unique low temperature environment, characterized by large variations in available solar energy and a predominant crustacean population, another source of nutrient has been investgated. Utilization of dissolved organic compounds by crustaceans was studied on Cruises 17, 18, 19 (McWhinnie and Johanneck, 1966).

Preliminary evidence suggested soluble nutrient absorption by *Parathemisto gaudichaudii* and *Euphausia triacantha* after incubation in sea water enriched with carbon-14 labelled glucose and acetate. Further study was extended to zooplankton in the South Indian and South Pacific Oceans (Cruises 46, 51, 52). Amino acid uptake was measurable in several species from six animal phyla whose protein showed levels of incorporation approximating that reported for diverse low latitude species. Whether this occurs by direct absorption or by way of heterotrophic bacteria must yet be determined. However, antibiotic treatment of these organisms does not diminish absorption of dissolved nutrient (McWhinnie, in preparation). When amounts of absorbed nutrient are specified for the dominant species in these waters, we may approach a realistic energy balance in numerical terms. The complexity of relations among trophic levels in the vast antarctic ecosystem renders solutions to these basic questions difficult and, for some time, remote. Multiple experimental analyses may offer insight into trophic relations and diverse approaches have been taken.

The importance of euphausiids in the economy of antarctic waters has made them a frequent subject of study by investigators from many countries. The regionalized occurrence and density of these populations has supported contemporary considerations of commercial harvesting of them.

Lipids and fatty acids

In an attempt to define trophic relations more precisely, study of lipid and fatty acid profiles of a number of planktonic species in that ecosystem has been conducted on *Eltanin* Cruises 17, 18, 27, 28, 46, 51. Analysis of four euphausiid genera has shown that phospholipids represented 48 percent of the total lipid while triglycerides contributed only 19 percent of the total; triglycerides are about equal to sterol esters and tocopherol combined. Work during Cruises 17 and 18 showed that free-fatty acids, sterols, monoglycerides, hydrocarbons and waxes, and diglycerides sum to approximately 13 percent (Jeffrey *et al.*, 1966). The fatty acids of phospholipids consist predominantly of unsaturated C_{20} and C_{22} acids (52 percent). In a preliminary study of data from Cruise 11, Correll (1965) reported a high phospholipid content (27 to 57 percent) in microzooplankton (less than 30 micrometer mesh net) based upon the origin of a large percentage of the total phosphate. He also reported that phospholipid in zooplankton exceeds that in phytoplankton. The same distribution pattern of these molecular classes has been found in six genera of antarctic fish. In both euphausiids and fish sampled from several *Eltanin* cruises the complex lipids contain more highly unsaturated fatty acids than occur in triglycerides (Bottino *et al.*, 1967). Thus, the high degree of unsaturation of lipids in these low temperature adapted organisms can be accounted for by the relatively high proportion of complex lipids. The arrangement of the fatty acids in euphausiid triglycerides also resembled that in lipids of the fish *Electrona antarctica*. It appears that the pentaene and hexaene fatty acids in phospholipids of antarctic fish originate in the lower levels of the food chains.

A comparable relationship has been found between *Euphausia superba* and its associated phytoplankton in the Ross Sea (Bottino, 1972; in manuscript). Similar fatty acid patterns in these two elements of the food chain correlate with the herbivorous habit of this euphausiid.

The more southern *Euphausia crystallorophias*, found only under ice and at the continent's edge, showed a different lipid profile when compared with *E. superba*. The former has considerably more unsaturated C_{18} fatty acid (oleic) and less saturated acids of the C_{14} and C_{16} type. In addition, 20-40 percent of its total lipid consists of waxes that have a high percentage of oleic acid. This is the molecular basis for the greater amount of unsaturated lipids found in *E. crystallorophias* as compared to *E. superba*.

Phytoplankton lipid contains up to 15 percent short-chain fatty acids (C_8-C_{13}) not detected in euphausiid lipid, and up to 23 percent highly-unsaturated fatty acids (20:5 and 22:6). It appears that the highly unsaturated fatty acids found in euphausiids and fish originate in phytoplankton.

The food preference of *E. crystallorophias* is not certain, but the lack of similarity in lipid profiles between this species and phytoplankton of the Ross Sea places a purely herbivorous habit for it in some question.

Carbon isotope ratios

In another approach to the study of the carbon pathway through the antarctic ecosystem, on Cruises 12, 13 Sackett *et al.* (1965) measured the ratios of natural carbon isotopes (C^{13}/C^{12}) in seawater, plankton, and sediments in the South Atlantic Ocean and Drake Passage. Those studies showed a strong temperature dependence in isotope composition; plankton at 0°C. preferentially select C^{12}, while low latitude plankton from water at 25°C.

show a higher percentage of C^{13}. The low temperature effect of a C^{12} preference was evident in all samples whether they were predominantly phytoplankton or mixed with zooplankton. Similarly, lipid fractions of these samples showed C^{12} enrichment. It appears that fractionation of the natural isotopes of carbon occurs in the process of photosynthesis that is not species dependent but rather is correlated with environmental temperature. However, other mechanisms of fractionation are not excluded (inorganic carbon equilibrium reactions that are also temperature dependent).

These studies were continued in the South Indian Ocean on Cruise 46 (Eady and Sackett, 1971) and in the South Pacific and Ross Sea areas on Cruise 51 (Sackett and Brooks, 1972).

One promising outcome of study of carbon isotope fractionation, and thus isotope ratios in the organic carbon of marine sediments, could be a working hypothesis in the reconstruction of paleoclimates. Fractionation of carbon isotopes by contemporary phytoplankton shows a minimum at 16°C., and the effect appears to be nearly universal.

Eady (1972) working with Cruise 46 data, has undertaken a more extensive study of the South Indian Ocean samples and has found that isotope fractionation appears to be systematic in the case of protein and carbohydrate occurring in the polymerization of amino acids and sugars, while the ratios of isotope are more random in lipids.

Conclusion

From this brief summary of *Eltanin*-based investigations into physiological and biochemical mechanisms of low temperature adaptation of antarctic fauna, it can be seen that some broad outlines have been established. In the present era of analytic studies of metabolic phenomena more remains to be done. However, through this past work critical questions can now be more clearly formulated and closely interacting programs can be developed. Only through these can we discover answers to the significant questions of mechanisms of low temperature adaptation and transfer of energy through this ideal ecosystem with special focus on its efficiency.

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Systematic Zoology

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Some years ago the director of the National Science Foundation remarked in a summary of work in the Antarctic that some specialists had gone back a hundred years in science to identify and describe the organisms being collected. Today, in our environmental as well as theoretical concerns, we are coming to realize that precise identification of material is essential to an adequate estimation of the impacts of environmental changes as well as to studies of the diversity and stability of natural aggregations or communities in nature. While the work may indeed be essential, much of it is being carried out on a volunteer basis by specialists all over the world, many of whom have other obligations or demands upon their time. Accordingly, it will be some years, especially at the present meager rate of support for systematic studies, before the full contribution of the *Eltanin* to systematic biology becomes part of the general fund of knowledge. It was 10 years after the return of the *Challenger* expedition before the first report was published; at least we are somewhat ahead of the schedule, but it will probably be more than 20 years before even the greater part of the *Eltanin* collections are worked up. (The *Challenger* reports were completed in 1895, just 20 years after the ship returned to England).

At present, specimens collected by the *Eltanin* are in the hands of specialists all over the world; only a few groups have been worked up and published. Several monographs or extensive papers are waiting their turn to be published, although the printing budgets at this time are draconically tight. It would take more time than available to track down every publication that depends on *Eltanin* material; some idea of the magnitude of the task can be obtained from the accompanying tabulation of the estimated number of species of invertebrates collected by *Eltanin* since her first cruise in 1962 (table 1). Many more collections await assignment, among them such important groups as sponges, bryozoa, and hydroids. For some of these, specialists have been tried and found wanting and the material must await a more qualified practitioner. In all, there are quite possibly several hundred or perhaps 2,000 species to be added to the total, and if the 10 to 15 percent figure of previously undescribed species indicated in this tabulation holds, there may be another 200 undescribed species, in a grand total of possibly 5,000 species of invertebrates.

This tabulation was compiled from 48 responses to a form inquiry sent to 78 persons who had at some time or another received *Eltanin* material for study from the Smithsonian Oceanographic Sorting Center. Most of those listed were specialists in various invertebrate groups; since this did not include ichthyologists, fishes have been omitted from the tabulation; one paper published in the *Antarctic Research Series* concerned 100 species of midwater fishes of which four were previously undescribed.

It must be remembered that the *Eltanin* collections are not exclusively from the Antarctic, hence these figures do not refer to the antarctic biota alone. However, the majority of the material is from below the Antarctic Convergence, and the estimated total numbers of species may be very similar to the antarctic fauna.

Among the more important contributions to systematic zoology based entirely or in part on samples obtained by *Eltanin* are the various monographs on Polychaete Annelids by Olga Hartman, the study of Ascidiacea by Patricia Kott, and that of Cirripedes by W. A. Newman. Several major papers are nearing completion, but the dim prospect of long delayed publication is slowing these works. At least 15 species have been, or will be named for, *Eltanin*.

A rough approximation of the recently published work on various systematic groups may be obtained from scanning the biology section of the *Antarctic Bibliography.** In table 2 a preliminary tabulation has been made of the groups represented, the total number of printed pages, and the number of species discussed as listed in that bibliography. This tabulation is not intended to indicate anything more than the comparative order of activity of study in certain groups from a quick sampling of the *Antarctic Bibliography.* Many papers concerning broader regions or concerning several groups at once (as zooplankton or parasitic helminths) have been deliberately omitted. Many shorter papers and several large ones are not included in the Antarctic Bibliography. When compared with the extant collections known to have accumulated in Washington, Moscow, London, Wellington, and other national depositories, it is obvious that we have a long way to go to obtain the base data for a comprehensive fauna of the antarctic benthos. Obviously, none of the national antarctic programs has been able to keep up with the material, and there is evidently as much unworked material in Moscow as there is in Washington (or dispersed among the specialists). Systematists have for the most part stood aloof from political considerations; one report of the USSR was written by a British subject, and in most of the smaller national efforts several reports are written by the best available specialist without respect to nationality. This is in the tradition set by the *Challenger* reports. Table 2 does indicate, for example, that the echinoderms have been well studied except in the Soviet Union, and polychaetes have received attention in five countries, but that all of us are lagging behind in the Mollusca.

Table 1. Preliminary estimate of species of invertebrates collected by *Eltanin.*

Group	Est no. species	New species[a]	Named for *Eltanin*[a]
Diatoms	100	1	—
Dinoflagellates	70	—	—
Foraminifera-Globigerina	9	—	—
Foraminifera	250	5	1
Radiolaria	100	1 (3)	—
Coelenterata-Octocorallia	67	12	—
Annelida-Polychaeta	367	57	1
Sipuncula	12	—	—
Copepods-commensal	20	7	—
Copepods-planktonic	299	28	—
Ostracoda	101	41	—
Amphipoda	158	40	—
Amphipoda-Capprellidae	20	5	1
Isopoda	150	72	1
Tanaidacea	50	?	3
Cumacea	25	8	—
Stomatopoda	2	—	—
Crustacea Decapoda	79	—	2
Arachnida Halacaridae	150	80	2
Pycnogonida	85	25	1
Mollusca			
Aplacophora	35	24	—
Polyplacophora	17[b]		
Scaphopoda	6[b]		
Bivalvia	66[b]		
Gastropoda	208[b]		
Cephalopoda	12[b]	4	1
Brachiopoda	65	12	1
Chaetognatha	9	—	—
Echinoderma			
Ophiuroidea	141	26	—
Holothuroidea	220	24	1
Crinoidea	42	2	—
Pogonophora	30	27	—
Ascidiacea	106	10	—
	3,071	511	15

[a] Estimated or in progress, includes manuscript species.
[b] These are Dell's estimates of the antarctic molluscan fauna, not of species collected by *Eltanin.*

* Prepared by the Library of Congress for the National Science Foundation. For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402. Vol. 1, 1965; vol. 2, 1966; vol. 3, 1968; vol. 4, 1970; vol. 5, 1971.

Table 2. Papers in systematic zoology of antarctic species, compiled from *Antarctic Bibliography,* vol. 1-5.

Group	No. pages	No. species	National effort (E: *Eltanin*)
Protozoa			
Radiolaria	189	67	USSR
Porifera	135	230	USSR
Mesozoa	18	4	USA-E
Coelenterata			
Octocorallia	14	4	Japan
	20	12	Norway
	23	3	USSR
Scleractinia	28	—	USA; N.Z.
	12	8	Japan
Hydroida	35	43	USSR
Stylasterina	23	27	Holland
Parasitic helminths—not tabulated			USA
Nemertea	25	11	USSR
Nematodes			
(free living)	19	9	USSR
	11	1	USA
Bryozoa	45	64	Belgium
	47	14	Chile
	49	20	USSR
Brachiopoda	4	1	Japan
	10	3	USA-E
Hirudinea	14	1	British
Annelida-Polychaeta	27	12	Argentina
	11	9	France
	5	15	N.Z.
	105	79	USSR
	406	367	USA
Sipuncula	8	4	N.Z.
Arthropoda			
Pycnogonida	2	13	Belgium
	147	50	USA: N.Z.
Halacaridae	5	3	USSR
Copepoda	32	16	Japan
	22	5	USA
Ostracoda	59	26	British
	42	6 (new)	USA-E
Cirripedia	15	1	Japan
	12	31	USSR

	257	85	USA-E
Mysidacea	16	5	N.Z.
	10	18	USSR
Cumacea	18	7	France
	43	20	USSR
Isopoda (incl.			
Tanaidacea	43	8	Chile
	5	2	Norway
	171	101	USSR
	96	28	USA-E
Amphipoda	32	10	N.Z.
	51	73	USSR
	20	—	USA
Euphausiacea	80	—	USSR
Decapoda	59	26	USSR
Mollusca			
Pteropoda			
(planktonic	157	—	N.Z.
gastropods)	7	9	USA-E
	26	7	Japan
Amphineura	9	4	Belgium
Bivalvia	2	—	Norway
	102	36	USA
Cephalopoda	28	2	USA-E
Chaetognatha	9	—	USSR
Echinoderma			
Asteroidea	27	8	Argentina
	104	77	British
	85	32	N.Z.
	1	6	Norway
Ophiuroidea	31	13	Argentina
	35	10	Chile
	7	11	Japan
	79	33	N.Z.
Echinoidea	—	7	N.Z.
Holothuroidea	17	10	British
	2	1	N.Z.
	36	12	USA-E
Crinoidea	50	17	British
Chordata			
Ascidiacea	239	122	USA-E (Austr.)
	25	—	Norway
	19	17	USSR
Pisces	90	2	Argentina
	16	18	Belgium
	17	12	France
	3	8	Japan
	119	47	USSR
	36	7	USA

The most comprehensive summary to date of the contributions of *Eltanin* and of the U. S. antarctic effort in general to the systematics of invertebrates is that provided *inter alia* by Folio 11 of the *Antarctic Map Folio Series* (1969), although several of the major contributions are based on material studied by other antarctic programs. It is indicative of the incomplete state of our systematic analyses that only 21 contributors were found to present the state of their art in terms of distribution patterns of known material (several of the groups reported upon in Folio 11 are missed in the tabulations of both tables 1 and 2). Since then some systematists who were unable to contribute at that time have progressed much further with their studies and could now contribute if the folio were to be opened to additions.

With systematic work still for the most part in progress, it is not surprising that we have hardly begun the other aspect of the synthesis, the examination of communities or associations of the various invertebrate groups both on antarctic bottoms and in the overlying seas. This step beyond taxonomy still needs more thorough systematic analysis than has so far been available, but when it comes it will be due in very large part to the extensive collections made by the *Eltanin* during her years of service in antarctic waters.

Solar Radiation

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Biological primary productivity in the ocean is a function, in part, of the radiation environment. In particular, photosynthesis by different species of phytoplankton is selectively dependent on energy of different wavelengths. Consequently, a knowledge of the spectral distribution of solar radiation that is made available to the water mass is basic to a better understanding of organic production in the marine ecosystem.

Measurement program

In keeping with the integrated approach of biological studies aboard *Eltanin*, a program was conducted during Cruises 46 and 51 to measure the quantity and quality of solar radiation entering the water mass. Although observations of incident global radiation had been made previously by the Australian contingent aboard the vessel (Zillman, 1973), the newly designed program included continuous measurements of the upwelling and the downwelling global fluxes, thus permitting determination of the net flux, *i.e.*, the energy entering and remaining within the water. To determine the quality of the energy, measurements were made of both the up and down fluxes over four broad wavebands: 280 to 500 nanometers (blue), 500 to 630 nm (green), 630 to 700 nm (red), and 700 to 2800 nm (infrared).

Similar instruments (Eppley precision spectroradiometers) were used for all measurements. These filtered hemispheric sensors are compensated for temperature and have a good cosine response. The down-facing set of four was established 9 meters ahead of the vessel on a bow-mounted retractable boom; the up-facing set was mounted high on the helicopter pad, aft on the vessel. Both sets were mounted on damped gimbals.

Results

Summary results for Cruises 46 and 51 are presented in Tables 1 and 2. Average and extrema of daily values of incident flux are given for 5-degree latitude belts. For each daily value, the spectral composition is shown in percent. Also included are related values of the net flux and the amount received between sunrise and local solar noon, both expressed in terms of percent of the incident downwelling flux.

Gross parameters. Of particular interest is the asymmetry of the incident flux with respect to local solar noon. This was a consequence of variable cloudiness. During Cruise 46, the a.m.-insolation ranged from 26 to 84 percent of the daily total; during Cruise 51, from 35 to 75 percent. Consequently, estimates of daily productivity that are based on either a.m. or p.m. *in situ* measurements should take this factor into account.

Table 1. Daily average and extrema of incident solar radiation, and the spectral composition of each, for 5-degree latitude belts.

Location		Amount			Spectral composition		
Lat/long Dates		% of daily a.m.	Net	Daily ly/day	% of daily b	g-o	ir
40S/115E	Avg	26	95	306	24	29	47
24	Max						
Nov	Min						
45S/115E	Avg	38	94	382	22	30	48
27-28	Max	39	95	566	21	30	50
Nov	Min	38	92	197	25	32	43
50S/115E	Avg	45	94	532	21	29	50
29 Nov-	Max	53	96	712	21	27	52
2 Dec	Min	43	91	223	23	31	45
50S/78E	Avg	45		361	25	27	48
7-12	Max	59		524	23	25	51
Jan	Min	33		192	28	29	43
55S/115E	Avg	47	95	509	22	28	50
3-5	Max	52		606	22	26	52
Dec	Min	42		443	22	29	48
55S/72E	Avg	40		365	25	28	48
5-6	Max	41		398	25	28	47
Jan	Min	38		332	25	27	48
60S/114E	Avg	48	94	411	21	28	52
6-8	Max	49	94	736	19	27	54
Dec	Min	44	94	248	24	29	47
60S/81E	Avg	64		261	25	28	48
23, 26	Max	84		331	23	27	50
Dec	Min	53	94	190	27	28	45
60S/74E	Avg	60		342	23	29	48
2-4	Max	78		499	22	28	50
Jan	Min	53		185	28	31	42
65S/94E	Avg	48	92	360	22	28	50
10-22	Max	59	95	553	21	27	53
Dec	Min	34	67	221	25	34	41
65S/75E	Avg	46		373	23	30	48
27-31	Max	57		576	21	30	50
Dec	Min	31		281	22	30	46

Spectral bands: b, 280-500 nm; g-o, 500-700 nm; ir, 700-2800 nm. Cruise 46, November-December 1970, January 1971. (Net=incident–reflected)

The daily net solar radiation over ice-free open waters was found to be 92 to 96 percent of the value of the incident flux. However, over areas with scattered to broken sea ice, the daily net radiation was reduced to 67 to 73 percent of the incident. From a biological standpoint, this represents an appreciable loss to the biomass owing to the high reflectivity of the ice. An additional loss would result from the absorption by the ice. This would have to be assessed by subsurface measurements.

The dramatic effects of clouds and sea ice are apparent in the data. In general, for each 5-degree belt, the maxima occurred with clear to partly cloudy skies, the minima with overcast conditions. Although a decrease in the daily average values of incident radiation was observed with increasing latitude, especially during Cruise 51, this result was masked during Cruise 46, when overcast skies produced the much reduced values at 40°S. and 45°S., while clear to partly cloudy skies at 50°S. and 55°S. were responsible for the maxima observed at these latitudes.

Important anomaly. A rather important cloud-associated result was observed at the southern extremities of both cruises, *viz.*, the incident radiation increased with nearness to the continental shelf as a result of a decrease in cloud amount. This en-

Table 2. Daily average and extrema of incident solar radition, and the spectral composition of each, for 5-degree latitude belts.

Location		Amount			Spectral Composition			
Lat-long Dates		% of daily a.m.	Net	Daily ly/day	% of daily b	g	o	ir
45S/173E	Avg	53		435	21	23	10	46
18-19	Max	54		658	20	22	10	48
Jan	Min	49		212	23	29	11	37
50S/170E	Avg	59		407	19	23	11	47
20-21	Max	62		510	19	23	10	48
Jan	Min	58		303	21	22	12	45
55S/173E	Avg	46		380	24	22	10	44
22-24	Max	69		508	23	22	10	46
Jan	Min	37		229	26	25	9	41
60S/171E	Avg	49		301	23	23	9	45
25-28	Max	54		439	23	21	9	47
Jan	Min	39		127	27	24	11	39
65S/166E	Avg	52		260	22	23	10	45
29 Jan-	Max	59		488	18	21	9	52
2 Feb	Min	41		169	24	23	12	41
70S/175E	Avg	48		186	24	24	11	42
3-6	Max	54		294	22	22	10	45
Feb	Min	42		158	25	27	11	37
75S/169W	Avg	50	89	143	25	22	10	43
7-15	Max	75	95	199	22	25	9	44
Feb	Min	35	70	116	27	20	10	42
80S/174W	Avg	51	86	300	20	21	10	49
16-24	Max	60	95	424	18	21	9	53
Feb	Min	39	73	130	28	21	9	43

Spectral bands: b, 280-500 nm; g, 500-630 nm; o, 630-700 nm; ir, 700-2800 nm. Cruise 51, January-February 1972. (Net=incident–reflected) hancement was due also to increased reflectivity from sea ice as well as from the shelf ice, *i.e.,* the continent. This is especially noticeable in the data for Cruise 51: there was a greater than 100-percent increase in going from 75°S. to the regions adjacent to the shelf. Consequently, if solar radiation were the primary constraint of photosynthesis, one would expect increased productivity in the near-shelf areas. *In situ* measurements made, indeed, do show this (El-Sayed, 1973).

Spectral composition of incident flux. Expected variations in the spectral composition of the incident flux were quantified. Although masked by cloud and sea ice effects, with increasing latitude, a decrease in the blue component and an increase in the infrared were observed. Increasing cloudiness increased the blue and green components and decreased the infrared. Little change was noted in the red band. These results may be seen by comparing spectral composition values associated with maxima (clear to partly cloudy) with those of the minima (overcast) as presented in tables 1 and 2. Selective absorption by the clouds of the infrared radiation is apparent. Although not shown in the tables, sea ice enhanced the blue and decreased the infrared components of the incident flux, a result similar to that effected by increased cloudiness.

Spectral composition of net flux. The important parameters, from both biological and physical standpoints, are the net fluxes. When compared to components of the incident fluxes, net fluxes were found to be smaller, of course, owing to losses represented by the upwelling streams. In general, the spectral composition of incident and net fluxes over open water were within 3 percent of each other, with the net radiation being poorer in the blue but richer in the infrared. Again, clouds and sea ice exerted a marked influence. Increased cloudiness decreased the infrared component 2 to 11 percent and increased the blue 2 to 10 percent. On the other hand, sea ice increased the infrared band 3 to 10 percent and decreased the visible bands 3 to 11 percent. Hence, clouds and sea ice exerted opposite influences on the spectral composition of the net fluxes, *i.e.,* the energy made available to the biomass.

Conclusion

The amount and quality of solar radiation was found to vary in a complex way with latitude, time of year, cloudiness, and sea-ice conditions. Consequently, future biological studies in the marine environment should include measurements of these parameters, if the effort is to be well integrated. Critical needs are to assess the spectral composition of the net flux as a function of depth within the water, especially in sea ice near the coast, and to determine the influence of reduced cloudiness and proximity of the continent on the net radiation in regions adjacent to the continental ice shelf. A large gap exists in our knowledge of these factors, as well as in the availability of solar radiation data for the oceans not yet surveyed around Antarctica.

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Meteorology

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The availability of *Eltanin* as a platform for surface and surface-based upper air measurements has rendered notable service to southern hemisphere meteorology in two important ways. First, the prompt radio transmission of routine coded weather reports provided, on occasion, invaluable information for synoptic analysis and weather forecasting in middle latitudes. Second, the unique set of meteorological data collected over a decade of operations in what is probably the meteorologically least-documented region of the globe has provided an opportunity to examine the nature and structure of little-known meteorological processes endemic to the region. It is also helping to clarify the role of the circumpolar ocean in shaping the large-scale atmospheric circulation and global climate.

With the first few years of operations confined mainly to the southwestern Atlantic and southeastern Pacific oceans, the *Eltanin* meteorological observations were of most immediate concern to weather forecasting in extratropical South America, but contributed also to the hemispheric analysis project of the South African Weather Bureau and to the International Antarctic Analysis Centre that operated in Melbourne from 1959 to 1965. Weather forecasting in the Australia-New Zealand region is critically dependent on a knowledge of synoptic patterns to the south and southwest of Australia—an area devoid of fixed observation stations and rarely visited by shipping. Thus when, in 1968, *Eltanin* commenced operations in this sector and the United States National Weather Service [which had maintained the meteorological program up to this time (Roberts, 1969)] found itself unable to continue, Australia willingly accepted an invitation from the National Science Foundation and the administrator of the then Environmental Science Services Administration to assume responsibility for the onboard meteorological activities. This report summarizes those activities during the 4½ years of Cruises 35 to 55 and highlights their contribution to southern hemisphere meteorology.

Onboard meteorology

The basic meteorological observation schedule comprised 6-hourly (00, 06, 12, 18 GMT) surface observations and one rawinsonde flight daily (23 GMT approximately). The surface observations included all the normal meteorological parameters:

(i) atmospheric pressure to the nearest tenth of a millibar: measured with a precision aneroid barometer (USWB type) in the meteorological office approximately 5 meters above sea level

(ii) wind speed and direction in tens of degrees and whole knots: for winds coming from "ahead of the beam," measured with a cup rotor anemometer on the forward ice house approximately 18 meters above sea level; for winds from "aft of the beam," measured with a Bendix impellor-type anemometer on the port aft King post approximately 18 meters above sea level (measurements in both cases corrected for ship's vector motion)

(iii) air temperature, dry and wet bulb, to the nearest tenth of a degree Celsius: during Cruises 35 and 36 measured with a sling psychrometer on the quarter deck (port or starboard) or the fantail approximately 6 meters above sea level; during Cruises 37-55 with a portable Stevenson screen on the flying bridge approximately 12 meters above sea level and (in conditions of near calm) with an Assman psychrometer exposed upwind of all obstructions

(iv) sea surface temperature to the nearest tenth of a degree Celsius: measured, for meteorological purposes, by immersion of a mercury thermometer in a sea water sample gathered in a brass cylinder or rubber bucket; three successive identical values were required to confirm a reading

(v) total cloud cover in octas; also amount, type, and height of low cloud, type of middle level cloud and type of high cloud: all visually estimated

(vi) visibility and present and past weather: assessed and codified according to standard meteorological practice

(vii) sea state: significant wave height, period and direction of travel of sea and swell waves estimated and recorded in half meters, seconds, and tens of degrees respectively

The rawinsonde flights to determine vertical profiles (to 20 kilometers or more) of temperature, humidity, and horizontal winds consisted of launching and tracking a helium-filled balloon with pressure, temperature and humidity sensors, 403-megahertz pulse-modulated transmitter and radar target attached. The shipboard radiosonde equipment comprised a USWB-type receiver-frequency converter and recorder switchable to any of three dipole antennas, two forward or one aft. For wind determination the balloon was tracked with shipboard air-search radar. However, the maximum range achievable was between 40 and 45 miles, and targets at greater elevation than 45 degrees or at low elevation astern could not be tracked successfully for more than half this distance. The air-search radar, which had been inoperative for some time prior to Cruise 35, continued to be susceptible to equipment failure and, despite considerable maintenance effort, no upper wind information was obtainable after Cruise 45. Various types of balloons were employed for the radiosonde and (when the radar was operative) rawinsonde flights. Rawinsonde train release (from the fantail—a short extension to the main deck at the stern of the vessel) proved a rather intricate operation in conditions of strong relative winds; to avoid loss or damage to the equipment, the ship had to be held into the wind during release. The procedures developed for optimum performance are described by Dingle (1969).

The basic observational program was supplemented in a number of ways during Cruises 35 to 55. The additional activities included:

(i) hourly measurements of sea surface and dry and wet bulb temperatures, temperature at the 18-meter level, wind speed and direction, atmospheric pressure, and cloud cover for protracted periods during the passage of significant atmospheric circulation systems and in the vicinity of oceanic fronts. In addition, during Cruise 47a and subsequently, full 3-hourly surface observations were made routinely

(ii) a second daily radiosonde flight (at approximately 1100 GMT) that was initiated with Cruise 38 and, except for Cruises 42 and 43, maintained for the remainder of the program

(iii) solar and atmospheric radiation recording. Equipment was installed for Cruises 39-49. The sensors consisted of an Eppley pyranometer and a Funk net radiometer modified by enclosing the underside in a black-body cavity whose temperature was continuously monitored. The radiometers were gimbal-mounted on the starboard side of the helicopter deck. The sensor output and cavity temperature were recorded on roll charts and an integrator produced half-hourly averages of the output of both sensors. The processed records consist of half-hourly averages of global radiation and downward long-wave radiation.

Meteorology-related measurements were conducted in cooperation with, or on behalf of, several other organizations:

(i) Special sea state observations were conducted for selected periods at the request of Professor J. F. Ward of the James Cook University of North Queensland

(ii) Ice nuclei sampling equipment installed from Cruise 39 to Cruise 52 was operated on behalf of Dr. E. K. Bigg of the CSIRO Division of Cloud Physics at Epping, New South Wales

(iii) Oxygen sampling was carried out for the U.S. National Bureau of Standards for a short period and carbon dioxide sampling for Scripps Institute of Oceanography until the termination of Cruise 52.

The distribution of meteorological data gathered during Cruises 35 to 55 is summarized in table 1. All original records, excluding the special data (i) to (iii) above are held by the Commonwealth Bureau of Meteorology in Melbourne. It is expected that, after appropriate processing and quality control, all the routine surface and upper air data from Cruises 35 to 55 will be made available in a format similar to that of the earlier cruise results already published by the U.S. Department of Commerce (Environmental Science Services Administration, 1968, 1970). The radiation measurements and selected special hourly data also are being prepared for publication.

In addition to gathering meteorological data the Bureau of Meteorology personnel were engaged from time to time in various other onboard activities, including provision of meteorological support for all scientific and shipboard activities (this included monitoring of radio-facsimile broadcasts of weather charts and prognoses prepared at the World Meteorological Centre in Melbourne), precision depth recorder watch as requested by the USARP chief scientist aboard (on average about 3 hours per day), and participation in the Interrogation Research Location System experiment (Cruises 38-40).

Contribution to operational analysis and forecasting

Except for the immediate environs of Tasmania there is not normally, in the entire 90-degree sector from Kerguelen Island to the longitudes of eastern Australia, a single meteorological observing site in the southern ocean. There are no islands and no permanently sited weather ships. Commercial shipping rarely ventures south of latitude 45°. The few stations on the fringe of Antarctica are located in a totally different meteorological regime and give limited indication of synoptic processes over the ocean to the north. Satellite pictures regularly available once or twice daily, since the mid 1960s have made it possible to identify and track the major weather systems but give no direct information concerning temperature, humidity, wind, and pressure on which to base a quantitative description of the state of the atmosphere. Such quantitative information is essential to the operation of numerical-dynamical forecasting models.

Time series of data from even a single observing site in such a large expanse of ocean can, when used in conjunction with satellite photos of the cloud formation, enormously increase the level of confidence in synoptic analysis. Thus, although not in a fixed position and clearly not always from the optimum location, the *Eltanin* reports made a major contribution to synoptic analysis over large parts of the southern ocean with a consequent improvement in forecasts for regions such as southern Australia. On many occasions synoptic patterns, ambiguous in the light of satellite data, were clarified by a single *Eltanin* report. On other occasions, when only the broad pattern was known, a sequence of *Eltanin* reports enabled the details of the pattern to be defined with considerable precision. Fig. 1 shows a typical cyclonic cloud vortex moving to the south of Australia. The satellite picture is a composite from successive orbits of the ESSA 8 meteorological satellite and applies approximately to 00 GMT on September 6, 1971. The small black circles along the Australian and antarctic coasts show the location of regular meteorological observing stations. The location of *Eltanin* at 00 GMT is arrowed. Cloud, wind, and atmospheric pressure at 00 GMT are shown plotted in conventional format. Now, by comparing the positions of various features of the cloud field over several days, the cyclone's track can be established as only slightly south of due east and its speed 30 knots. Assuming the pressure field of the moving cyclone to be changing only slowly, the sequence of 6-hourly reports as the cyclone passes over *Eltanin* may be interpreted as an equivalent movement of *Eltanin* relative to the cyclone. The 6-hourly observations shown plotted on this basis enable the pressure field at 00 GMT to be drawn with considerable confidence. The sharp wind change from northerly to almost due southerly as the vortex center passed over *Eltanin* (fig. 1) provides strong evidence that,

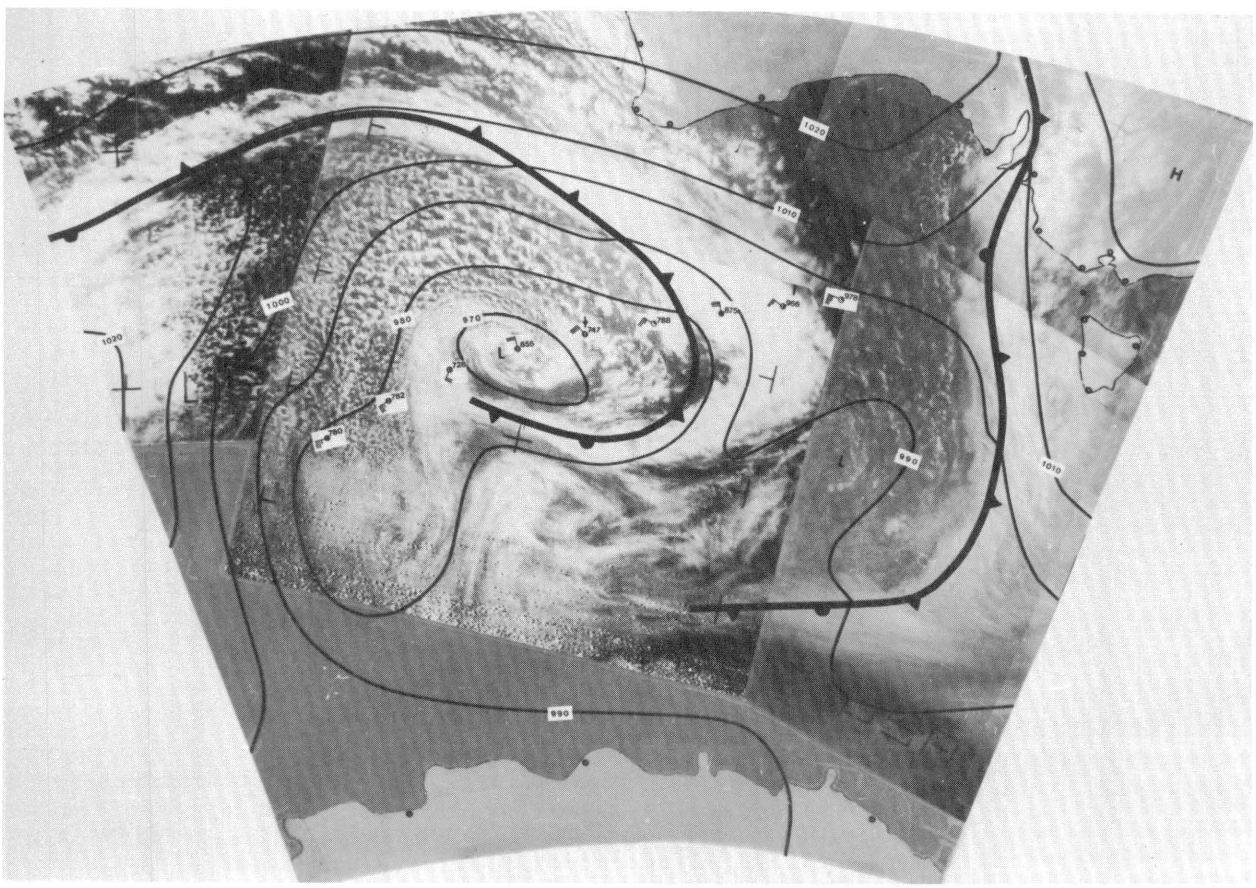


Figure 1.

Synoptic situation between southern Australia and Antarctica, at about 00 GMT, September 6, 1971. The small, black circles around Australia and Antarctica are meteorological reporting stations. Satellite depiction of the cloud cover is a mosaic from several orbits of the ESSA meteorological satellite. *Eltanin* observations of cloud cover, wind, and atmospheric pressure from OO GMT, September 5, 1971, to OO GMT September 7, 1971, are arrayed as if the ship were moving relative to the cloud vortex. Atmospheric pressure is in tenths of millibars, and winds are in the direction of the arrows (each long barb equals 10 knots). Isobars are labelled in millibars.

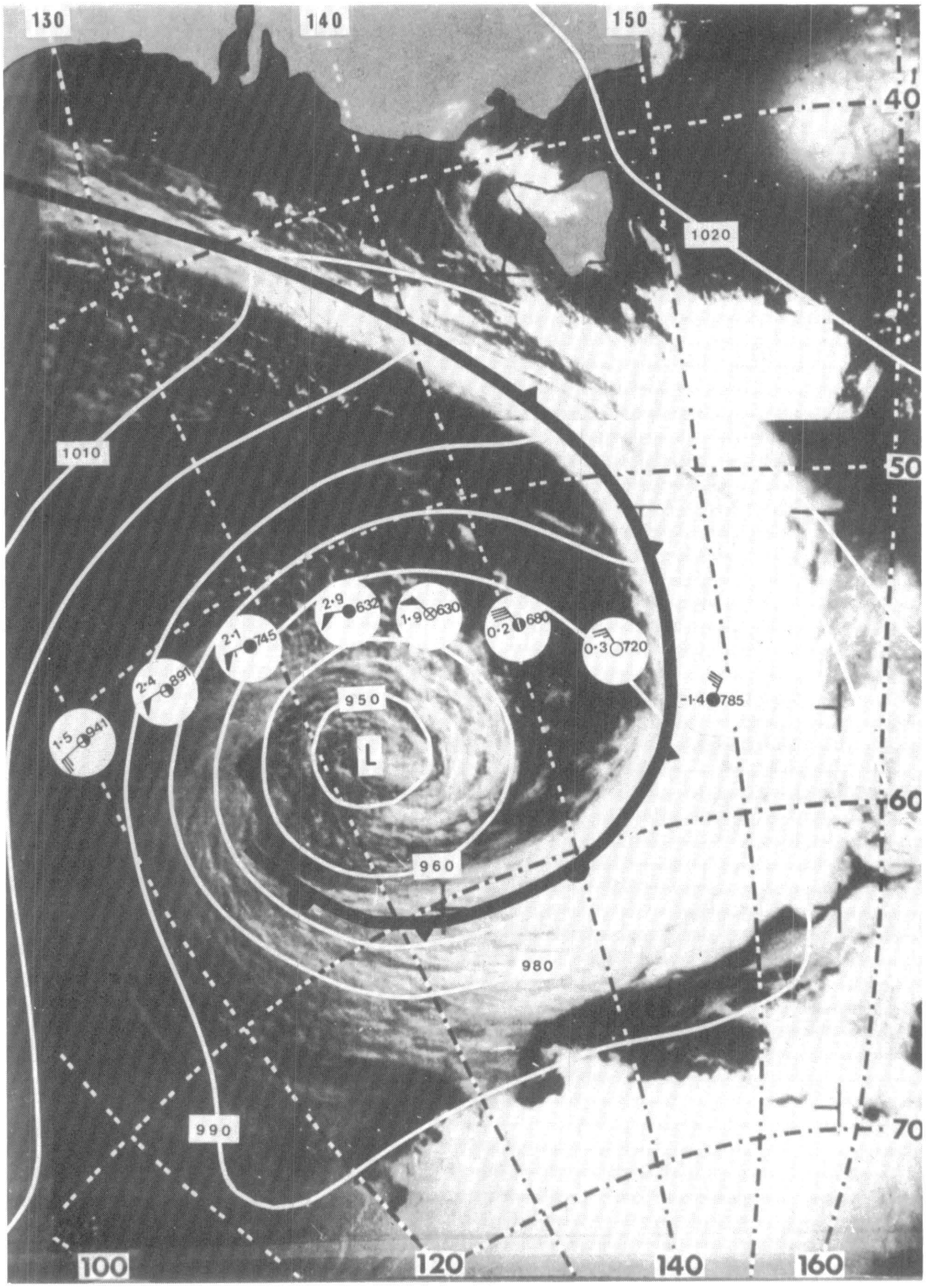


Figure 2.
A time section of *Eltanin* observations confirms the intensity of the cyclone which passed south of Australia during February 17-18, 1969. Triangular barbs on the wind arrows equals 50 knots. Figures to the left of each plot are temperature differences, sea minus air.

in this mature cyclone, the surface pressure minimum was directly below the cloud vortex and the cyclone's central pressure at about 00 GMT is accurately determined. Fig. 2 shows a rather different situation. Both satellite information and the slow backing of the wind indicate that the center of the cyclone passed well south of *Eltanin*. Although the central pressure in this case cannot be inferred so precisely, the sustained gales (among the most severe encountered by *Eltanin* during 10 years in antarctic waters) provided clear indication to synoptic analysts of the intensity of the storm.

Over the decade of *Eltanin* operations in the southern ocean, the World Meteorological Centre (and its forerunners, the Southern Hemisphere Analysis Centre and the International Antarctic Analysis Centre in Melbourne maintained continuous "time sections" of surface and upper air *Eltanin* observations received by radio. Unfortunately the failure of the wind-finding radar and the fact that the surface and upper air reports could not always be inserted promptly into the meteorological communication networks detracted, at times seriously, from the total value of the program. There is no question, however, that, during operations south of Australia, there was direct benefit to Australian forecasting. Similar benefit was undoubtedly derived by other national meteorological services. *Deep Freeze* air operations between New Zealand and the Antarctic received direct support from the *Eltanin* meteorological program from time to time. During operations in the south Pacific (Cruises 42 and 43), Australia saw fit to continue to man the program as a contribution to the World Weather Watch. The termination of the cruises at the end of 1972 cut short anticipated benefit to the World Weather Watch and to regional forecasting during operations in the southern Indian Ocean.

Meteorological research using *Eltanin* data

The meteorological data gathered during the *Eltanin* cruises will provide a basis for research into a number of aspects of southern ocean meteorology. Initial studies already have led to important results. Some of this work is described briefly below.

The Global Atmospheric Research Program (GARP) Basic Data Set Project (Phillpot *et al.*, 1971; Thompson, 1971, 1972) aimed to assemble, for the months of November 1969 and June 1970, the best possible sets of global meteorological analyses for subsequent research. Though the ship was not at sea for all of the two months, the available *Eltanin* data contributed to both the sea surface temperature and standard meteorological analyses over the western Pacific. In particular the extensive sea surface temperature records permitted confident

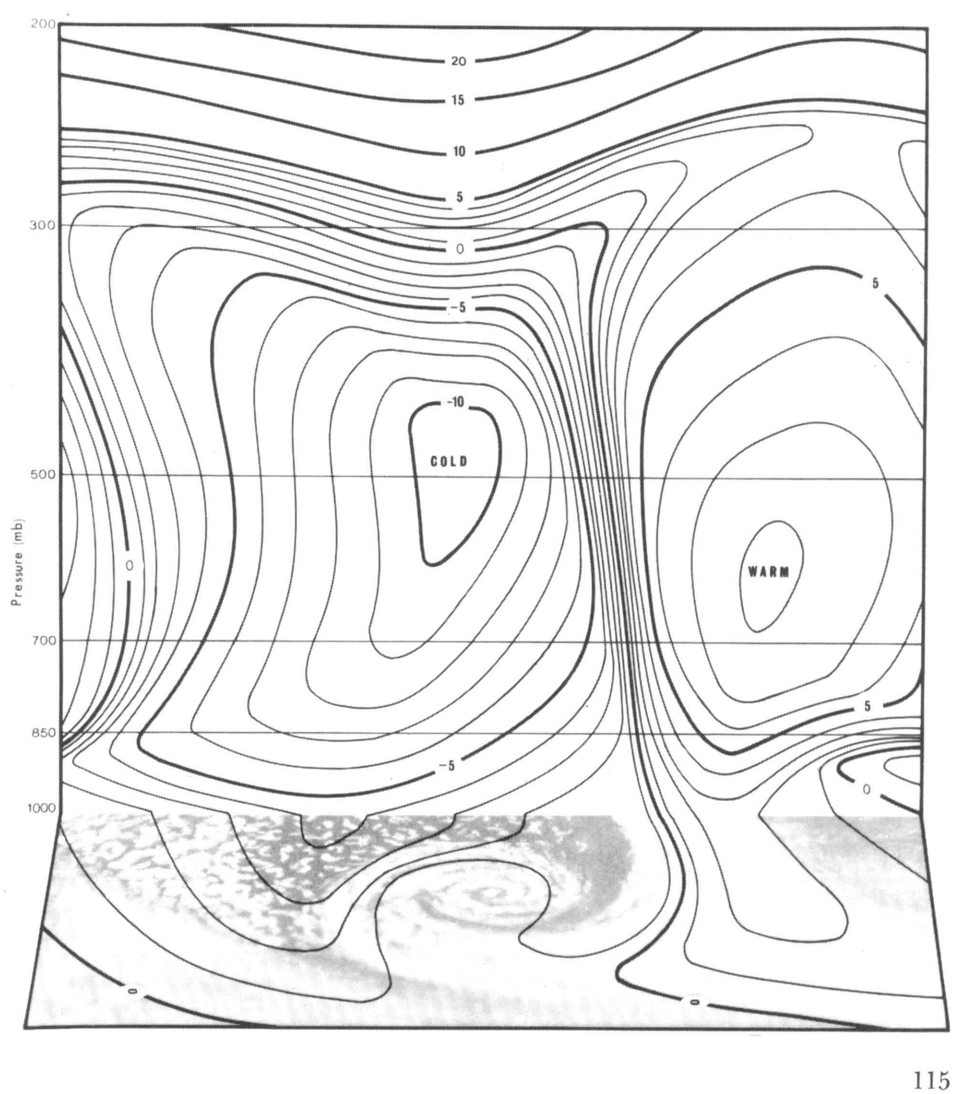
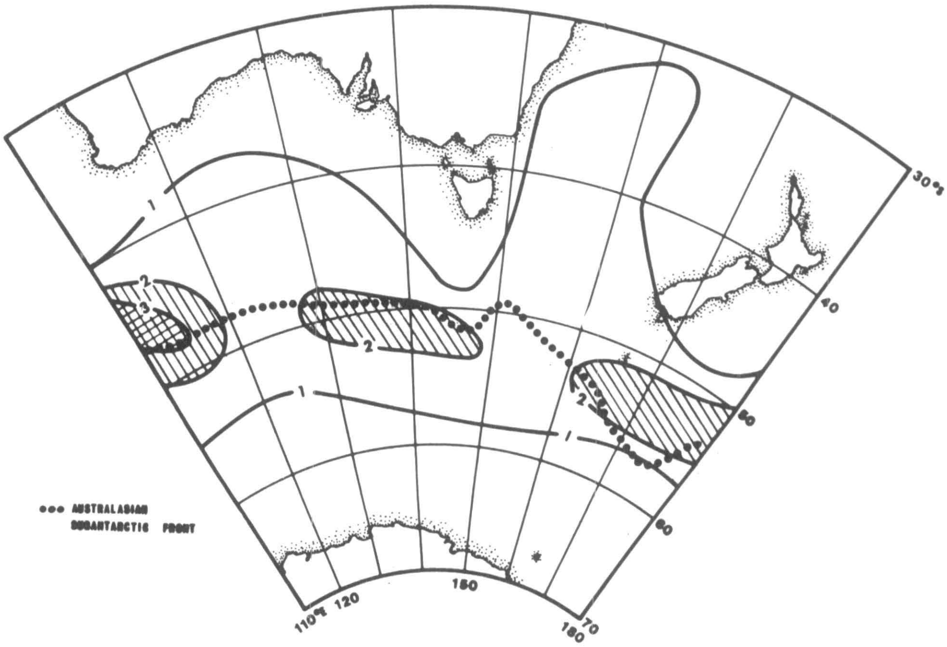


Figure 3.
A west coast cross section of temperature departures from a reference atmosphere equatorward of the core region of an idealized cloud vortex. Vertical scale is in millibars with 500 millibars near 5½ kilometers. Reference atmosphere has a 74°C temperature decrease from the sea surface temperature to 200 millibars, and approximates the climatological normal through the troposphere.

Figure 4.
Association of cyclogenesis with the dominant oceanic front of the Australian sector. Isopleths of the relative frequency of developing cloud vortices in summer (Streten and Troup, 1973) are compared with the location of the Australian Subantarctic Front, from *Eltanin* data (Gordon, 1972).



analysis over the limited region of the *Eltanin* operations.

Because of the paucity of conventional meteorological data over the southern ocean, it has always been necessary to rely heavily on the use of structural models for synoptic analysis (Gibbs, 1960). The need for methods to infer the thermal and dynamic structure of the atmosphere from a knowledge of the large scale cloud field has become even more widely felt with the operational availability of satellite cloud pictures during the 1960s. The organized mature cloud vortex (figs. 1 and 2) is a feature that readily lends itself to structural modelling. A large number of *Eltanin* temperature profiles from the surface to 200 millibars were classified according to synoptic and mesoscale cloud configuration and combined with radiosonde data from a few island stations and sea-air temperature difference statistics (*Eltanin* and other sources) to develop the prototype of such a model. Fig. 3 (Zillman and Price, 1972) shows a west-east cross section of temperature departure from a reference atmosphere just equatorward of the core region of the modelled mature cloud vortex.

Meteorologists have long been conscious of the influence of oceanic temperature anomalies and gradients on the atmospheric circulation. Data from *Eltanin* Cruises 35 to 41 was used in conjunction with that from Australian antarctic relief ships to identify the semipermanent features of the sea surface temperature field likely to exert significant influence on atmospheric development south of Australia. The approximate location of the Australasian Subantarctic Front was identified (Zillman, 1970) and shown to be associated with a belt of high evaporation and large heat flux to the atmosphere (Zillman and Dingle, 1969; Zillman, 1972a). Based on satellite data it also appears as a region of frequent cyclogenesis (Zillman, 1972a). Fig. 4 shows the position of the Australasian Subantarctic Front after Gordon (1972) superimposed on isopleths of the relative frequency of occurrence of "developing" cloud vortices in summer (Streten and Troup, 1973). More detailed examination of the heat and moisture fluxes associated with the Australasian Subantarctic Front is continuing on the basis of the further cruise data.

The extensive sequences of hourly measurements of sea-air energy exchange parameters along with *Eltanin* upper-air data have been used to investigate the energetics of individual synoptic systems. Zillman and Dingle (1969) and Zillman (1972a) evaluated the variation of sea-air heat flux and evaporation with the passage of atmospheric fronts. Bullock and Johnson (1972) relied heavily on *Eltanin* data from Cruise 37 to adduce evidence that surface sensible heating may be an important factor in the generation of available potential energy in southern ocean cyclones. Their finding is important in that it suggests that currently accepted conclusions on the role of eddy diabatic processes in the development of cyclones and the maintenance of the general circulation are open to question, and reaffirms the belief of Petterssen (1960) that energy sources for the general circulation are to be found at the cyclone scale.

Solar and longwave radiation measurements from Cruises 39 to 41 were used along with bulk aerodynamic determinations of the interfacial sensible and latent heat fluxes to examine the latitudinal and seasonal variation of the major heat budget components in the Australian sector of the southern ocean and to assess the influence of the heavy cloud cover of the region on short and long wave radiation fluxes (Zillman 1972a, b). Fig. 5 shows the variation with latitude of the sensible and latent heat fluxes based on all 6-hourly data from Cruises 35 to 41. Maxima are evident in both fluxes just poleward of 45°S. This work is continuing, and the complete cruise data are expected to provide more definitive information on the heat budget of the southern ocean than has been available hitherto.

The Antarctic Circumpolar Current is primarily a wind-driven circulation. The location of climatic oceanic divergence and convergence zones is largely determined by the pattern of mean wind stress on the sea surface. Thus a knowledge of the wind stress holds important clues to certain basic aspects of the oceanic circulation. Computation of the mean wind stress as a function of latitude from all 6-hourly data of Cruises 35 to 41 suggested a single maximum in the west-east component near 46°S. The profile of zonal stress component from these early data is included in fig. 5.

The high level radiosonde data from earlier *Eltanin* cruises were used to ascertain whether the stratospheric behaviour over the South Pacific is significantly different from that of other sectors. The result (H. R. Phillpot, unpublished) suggested that this was not the case.

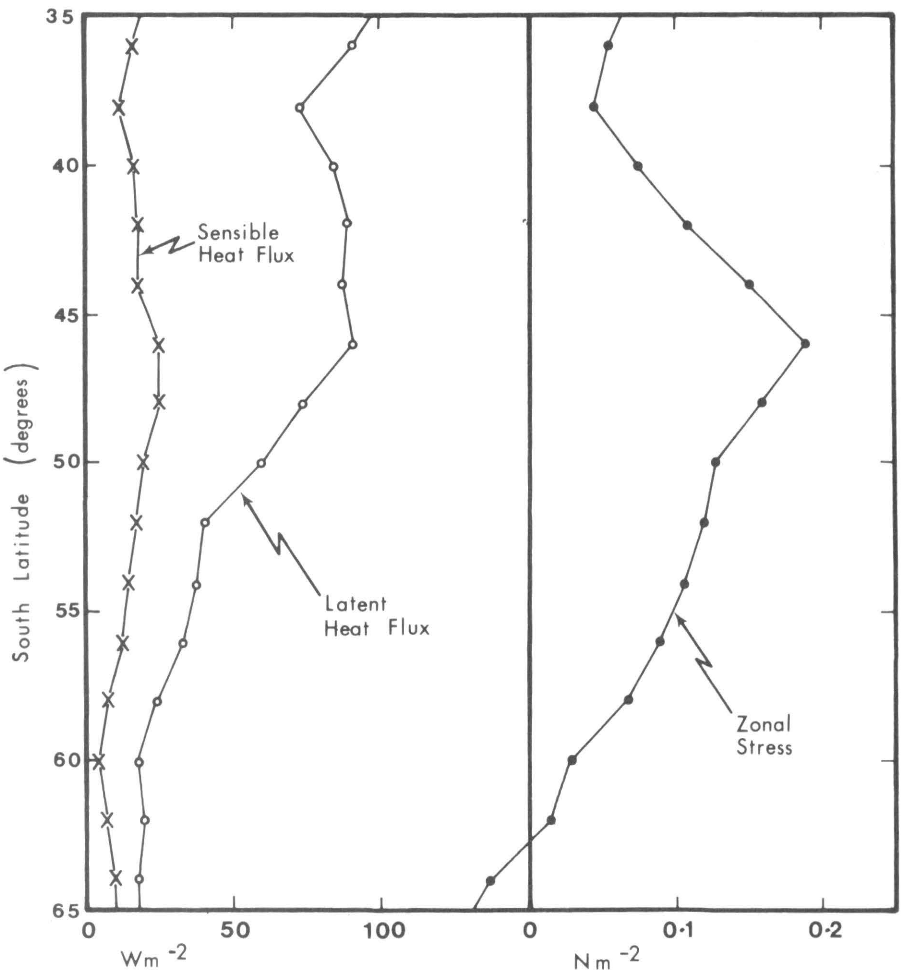


Figure 5.
The latitudinal variation of sensible and latent heat fluxes from sea to air and the zonal wind stress on the sea surface from data of *Eltanin* Cruises 35-41 (between 115° and 160°E).

The special *Eltanin* sea state observations commissioned by the James Cook University of North Queensland were used in an evaluation of the potential use of HF radar backscatter with an ionospheric propagation mode to determine certain features of the sea wave spectra in remote ocean regions (Dexter 1970, 1972).

Bigg (1973) has analysed the results of the ice nucleus sampling program on Cruises 39 to 52. His results show that natural cloud seeding par-

Meteorological personnel and summary of data gathered during *Eltanin* Cruises 35 to 55

		Surface observations		Upper air observations						
Cruise	Personnel	Routine 6-hourly	Additional	Upper winds	Radiosonde 11 GMT Approx.	Radiosonde 23 GMT Approx.	Radiation	Special sea and swell observations	Carbon dioxide samples	Ice nuclei samples
35	M. L. Fields (USWB) W. R. J. Dingle	223	33	52	0	55	Nil	Nil	8	Nil
36	M. L. Fields (USWB) W. R. J. Dingle	241	0	56	0	56	Nil	Nil	9	Nil
37	W. R. J. Dingle T. S. Fernandez	206	148	11	0	48	Nil	Nil	8	Nil
38	W. R. J. Dingle D. McLeod	212	274	69	35	50	Nil	Nil	8	Nil
39	W. R. J. Dingle D. McLeod	206	235	40	42	49	Continuous records	July 20-28	8	204
40	W. R. J. Dingle C. R. McCulloch	254	0	40	0	60	Continuous records	Nil	9	256
41	W. R. J. Dingle C. R. McCulloch	221	614	0	50	54	Continuous for most of cruise	Nil	7	32
42	W. R. J. Dingle S. N. Summers	168	116	0	0	41	Feb 28 to March 5 only	March 3-6	12	166
43	W. R. J. Dingle S. N. Summers	178	280	0	0	43	Nil	Nil	13	172
44	W. R. J. Dingle A. H. Murphy	221	465	58	23	54	Continuous records	Nil	14	216
45	W. R. J. Dingle A. H. Murphy	195	636	4	48	47	Continuous records	Nil	12	194
46	W. R. J. Dingle A. H. Murphy	242	561	0	59	60	Continuous records	Nil	14	240
47	W. R. J. Dingle L. M. Lloyd	274	926	0	61	66	Continuous records	Nil	17	264
47A	W. R. J. Dingle L. M. Lloyd	79	101	0	16	15	Continuous records	April 20 to May 9	4	82
48	W. R. J. Dingle G. J. Whiteside	204	523	0	45	51	Continuous for most of cruise	June 28 to July 1	13	206
49	W. R. J. Dingle G. J. Whiteside	226	768	0	55	55	Continuous for most of cruise	Nil	12	228
50	W. R. J. Dingle M. W. C. Scott	221	660	0	50	54	Nil	Nil	12	224
51	W. R. J. Dingle M. W. C. Scott	156	423	0	58	66	Nil	Nil	11	292
52	W. R. J. Dingle M. W. C. Scott	117	296	0			Nil			
53	M. W. C. Scott B. A. McGurgan	238	532	0	51	54	Nil	Nil	Nil	Nil
54	B. A. McGurgan G. K. Naughton	251	488	0	58	59	Nil	Nil	Nil	Nil
55	G. K. Naughton D. W. Moore	170	170	0	30	30	Nil	Nil	Nil	Nil
					(Approx.)	(Approx.)				

ticles are not obviously of continental origin. Concentrations tend to be highest around latitude 40°S. at all longitudes visited by *Eltanin*.

Outlook

Resumption of systematic oceanographic research cruises in the southern Indian Ocean would constitute a significant contribution to the World Weather Watch. Likewise, if the GARP experiments of the latter part of this decade are to be truly "global" huge data voids in the southern oceans must be filled. The meteorological community looks to the availability of such platforms as the *Eltanin* to help achieve this goal. Aside from the short-term benefits, there is a school of thought with much of its origin in the work of Fletcher (1969) that sees the brightest prospects for understanding the mechanisms controlling climate and for long-range prediction of climatic trends in programs to monitor the evolving oceanic heat sources and sinks. Continued oceanic heat budget studies such as mounted on the basis of *Eltanin* Cruises 35-55 would be invaluable to that end.

Acknowledgements

Participation in the *Eltanin* cruises at the invitation of the National Science Foundation has proved a most rewarding venture for the Australian Bureau of Meteorology. The Australian meteorological personnel associated with Cruises 35 to 55 acknowledge the assistance and cooperation of the National Science Foundation, the National Oceanic and Atmospheric Administration, and particularly the ship's master and crew in all aspects of the meteorological program. This report is published by permission of the Director of the Commonwealth Bureau of Meteorology. For discussion during its compilation acknowledgement is due to Messrs. J. N. McRae, H. R. Phillpot, H. N. Brann, E. A. Mizon, A. H. Muffatti and P. E. Dexter of the Bureau of Meteorology and Dr. E. K. Bigg of CSIRO Division of Cloud Physics.

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Antarctic Marine Geology Research Facility and Core Library

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The Antarctic Marine Geology Research Facility and Core Library (fig. 1) is an NSF-established curatorial and research activity designed specifically as a national depository for geological materials collected in polar regions. Particular emphasis is given to materials retrieved from the floor of the ocean in antarctic and subantarctic waters aboard USNS *Eltanin,* and the Department of Geology has maintained a marine geology coring program from the first cruise of the *Eltanin* in 1962 to its most recent one, Cruise 55, in 1972.

Funded activities of the facility, although highly integrated, can be grouped into three areas. First, there has been the year-round shipboard operation of the marine geology coring program aboard *Eltanin,* which has included retrieval of geological materials by coring, dredging, and grab sampling of the ocean floor and the logistics involved in pur-

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Figure 1. Partial exterior view of the Antarctic Marine Geology Research Facility and Core Library, Flordia State Uuiversity.

chasing, shipping, and maintaining materials and supplies needed to support the shipboard operation. Twenty-nine graduate students, one undergraduate, one staff technician, and one faculty member have participated in this program. These numbers do not include faculty and students from other departments of the Florida State University who have participated in separately funded *Eltanin* and antarctic continental programs.

Second, there are the administrative and supportive curatorial functions of the facility, which comprise—

(a) receipt and initial processing of the cored and dredged material. Plastic-encased, 3-meter sections of cored sediment are cut, split, and tagged, using an adjustable, track operated, high speed, radial power saw (fig. 2). The sediment core is manually split after the saw cuts through only the thickness of the cellulose acetate butyrate (CAB) plastic liner, on opposite sides. The resulting halves are thereafter handled and stored in their entire length. Future core cutting may be done by a motorized-capstan core-liner splitter similar to that aboard *Glomar Challenger*.

(b) preparation of detailed descriptions of the sedimentary material on the basis of both macro- and micro-observable lithology. These descriptions include but are not limited to color, texture, mineralogy, structure, and paleontology of the sediments and the relationships of these features to the modes of paleoenvironmental deposition. These descriptions are published and made available to all interested investigators. Early volumes of core descriptions (Goodell, 1964, 1965, and 1968) were prepared manually. Beginning with cores obtained on Cruise 32 (Frakes, 1971b), descriptions are in a standard, computerized format (Frakes, 1971a).

(c) preparation for storage, and care and storage of, the sedimentological materials in a temperature and humidity controlled core library that serves as a worldwide sampling and distribution center for NSF-authorized investigators.

(d) distribution of the samples to these investigators.

(e) maintenance of adequate records and statistical information on the *Eltanin* and other collections and, in particular, an inventory of samples removed from those collections.

(f) general assistance by provision of supplies, equipment, and personnel for resident and visiting investigators.

(g) maintenance, stockage, control, and calibration of equipment and supplies.

Third, the facility provides support to independent investigations of, in particular, antarctic and subantarctic geology, oceanography, and biology,

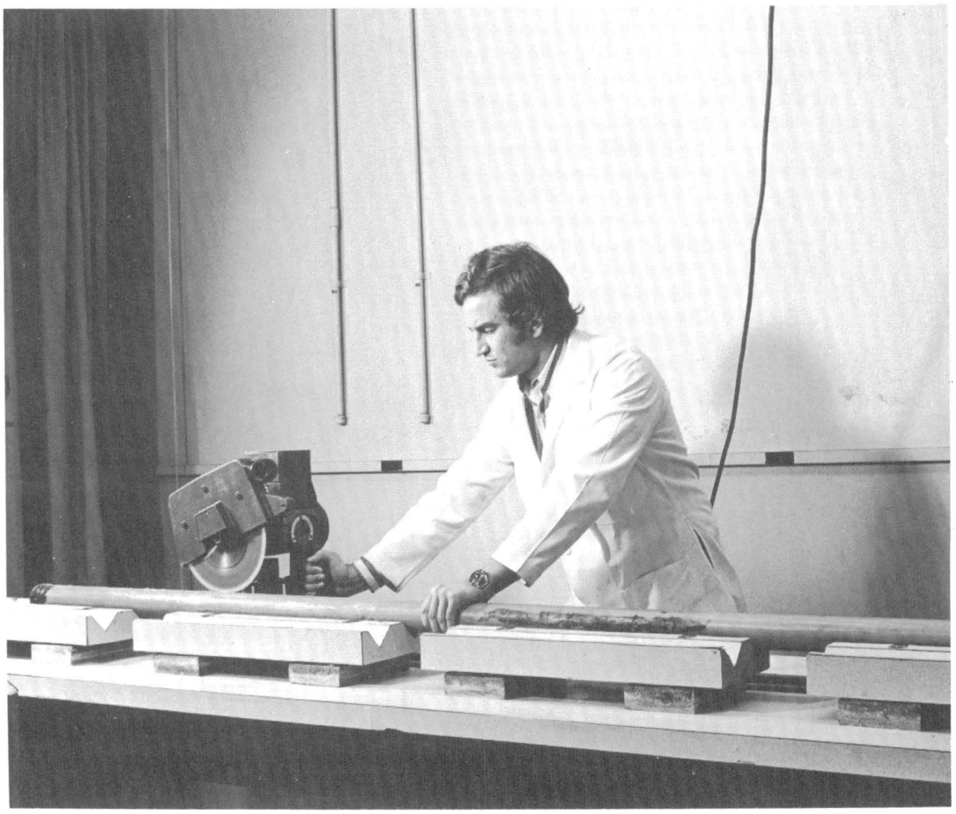

Figure 2.
Only the core liner is cut, not the sediment within.

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with special emphasis on marine sedimentation as it relates to larger problems of marine geology, geochronology, paleostratigraphy, and paleoclimatology.

Transcending, perhaps, the activities of the facility, even though inseparable from them, are the research and educational experiences afforded students and faculty who have been associated with the program, situated in the heart of a science complex at a major state university.

The collections

The permanent collection of cores and other materials consists of 1,139 *Eltanin* piston cores (no cores or other geological materials were taken on nine of the 55 cruises) totaling approximately 7.5 kilometers in length. Average core length is 7 meters, with the longest undisturbed core (no. 13-17, 65°41.0'S. 124°06.8'W., 2,583 fathoms) being 26.42 meters (described length).

Also, there are an approximately equal number of *Eltanin* trigger, phleger, and camera-phleger cores of small diameter (from a few centimeters to slightly over a meter in length), a collection of *Eltanin* sedimentary materials recovered by dredges, trawls, or grabs (held for cataloging by the Smithsonian Oceanographic Sorting Center, Washington, D. C., from 1969 to 1973), and approximately 350 piston, phleger, and large-diameter hydrocast cores and grab samples taken during non-*Eltanin* antarctic operations (such as the *Deep Freeze* expeditions and the 1968, 1969, and 1970 International Weddell Sea Oceanographic Expeditions).

Also within the collection are 60 small-diameter gravity cores from the Kara Sea taken aboard the

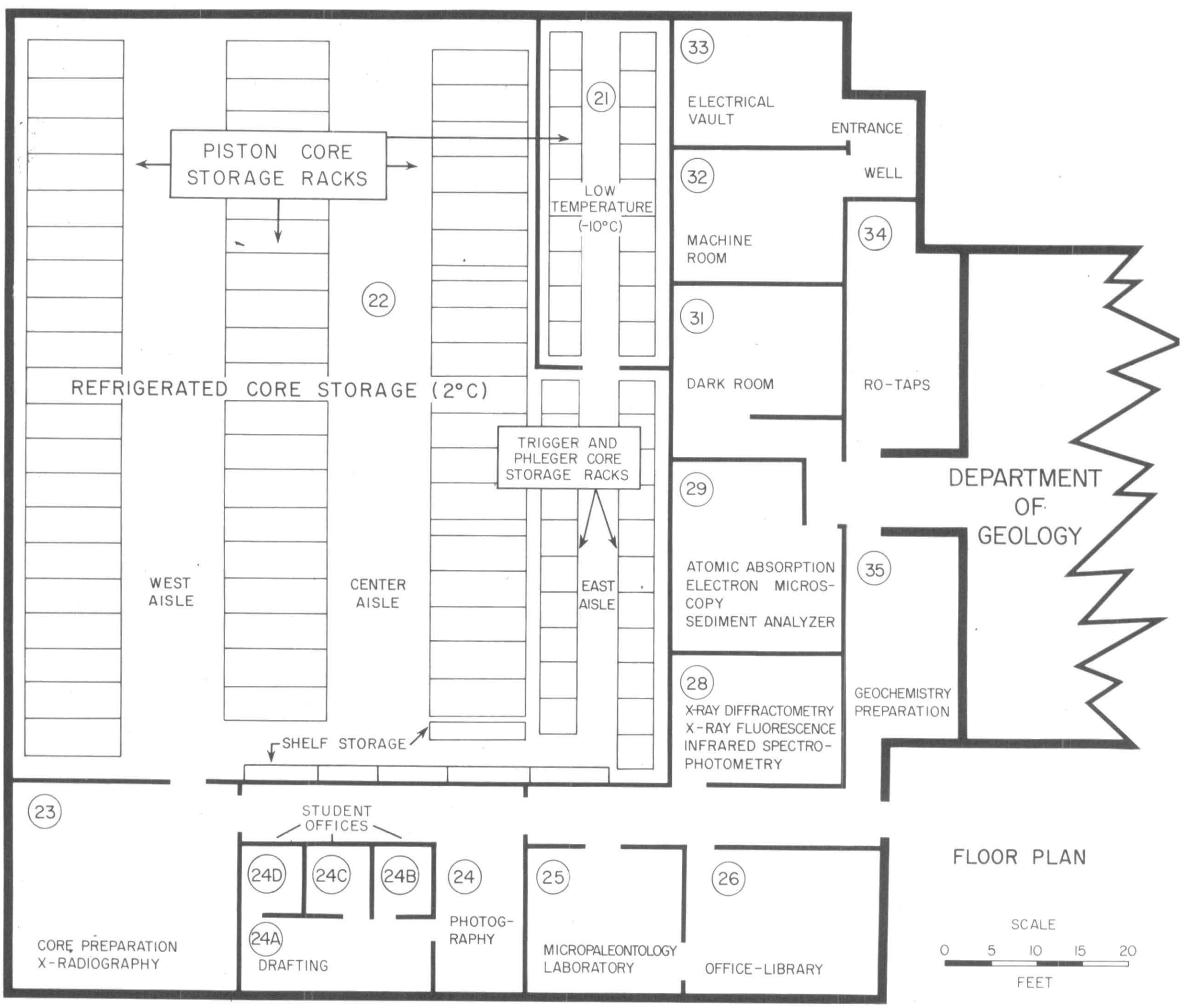

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Figure 3. Floor plan of the Antarctic Marine Geology Research Facility and Core Library.

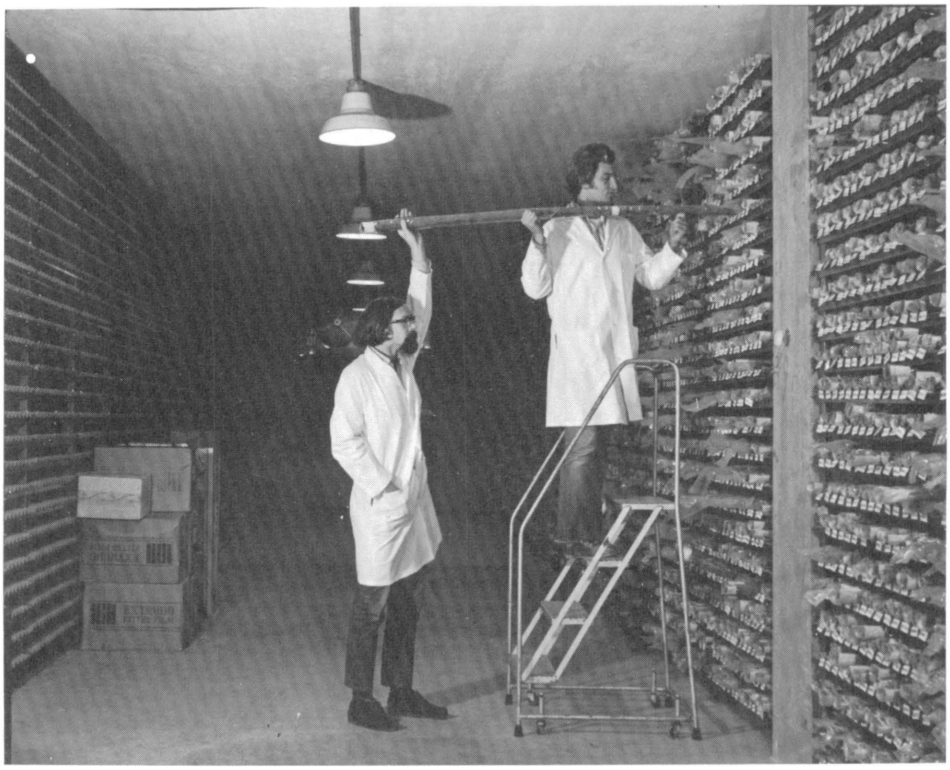

Figure 4.
Central aisle of the 2°C storage room in the Core Library. Being removed is a 10-foot core from the *Eltanin* collection.

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U.S. Coast Guard icebreakers *Northwind, Eastwind,* and *Edisto,* and approximately 300 miscellaneous sediment cores of all types taken aboard various research ships in nonpolar waters.

All core materials are stored in a refrigerated (2°C.) controlled storage area and are in plastic liners, with the liner and sediment being completely encased in a 6-mil polyethylene sleeving, which is sealed to prevent dessication of the sediment. Storage in this manner has preserved the core material in its original moist state, easing sampling and storing.

Also a part of the collection are the thousands of non-refrigerated cabinet- and drawer-stored processed sample residues from antarctic geological materials.

Distribution of samples

From the *Eltanin* core material alone, there has been removed, recorded, and distributed, as authorized according to guidelines established by the National Science Foundation (document of December 4, 1969, from Dr. Louis O. Quam), a total of 73,310 samples by, or for, over 100 investigators representing approximately 35 institutions, both foreign and domestic, as of the period ending June 30, 1972. An additional 614 samples have been removed, recorded, and distributed from the various *Eltanin* dredge, trawl, and grab hauls. Since June 30, 1972, resident and visiting scientists have removed an additional 20,000 samples.

These totals do not include samples removed from non-*Eltanin* materials (about 10,000), or an additional number (about 5,000) of *Eltanin* samples of miniscule amounts used in preparation of smear slides, etc.

Physical data—antarctic facility

Fig. 3 is a floor plan of the one-story building. The building foundation can support six additional stories, with all ceilings being 10 feet in height. The area of usable space is approximately 10,000 square feet. Of this, the refrigerated core library constitutes 5,500 square feet; the remainder (4,500 square feet) consists of offices and research laboratories.

Most of the core storage area consists of a refrigerated room (room 22) of 5,050 square feet that is kept at 2°C., the temperature of Antarctic Bottom Water (fig. 4). Within this room is a low-temperature storage room (room 21) of 450 square feet that is kept at —10°C. (With modification, a constant temperature of —20°C. can be maintained.) Sixty wall shelves provide over 400 cubic feet of large box and tray storage, of which more than 50 percent is unused.

The two multitiered racks for trigger and phleger cores up to $1\frac{7}{8}$ inch diameter (fig. 5) can store 8,800 cores up to 6 feet in length, or 52,800 linear feet. Less than an eighth of the total capacity of these spaces is in use; less than 6 percent of these spaces is in use with respect to total footage capacity.

The three multitiered racks for piston cores up to $2\frac{3}{4}$ inches diameter can hold 18,624 individual core sections in lengths of 11 feet, or 204,864 linear feet. At present, there is less than 25,000 feet of *Eltanin* and other large-diameter core materials in 6,000 of these 18,624 slots. The total storage capacity, then, is 88 percent unused with respect to total footage capacity and 67 percent unused with respect to total storage slots in 11-foot lengths.

The low-temperature storage room has space for 5,852 large-diameter cores in lengths of 5 feet, or 29,260 feet of core. This area is totally empty.

Physical data—peripheral facilities

Integral to the antarctic program within the Department of Geology are the extensively equipped laboratories of the Sedimentology Research Laboratory complex and the Nuclear Research Laboratories, both of which are operating arms of the antarctic research facility.

The Sedimentology Research Laboratory consists of 2,000 square feet of laboratory and office space, in which is carried out almost all the routine processing of antarctic samples not involved in either the core description processes or isotope geochemistry. Student theses and dissertations that have used *Eltanin*-collected materials in some aspect of their research are published as Contributions of the Sedimentology Research Laboratory. These occasional publications are distributed in advance of final, official publication of the data therein, in an attempt to further the efforts of other investigators with immediate needs.

The Nuclear Research Laboratory, located in the Nuclear Research Building, comprises 800 square feet of laboratory space fully equipped for isotope geochemistry.

Instrumentation and equipment

Major equipment belonging to or used regularly by the department's antarctic program includes two transmission electron microscopes, complete systems for x-ray diffractometry, x-ray spectrography, x-ray fluorescence, and industrial x-radiography, and automated systems for alpha, beta, and gamma spectrometry. There are complete facilities for atomic absorption and infrared spectrophotometry, an automated, "rapid" sediment analyzer, and more than $50,000 worth of research microscopy and photomicroscopy equipment, including a Zeiss Universal Photomicroscope II, complete with internal camera and automatic exposure control module.

The photography facility has evolved into the most versatile and specialized research photographic complex at the Florida State University; its services are made available routinely to antarctic investigators at other institutions.

Of interest to resident and visiting investigators is the on-campus availability of numerous supportive facilities of the Florida State University, of which the antarctic program has become a major user. These include fully equipped laboratories for transmission and scanning electron microscopy (a Cambridge Stereoscan Mark II A scanning electron

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Figure 5. Trigger and phleger cores stored at 2°C.

microscope), the university's computing center (CDC 6500 computer) adjacent to the antarctic facility, and several professionally attended machine shops.

History of funding

Even before construction of the facility in February 1966, or *Eltanin's* initial cruise in early 1962, the Department of Geology had been actively engaged in National Science Foundation funded antarctic projects and activities. The work centered about an extensive collection of sediment cores and grab samples obtained in antarctic shelf waters by the U.S. Navy Hydrographic Office in the early *Deep Freeze* expeditions.

To handle the techniques of mass sedimentary analysis needed for investigation of the *Deep Freeze* materials, the Sedimentology Research Laboratory was established within the Department of Geology. This laboratory consists of approximately 2,000 square feet of laboratory and office space, originally an unused, ground-level, basement area contributed by the Department of Geology. Out of these efforts arose the commitments of the department to the coring program aboard *Eltanin* and the construction of the facility.

Funds total received to date from the NSF Office of Polar Programs total $1,551,182, of which $230,600 was for construction. Although no state funds were involved in the costs of construction, the university contributes all building maintenance and janitorial services, costs of air conditioning, refrigeration, heating operation, and equipment repair, and installation costs of fixed equipment.

These funds have provided (1) support of the *Eltanin* shipboard coring operation and the curatorial responsibilities of the facility (table 1) and (2) research grants to individual investigators in this department for study of *Eltanin* materials (table 2). Neither table shows university contributions of additional space, office functions, laboratories for micropaleontology and paleomagnetics, facilities for radiochemical and radioisotopic geochemistry and geochronology, and such major equipment as a 100-kilovolt Philips EM 100B transmission electron microscope, acquired in 1972. The university also has contributed supplemental funds, student assistantships to antarctic investigators, and numerous short-term awards from state funds to support investigations of *Eltanin* materials. The most recent (1972-1973) award, of $2,500, was from the University's Committee on Faculty Research Support and was entitled, "evolutionary trends in southern ocean diatoms" (McCollum, 1972). This award allowed the purchase of specialized photomicroscopy equipment, assigned to the facility and

Table 1. National Science Foundation support for curation and shipboard coring.

Grant	Amount	Initial funding	Project
G-19615	$ 81,320	1961	South Antilles Basin and associated areas
GA-85	230,600	1963	Geological sample storage facility and core library (FSU Antarctic Marine Geology Research Facility)
GA-40	237,050	1963	Marine geology investigations, USNS *Eltanin*, South Pacific Ocean, 1963-1968
GA-523	94,900	1966	Marine geology of the southern ocean
GA-1066	104,000	1967	Marine geology of the southern ocean
GA-4001	88,700	1968	Marine geology of the southern ocean
GA-15703	78,900	1969	Marine geology of the southern ocean
GV-27549*	192,100	1971	Marine geology of the southern ocean
NSF-C564*	183,034	1968	Curatorship of *Eltanin* core collection
	$1,290,654		

*Active.

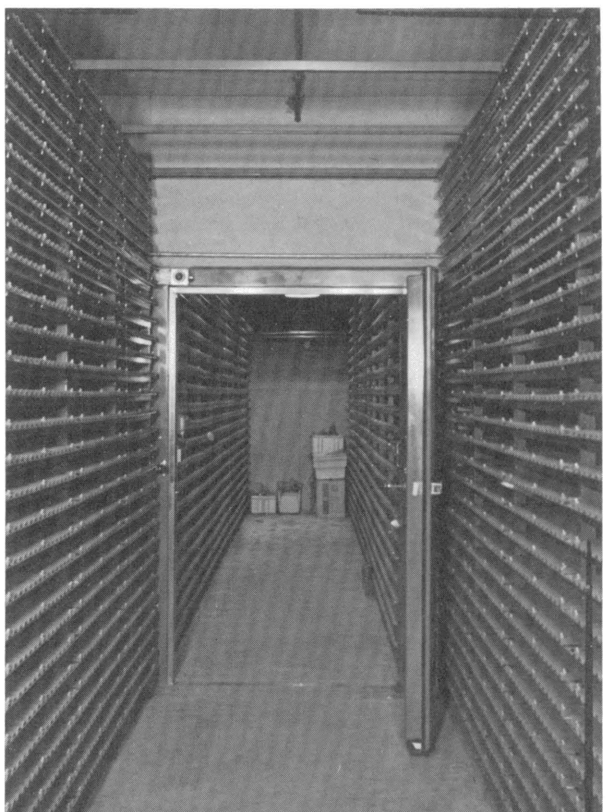

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Figure 6.
The low temperature (—10°C) storage room as seen from the east aisle of the trigger-phleger core storage area.

designated for use by a salaried staff member of the curatorial operation.

Also, the totals in tables 1 and 2 do not include Office of Polar Programs awards to several members of the Florida State University faculty in the Departments of Biology and Oceanography in support of their own investigations, both aboard *Eltanin* and on the continent of Antarctica.

Administration

The chairman of the Department of Geology is both the director of the antarctic research facility and the principal investigator of the contract that supports the curatorial functions of the facility. The associate curator and the faculty antarctic investigators are responsible to the director.

Table 2. National Science Foundation support for research on sedimentary cores by FSU Department of Geology.

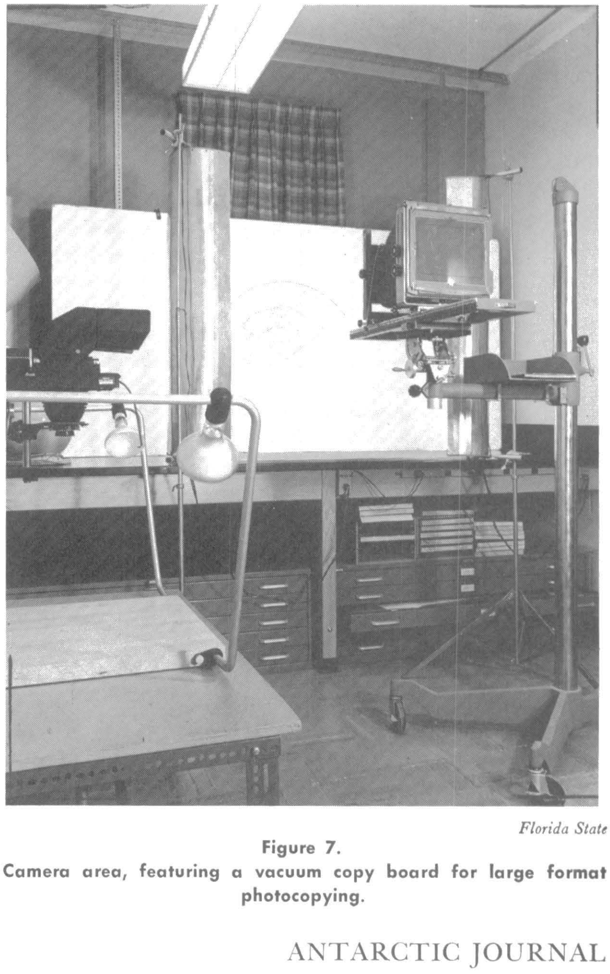
Grant	Amount	Initial funding	Project
G-15043	$ 40,704	1960	Analysis of oceanic bottom sediments collected by the U.S. Navy Hydrographic Office, including antarctic samples for *Operation Deep Freeze*
G-19602	15,924	1961	Analysis of antarctic bottom sediments collected by the U.S. Navy Hyrdographic Office from *Operation Deep Freeze 61*
GA-4	19,100	1962	Analysis of antarctic bottom sediments collected by the U.S. Navy Hydrographic Office from *Operation Deep Freeze 62*
GA-76	17,500	1963	Analysis of antarctic bottom sediments collected during *Deep Freeze 63*
GA-246	13,600	1965	Geochronology of *Eltanin* cores from the South Pacific Ocean
GA-1123	46,100	1967	Study of the magnetic properties of submarine sediments and igneous rocks from the southern ocean
GA-4002	4,000	1969	Micropaleontology and paleoenvironment of southern ocean marine sediments
GA-15230	14,300	1969	Micropaleontology and paleoenvironment of southern ocean marine sediments
GA-4571	4,000	1969	Geochronology of *Eltanin* cores from the southern ocean
GA-13132	33,700	1969	Magnetic properties of antarctic marine sediments and rocks
GA-1620	29,600	1970	Magnetic properties of antarctic marine sediments and rocks
GV-25786*	22,000	1971	Geochronology of *Eltanin* cores from the southern ocean
	$260,528		

*Active.

Patterns for the future

To date, the facility has been concerned largely with the shipboard coring program, the receipt, processing, and distribution of geological materials, and the maintenance of the research and curatorial facility. The result of these efforts has been the creation of an unparalleled opportunity to make an in-depth study of the *Eltanin* materials so laboriously obtained during the past decade. However, a complete understanding of the geologic and oceanographic history of the southern ocean, its basins, and the continent of Antarctica is still far off. Continuity between past and future research already is being provided by participation of the facility in other similar research, notably the Deep Sea Drilling Project. Aboard *Glomar Challenger's* initial cruise into Antarctic waters were three scientists from the facility.

To make better use of the available space, cores from the Dry Valley Drilling Project, the Ross Ice Shelf Project, and other future coring projects will



Florida State

Figure 7.
Camera area, featuring a vacuum copy board for large format photocopying.

be housed at and disseminated from the facility. Acquisition of equipment to handle hard-rock cores is planned, and the temperature of the cold-storage area (room 21, fig. 3) will be lowered to —20°C. for storage of frozen core.

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Sea Floor Photographs

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The collection of ocean bottom photographs made during the United States Antarctic Research Program (USARP) represents an extensive survey of the sea floor surrounding much of the antarctic continent. The geographic positions of the camera stations occupied from *Eltanin* Cruises 3 to 55 (and those of *Hero* and USCGC *Glacier*) are plotted in fig. 1. Over 20,300 individual frames from 1,064 locations are stored at the Smithsonian Oceanographic Sorting Center (SOSC) in Washington, D. C. During the past 8 years thousands of prints and much related data have been distributed to scientists involved in various research. Published results of such studies already have contributed substantially to the understanding of oceanic environments and benthos.

Because of the size of the collection and complexity of information contained in it, the bottom photographs constitute a considerable scientific resource that has been only partially tapped: few biologists, for example, have worked with the collection to any great extent. Present activities at SOSC, therefore, include establishing the capability of efficient picture retrieval coupled with availability of other data products through use of a computerized data bank. This report describes the collection, historically and materially, and then discusses the electronic data processing system selected for the photographic project, including the types of data and information to be stored. Additionally, some of the possibilities for data manipulation are suggested for new investigation.

Photographing the ocean bottom

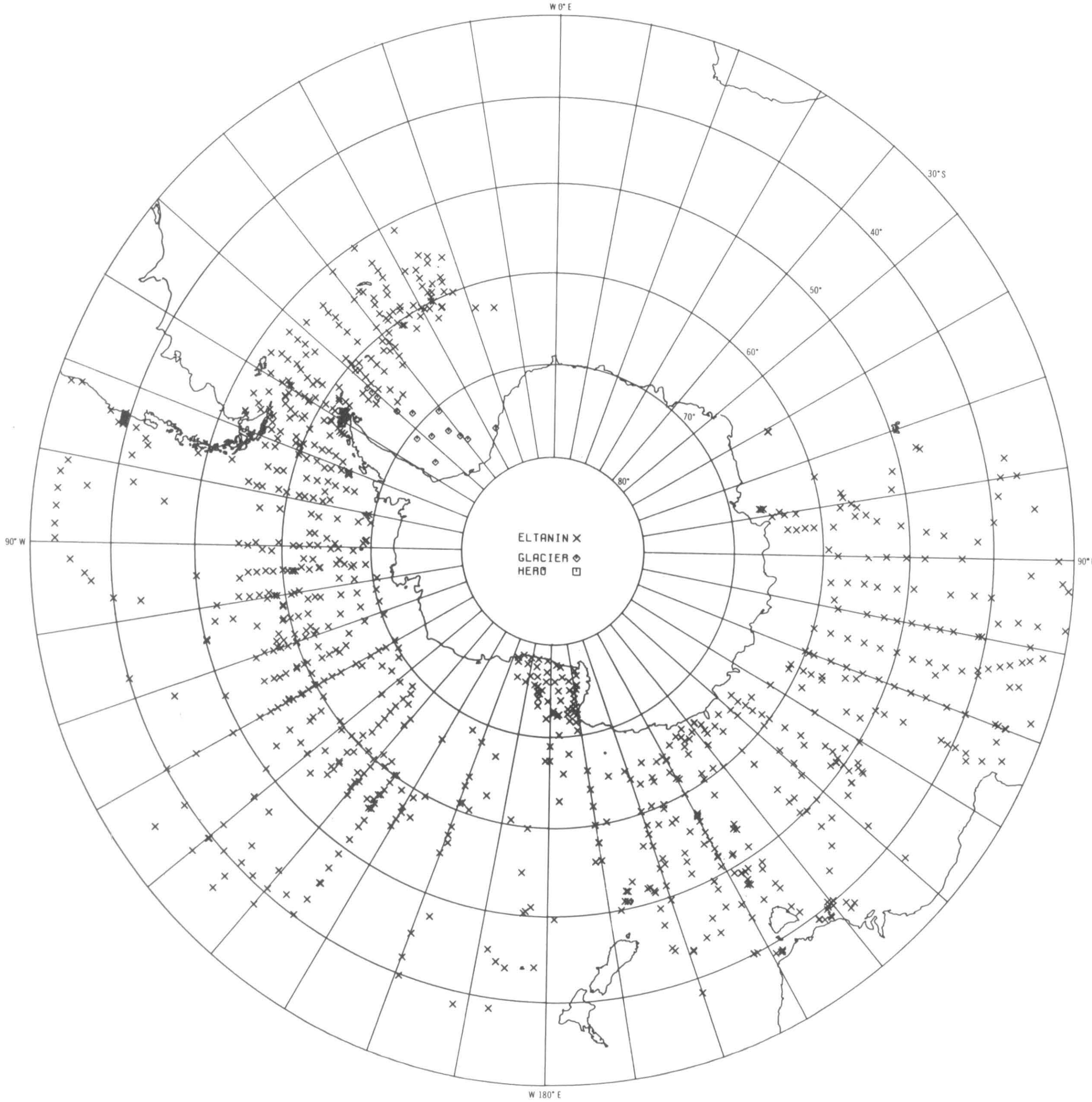
Participants on cruises of *Eltanin* produced 99 percent of the bottom photographs in the collection. The other photos were made from *Hero* and *Glacier.* On *Eltanin,* technicians employed by Texas Instruments, Inc., operated the bottom camera during Cruises 2-9; on Cruises 10 through 27 photographs were made by support staff of Alpine Geophysical Associates, Inc.; starting with Cruise 32, personnel of Lamont-Doherty Geological Observatory assumed the bottom photography project at sea, with the exception of Cruise 38 on which participants from Dartmouth Medical School made a set of photographs concomitant with specific collections of bottom organisms taken by University of Georgia participants.

Through Cruise 27 and at many stations during later cruises, photographs were made with the Alpine Model 311 underwater multi-exposure camera assembly. For their purposes, staff of Lamont-Doherty designed and constructed special camera systems (Jacobs *et al.,* 1970b, 1972) which consisted of a 35mm shutterless camera, strobe light, and an electrical source integrated with a bottom current meter and nephelometer. The units are sealed in pressure resistant housings and attached to an aluminum frame. A compass mounted to the frame extends into the camera's field of view and provides directional orientation on the photographs. The unit is lowered by cable to the sea floor. The strobe flashes and a photograph is taken when tension is released in a trigger wire as an attached weight contacts bottom. The system is then repeatedly raised a few meters and lowered again as the ship drifts. These maneuvers bounce the camera system across the bottom in a series of short arcs, taking a photograph with each hit.

During *Eltanin* operations, an average of about 20 good frames per camera station were taken. Camera operators recorded pertinent data in camera logs. Immediate development of the film alerted operators to equipment malfunctions, reduced the possibility of exposure mishaps enroute to the United States, and provided shipboard scientists with immediate information concerning the bottom. Shortly after each cruise, the negatives and camera logs were forwarded to sosc.

Bottom photograph archives

In 1963 the National Science Foundation designated sosc as a national repository for data and information on natural history collections made by United States investigators in antarctic regions. The following year the USARP ocean bottom photographs were included in the antarctic records program at



Smithsonian Institution/National Oceanographic Data Center

Figure 1. USARP camera stations circumscribe three-fourths of the anarctic continent.

SOSC with the understanding that prints would be provided to qualified scientists for their research.

Presently, about 19,000 black and white negatives, a file print for each, some duplicates, and numerous enlargements of portions of photographs with especially interesting features are archived. Some 1,500 color transparencies from 143 camera stations are on file with duplicates for loan purposes. Also on file are close-up photographs from *Eltanin* Cruise 35, which traversed an area between Australia and Antarctica. Reference materials include camera station logs, cruise reports, daily data sheets, and official cruise tracks. A small library contains papers illustrated with pictures from the collection and other literature on deep-sea photographs, benthic biology, marine geology, and methods for management of photographic collections.

In the past year, SOSC has established its own darkrooms for printmaking. This has enabled us to provide a degree of custom work on a routine basis. Extensive dodging and burning-in during printing often is required to produce quality prints from negatives with tremendous density variations owing to difficult lighting conditions inherent with deep-sea photography.

One of our aims in providing scientific services has been to consistently and reliably document the voluminous bottom photographic data and present them in a meaningful and useful manner to specialists. Camera station data are routinely stamped on the reverse side of each print distributed. These data include cruise number, station and frame numbers, station location, depth, date, and photo credit. When prints are shipped, they may be supplemented with copies of the camera station lists so that the user can readily review the areas, depths, etc., covered during a cruise.

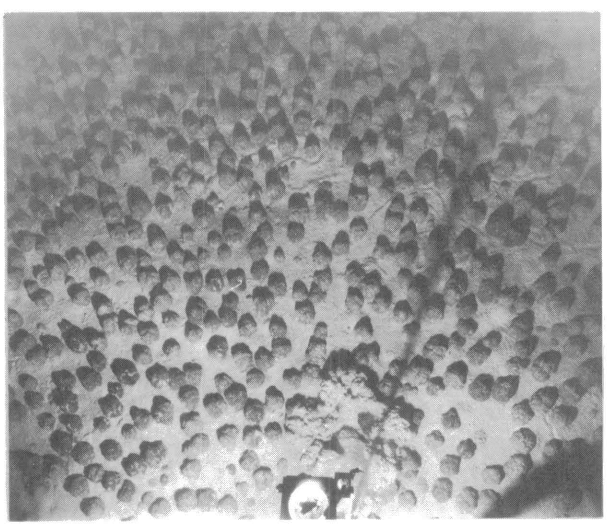


Figure 3.
A field of robust manganese nodules on the muddy bottom of the Indian Ocean. Fauna is sparce; an actinarian appears in the upper central portion of the photograph (*Eltanin* Cruise 48).

Figure 4.
Pillow lava crops out on the sea floor between Australia and Antarctica. A thin veneer of sediment coats the outcrop (*Eltanin* Cruise 54).

Distribution and usage

Prints of all negatives have been prepared routinely for four institutions engaged in long-term USARP projects; selected prints have been made on request for other researchers. The total distribution since 1964 is over 50,000 prints. For many of these investigators, studies are still in progress; others have used part or all of the prints sent them and have published results. A brief literature survey illustrates the diversity of usages by marine geologists, biologists, and physical oceanographers (table 1).

The scope of these studies demonstrates that considerable information is contained in the sea floor photographs. Because most of these reports used only limited numbers of pictures, and sometimes only a single frame showing a particular feature or organism, it is apparent that the information potential of the collection is tremendous. But new, efficient, and thorough analyses of the photographs are contingent to a large degree upon voluminous data storage, rapid retrieval, and related processing techniques for data reduction, synthesis, and correlation. In the last year we have adopted a computerized data processing system that has considerable promise in application to the problems of establishing a useful and viable data bank.

Electronic data storage and retrieval system

The criteria for an electronic data processing system developed from a philosophical approach to establish a highly organized and dynamic file whereby we might better meet the present and anticipated varied needs of specialists. Required was a system with sufficient flexibility to locate an individual photograph displaying a unique feature or combination of features and that could provide deductive information about sets of photographs.

Each USARP bottom photograph is undergoing thorough examination, and the observations are coded, keypunched, edited, and entered into the data bank. Processing, using the Smithsonian's Honeywell 2015 computer, employs a specially modified system, SELGEM, an acronym for SELF-GEnerating Master. The SELGEM system already has been applied successfully to a number of similar data storage and retrieval problems within the Smithsonian museums and at other institutions (Creighton and Crockett, 1971; Creighton *et al.,* 1972). The bottom photo project benefits enormously from the trials of these other users. Costs for modification are minimal, and in the future we will have access to useful program modifications incorporated into the SELGEM system by other users. A prime advantage in using SELGEM is that it is designed specifically for ease in modifying existing data and for later addition of new information, even if the need is unanticipated when the file originates. A user, therefore, could select portions of the data bank that are relevant to his research, readily include other data for his specific analytical purposes, and produce new results. After his research is complete, the new data could become part of the data bank and be made available to other users with related problems.

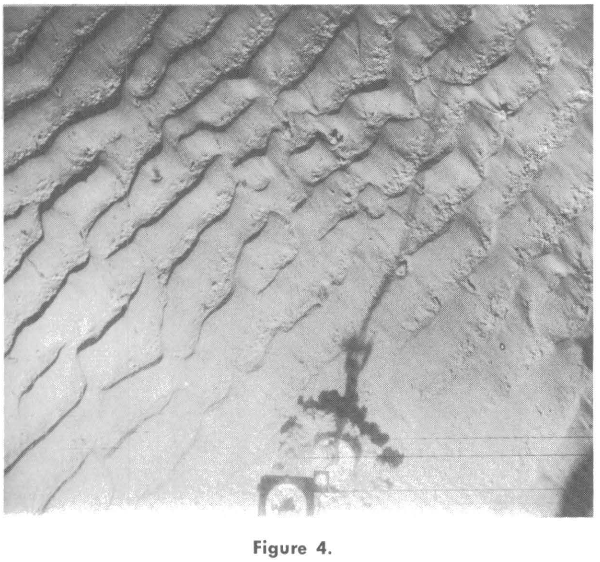


Figure 4.
Pronounced asymmetrical transverse ripple marks, crescentric scour and crag and tail structures, sorting of coarser material into ripple troughs, and sessile rheotaxis provide evidence of strong currents from the west, sweeping the bottom in an eastern portion of Bass Strait (*Eltanin* Cruise 55).

Table 1. Partial review of studies employing USARP bottom photographs.

GEOLOGY

Depositional milieu in relation to core data (Drake Passage, Scotia Sea, South Sandwich Trench): Goodell, 1964.
Depositional milieu in relation to core data (Pacific-Antarctic and Scotia Basins): Goodell, 1965.
Characteristics of the sea floor surrounding a large seamount (Peter I Island): Johnson, 1966.
Distribution and concentration of manganese nodules: Mero, 1965.
Geology of the sea floor (Bellinghausen Sea): Hollister and Heezen, 1967.
Location as a factor in mineral recovery. Hibbard, 1967.
Economic potential of antarctic regions: Potter, 1969.
Precipitation of manganese from sea water: Weyl, 1970.
Geology of the sea floor: Heezen and Hollister, 1971.
Cataloguing and correlating antarctic rocks: Simkin, 1971.
Sedimentary patterns (Indian Ocean): Conolly and Payne, 1972.
Manganese pavement production (Tasman Basin): Payne and Conolly, 1972.
Sedimentary disconformities (Indian Ocean): Watkins and Kennett, 1972.

BIOLOGY

Spirally coiled feces indicating large enternopneust population: Bourne and Heezen, 1965.
Ultraabyssal benthos (Peru-Chile Trench, South Sandwich Trench): Belyaev, 1966.
First isopod crustacea seen on deep-sea floor: Menzies and Schultz, 1966.
Tunicate distribution (Drake Passage): Caldwell, 1966.
Habitats of various isopod crustacea (antarctic regions): Menzies and Frakenberg, 1967.
Habitat of isopod crustacea *Mesosignum* (antarctic regions): Menzies and Schultz, 1967.
Dermechnius horridus in situ: *Antarctic Journal of the United States,* 1967.
First recognized brachiopods in the deep ocean (Ross Sea): Foster, 1968.
Larger members of the benthos: Heezen and Hollister, 1971.
Scalepellid barnacles (antarctic regions): Newman and Ross, 1971.
Marine ecology: Menzies *et al.,* 1973.

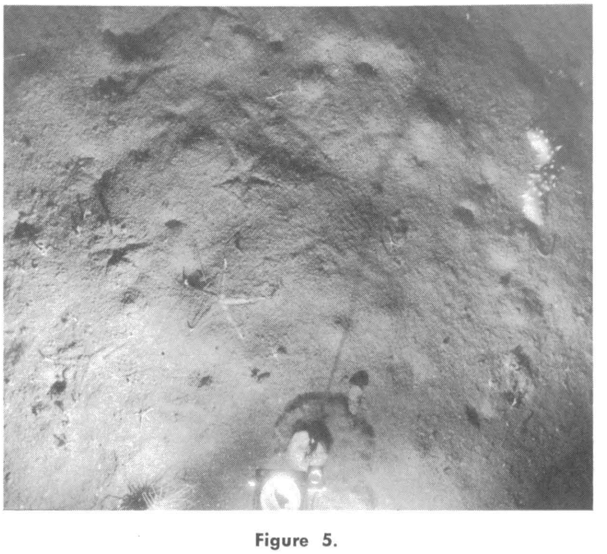


Figure 5.
Abundant and diverse benthos are seen in this 2-square-meter area of the southern Indian Ocean floor (*Eltanin* Cruise 47).

Benthic variety (Indian Ocean): Simmons and Landrum, 1973.

Ostracod habitats (antarctic and southern oceans): Kornicker, in press.

CURRENTS

Deep-sea current activity is substantiated: Heezen and Hollister, 1964.

Disposition of dangerous chemicals at sea: Marine Technology Society, 1969.

Bottom water formation, strength of currents (Ross Sea): Jacobs *et al.*, 1970a.

Current produced sea floor features: Heezen and Hollister, 1971.

Bottom currents and nepheloid layers (Indian-Pacific area): Eittreim *et al.*, 1972.

The initial steps in building the file include the entry of all pertinent data related to each camera station. Then, each photograph, or set of similar photographs made at a station, is examined, and the observations recorded. Table 2 lists station and frame data entered into the data bank.

On entry of sufficient quantities of data, specific and collective types of features and other data may be represented in hierarchial indices and on computer-produced plots and graphs. Plots may symbolically depict faunal diffusion, diversity, and density; vectorally indicate bottom currents; locate volcanic outcrops and debris; and represent varying concentrations of manganese nodules. These types of products will provide a new wealth of information for evaluation by specialists.

Table 2. Bottom photograph data categories.

CAMERA STATION DATA

Program, collector, vessel, cruise, ship station number, camera station number, number of frames, archiving institution.

Area topography, location

Position: Latitude, longitude, marsden square number, depths, date, time

Photograph type, film, camera equipment

Collectors of biological and geological specimens onboard

Related instrumentation, sampling

Relationships among frames

FRAME DATA AND FEATURES

Frame number(s), photo quality, directional orientation, scale

Referral and references

Striking features, man-made objects

Geologic features:

- Sediments—percentages of mud, sand; percentages and shape of pebbles, cobbles and boulders
- Outcrops—pillow lava, blocky lava, etc.
- Facies—bedrock/sediments, nodule field/sediments, etc.
- Inferences—Mn nodules, encrustation, solutioning, volcanic debris, organic debris, rafted erratics, etc.
- Gravity features—slipping, depressions
- Joints—systematic, nonsystematic
- Microtopography—ridges, slope, imposed marks

Current features:

- Scour marks—elongate marks, flutes, transverse scour, crescentric
- Deflation—rock nests, lag deposits, winnowed ridges
- Current lineations—elongation of burrows, fecal crag and tail, crag and trail
- Ripple marks—transverse symmetrical, transverse asymmetrical, linguoid, lunate, or cuspate (wave length and amplitude)
- Tool marks—continuous, discontinuous
- Suspended sediment—murky, streaming, stationary trigger weight plume, drifting plume
- Sediment cover—uniform, nonuniform, none
- Miscellaneous current features—smoothing, vague fabric, preferential organism growth, sorting, nodules, detailed lebensspuren
- Orientation—nonsessile rheotaxis, sessile rheotaxis, floral rheotaxis, embrication, oriented lebensspuren
- Current inferred—direction and strength

Biologic features:

- Lebensspuren—abundance of traces of locomotion, dwelling, defecation
- Animal with associated lebensspuren, animal inferred from lebensspuren
- Flora—macroalgae, algal debris
- Fauna present—major taxonomic groups, numbers of individuals per taxa

Conclusion

Paradoxically, while Apollo astronauts could directly observe the features of the moon's surface 250,000 miles distant, scientists on earth can only glimpse this planet's surface below the seas by remote photography, often only with a camera dangling on 5 miles of cable. The 20,300 different views of the antarctic sea floor contained in the USARP collection have contributed new and significant information concerning the marine environment, but an estimate of the actual area observed is only equivalent to that of about 12 football fields.

The continued growing national interest in understanding the world's oceans with the expectation of exploiting their resources will likely include the southern oceans. Concomitantly, sophistication of deep-sea single lens and stereo cameras, circular scanning cameras, movies, television, videotape, and time-lapse photography will probably produce large quantities of pictures. Should new and extensive photographic surveys be undertaken in future USARP investigations, the flexibility inherent with the SELGEM system will provide a means for efficient collection management, data retrieval, reduction and syntheses essential to the analyses of photographs and evaluation of the sea floor. The present USARP collection is thus not only a source of diverse information, but a model and a tool for future work in the antarctic and world ocean.

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Capabilities and Specifications

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Originally an arctic supply ship with a double hull, a cutaway icebreaker bow, and protected screws, *Eltanin* was converted in 1961-1962 to meet the National Science Foundation's need for a research platform that could operate in the oceans surrounding Antartica. During extensive refitting at Mobile, Alabama, and Staten Island, New York, the ship's cargo spaces were transformed into laboratories, support facilities, storage areas, and scientists' accommodations. Protective bulwarks were added forward to shelter a deck working area. Antiroll tanks were installed at the 0-1 level forward; together with the wide beam and flat bottom, they made *Eltanin* an extraordinarily stable working platform in heavy seas.

After two North Atlantic shakedown cruises, she sailed for Valparaíso, Chile, in May 1962 to begin a decade of cruises in the Antarctic; she returned to a United States port only once (September 1967) in that time.

Eltanin steamed over 400,000 survey miles in the last decade. From the beginning of Cruise 1 to the end of Cruise 55, she was at sea 75.3 percent of the time and travelled an average of 136.3 nautical miles per day at an average speed of 5.67 knots (table 1).

Eltanin's maximum scientific complement is 38 persons, including a representative of the National Science Foundation and a nine-man support party that supplied the technological and logistical needs of the operation. The 48 Military Sealift Command crew members were civilian licensed seamen.

Scientific operations included auroral observations, bathythermograph tows, bottom photography, coring (piston and Phleger), carbon-14 measurement, cosmic ray monitoring, continuous sea surface temperature recording, current measurement, bottom and midwater trawling, bottom grab sampling, dredging, nephelometer recordings, precision depth recording, water sampling, salinity, temperature, and depth recording (STD), magnetic recording, meteorological upper air (radio-rawin and ozone sonde) soundings, seismic reflection and refraction recordings, VHF and VLF recordings, sediment heat-flow measurements, incident and net radiation measurements, submarine photometry, colorimetry, fluorometry, free fall net biosampling, heterotrophic analysis, particulate chemical analysis, deep sea tide measurement, and others.

Perhaps two-thirds of the scientific complement (other than support personnel) were engaged in programs that continued over many cruises. Examples are seismic, magnetic, gravity, and hydrology measurements, sediment coring, primary productivity and solar radiation measurements, and respiratory studies. The balance of the science complement made brief, often comparative, studies, many being completed on a single cruise.

Eltanin has accumulated some of the most sophisticated scientific equipment available to oceanographers. Her laboratories, equipment, support facilities, and storerooms are described below and can be located by means of the inboard profile (see inside back cover).

Two systems that most investigators have benefitted from are the ship's computer system and the satellite navigator. The computer complex, an IBM 1130 System with plotter (see details below) was installed in September 1969 at the end of Cruise 39 in Aukland, N.Z. The computer room adjoins the science office drafting room, giving adequate space for chart and printout inspection. Addition of this complex greatly reduced the time required for primary data reduction, especially in navigation, magnetics, and gravity (Hayes and Griffiths, 1969). The system proved remarkably effective and failed only rarely.

The satellite navigator was installed in September 1965 between Cruises 19 and 20. Before its installation, navigation had been a major problem; the ship worked under an almost constantly overcast sky and in long periods of darkness. The system is an AN/SRN-9, developed and manufactured by the Applied Physics Laboratory at Johns Hopkins University. Although a prototype, the unit served well, and, even if the system's computer failed, fixes could be computed on the IBM 1130 System from the raw Doppler/Keppler data. *Eltanin* was the first research ship to be equipped with a satellite navigation system.

Deck equipment

Deep sea trawl winch. Alpine Geophysical Associates model 600; powered by General Motors 671 diesel. The winch has a drum capacity of 30,000 feet of ½ inch wire rope and is located midships on the main deck, serving a starboard side A-frame (overside fairlead by means of roller bearing fixed heel block). The winch has an integral quadrant accumulator system.

Table 1. USNS *Eltanin* operating statistics, cruises 1-55

Fiscal year	Days at sea	Days in year	Percent of total days at sea	Nautical miles
1962	80	122	65.6	9,096
1963	311	365	85.2	29,163
1964	295	366	80.6	38,616
1965	246	365	67.4	34,432
1966	282	365	77.3	35,795
1967	312	365	85.5	40,714
1968	259	366	70.8	38,471
1969	293	365	80.3	33,315
1970	222	365	60.8	38,740
1971	253	365	69.3	37,249
1972	309	366	84.4	45,604
1973	152	227	66.96	29,493
	3,014	4,002	75.30	410,688

Hydrographic winches (two). New England Trawler Equipment Company; hydraulically operated by a Dennison pump in the masthouse. Both drums have a capacity for 30,000 feet of 3/16-inch wire. The two winches share the same accumulator system and telescopic boom. One drum is used for regular hydrographic wire (usually Aluflex); the other is for STD wire, normally four conductor wire making electrical contact through a slip ring within the winch. A new single-conductor wire, to have been used on Cruise 56, remains untested.

Bathythermographic winch. Located on the starboad quarter, this winch has a capacity 30,000 feet of 3/32-inch wire. A complete spare winch is kept aft.

Horizontal gypsy head. This head is mounted on the main deck, starboard side, just beside the core winch. It is used for core extrusion and trawl and dredge warping.

Ten-ton cargo boom. This boom, which serves the main deck, handles trawl, dredge, current meter, grab, and large-volume water samplers.

Magnetometer. The magnetometer uses its own winch, located in the balloon shed aft.

Seismic equipment. A winch on the port quarter (a vertical gypsy) hauls the airgun and the hydrophone eel.

Cores. The ship can take gravity cores of up to 100 feet, using five 20-foot sections of pipe. On Cruise 48 a six-pipe, 112-foot core was rigged using short pipes, but the operation involved considerable jury rigging. An A-frame (starboard side—just abaft the beam) has proved satisfactory for dredging, trawling, and coring.

Laboratory space

Electronics laboratory. This air conditioned, 526-square-foot lab handles remote sensing and recording instrumentation. Usually the lab is manned 24 hours a day and provides a central point for the coordination of the scientific activity.

There are 11 full equipment bays with overhead wireways. Equipage includes two EDO 333 precision depth recorders used in conjunction with an EDO 3.5-kilohertz, 10-kilowatts bathymetric transceiver and an Alpine 12-kilohertz, 2-kilowatt transceiver; a Hytech continuous surface water temperature recorder; a Varian magnetometer with paper tape punch; the Askania sea gravimeter system with a Lamont-Doherty cross coupling computer; the seismic reflection/refraction system using a Lamont-Doherty drum recorder and EPC graphic recorder; and a Bisset-Berman STD with magnetic tape output. Readouts are available from the ship's electromagnetic log and gyrocompass. Coordinated timing and event-mark data can be provided from precision chronometers.

Wet hydro laboratory. This 418-square-foot lab is on the main deck and provides the primary access to the over-the-side operations. Racks are installed for Nansen and Nisken bottles. There is a long bench for piston core examination and an additional 40 linear feet of bench space for other work. Permanent equipage includes a refrigerator and a water distillation unit.

Meteorological laboratory. This 248-square-foot deck office is equipped to handle all aspects of both synoptic and research meteorology. Permanent equipment includes radiosonde receiver/recorder, temperature/dew point recorder (sensor installed on ice-pilot station), baragraph, barometers, and hygrometers. Much of the space in this lab is given over to the desks and drafting tables necessary for data reduction. Facsimile equipment is available for the receipt of weather maps.

Biology wet laboratory. This 220-square-foot deck space lab, forward on the main deck, eases processing of biological trawl and dredge samples. There is 22 feet of bench space, with sink and fume hood. Two incubator/refrigerators are normally located here, along with three constant temperature baths.

Microbiology laboratory. This 476-square-foot deck space lab is below deck and close to the center of roll and pitch. This location minimizes the effect of ship's motion on preparation and examination of delicate samples. There is over 75 linear feet of bench top space. Sinks are provided with uncontaminated salt water taken from the ship's keel and handled in plastic piping. The lab is air-conditioned, and a fume hood is vented overboard. Scientific instrumentation includes 2 DU spectrophotometers, auto analyzer, microscopes, constant temperature baths and pH meters. There is a broad stock of general purpose lab equipment and supplies. Permanent equipment includes freezer, incubator, drying oven, autoclave, a refrigerated centrifuge, and a Gilson differential respirometer.

Photographic darkroom. This 66-square-foot deck-space darkroom is equipped for processing bottom camera, nephelometer, and current meter films. Equipage includes an Omega enlarger, a print dryer, and a temperature-controlled sink. Color film bottom photographs and X-ray film can be processed onboard.

Computer room. This 180-square-foot deck-space laboratory was converted from the atmospheric physics lab to the computer room in September 1969. Installed is an IBM 1130 computing system consisting of an 8K memory 1131 central processor, 1132 printer, 1442 card read/punch, 1055 paper tape punch, 1134 paper tape reader, and Calcomp 563, 30-inch plotter. Data preparation and storage is accommodated by an IBM 029 keypunch and two card files. A recirculation-type air conditioner provides filtered air at constant temperature.

Science office. The science office is a 216-square-foot room for data reduction and planning. It is equipped with desks, files, a light table, chart table, chart storage, an additional IBM 029 keypunch, and a 3M copier. Typewriters and workspace are available for all investigators.

Gravimeter room. The gravimeter room is a 200-square-foot deck space, air-conditioned lab located at the center of the ship's roll and pitch axis. The location minimizes the effect of ship's motion on the gravity measuring equipment. Installed in the room is the Askania GSS-Z gravity meter, mounted on an Anschutz gyro-stabilized platform. The readout for this system is remotely located in the electronic lab.

Storage

There is some 2,000 square feet of deck space allocated to scientific storage. This area is subdivided as below:

Aero stores. Storage for tools, engine, and compressor parts, trawl, dredge, core, and bottle parts, and hardware and deck equipment.

Science stores. Chemicals, lab supplies, analytical instrumentation, radioactives, and magnetic tape.

No. 1 hold. Metal stock, wire stowage, nets, large spare engine and winch assemblies.

Starboard magazine. Chemical glassware.

Clothing stores. Clothing, stationery supplies, photographic supplies, and camera parts.

No. 2 hold. Trawling, dredging, and coring equipment, grabs, large-volume samplers, wire, and heavy winch parts.

Stationery stores. Computer supplies and sundry stationery stores. Also, there are red label, alcohol, oil, and deck lockers for smaller items.

Other

Conference room. Located at accommodation area midships, this room contains recreational facilities for the scientific party and a fairly extensive reference library.

Hamshack. At the 0-2 level aft, the hamshack contains a full amateur radio facility (Collins 2KW PEP) that any licensed ham operator may operate.

Support facilities

Electronics shop. With 345 square feet of deck space, the electronics shop has oscilloscopes, signal generators, meters, and counters—in general, test equipment adequate to maintain any instrumentation onboard. Sufficient parts are carried so that many instruments can be constructed or modified without the need to requisition material from the United States.

Machine shop. This 402-square-foot shop has a Rockford gearhead lathe, Do-All bandsaw, Bridgeport Model J milling machine, South Bend drill press, and Linde model 305 TIG welder. Sufficient tools and material are carried onboard to make or repair instruments ranging from microscope camera shutters to rock dredges.

Balloon shed. This area is for inflation of meteorological balloons. It also houses the magnetometer winch and spare airgun fishes.

Compressor room. Two 3,000 psi air compressors (Rix 4x1-S/8x3/4x4W-one on line and one reserve) serve the airgun.

Seismic workshop. This shop ajoins the compressor room and contains the Rayflex sparker system. It now acts as a repairs and maintenance area for the seismic overside equipment.

Ship specifications

Constructed:	1957, Avondale Marine Ways, Avondale, Louisiana
Converted:	1962, Mobile, Alabama, and Staten Island, New York
Hull:	All welded steel with raked ice-breaker bow, modified cruiser stern, two continuous steel decks, and enclosed main deck forward
Length overall:	266 feet 2 inches
Maximum beam:	51 feet 6 inches
Draft hull:	19 feet 9 inches
Draft to bottom of transducer tub:	23 feet 7 inches
Displacement:	3,886 tons on full load
Tonnage:	Gross 2,703 tons; net, 1,356 tons
Speed:	Cruising 12.5 knots Maximum 13.5 knots Minimum 2.0 knots
Cruising range:	10,000 miles at 12 knots
Endurance:	90 days
Complement:	48 crew, 38 scientists
Propulsion:	Diesel-electric (Alco/Westing-house)
Power:	2,700 shaft horsepower continuous
Propellers:	Two fixed pitch
Navigation equipment:	Two radar sets, Loran, radio direction finder, echo sounder, and satellite navigation system.

Reference

Hayes, D. E., and K. H. Griffiths, Jr. 1969. *Eltanin* shipboard data processing. *Antarctic Journal of the U.S.*, IV (6) : 275-278.

USNS *Eltanin* Cruise 55

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The idea that an ancient southern continent known as Gondwanaland split apart in the Mesozoic to create the continents that now surround the Indian Ocean is among the earliest and most persistent themes of continental drift. Studies of the past decade have allowed us to trace in some detail the Tertiary and Late Mesozoic drift of the continents surrounding the Atlantic, South Pacific, and southwest Indian Oceans; however, for lack of studies in the critical antarctic sector, the original fit and pattern of dispersion of the Gondwana continents has been left as a matter of conjecture and debate, hardly any better documented now than it was half a century ago. The area to the west of Kerguelen is nearly unknown. The vast, smooth, exceedingly deep basin suggests a long period of subsidence and sedimentation; perhaps the earliest remains of the antarctic abyss are to be found here. It seems likely that the most favorable locations for deep sea drilling within the entire circle of the Antarctic seas lie in this promising but little known area. Since *Eltanin* was the only ship capable of conducting the necessary studies in the remote and ice-bound area, we proposed a shift in *Eltanin's* operations to this area, and on October 30, 1972 we sailed from Newcastle, New South Wales, bound for the deep basin west of the Kerguelen Plateau.

Drs. Heezen and Tharp were the U.S. Antarctic Program co-representatives on Cruise 55.

The cruise

Our direct route took us south along the east coast of Australia and across the great submarine canyon system at the eastern end of Bass Strait (figure 1). Our interest in submarine canyons having been recently aroused by data of contemporary erosion observed in North American canyons, we briefly investigated the Bass Canyon system. Photographs, a current meter measurement, nephelometer profiles, and a serial hydrographic station failed to reveal evidence of contemporary current activity in either the northwest branch or the master canyon in depths of 2,000 to 4,000 meters. However, a series of photographs obtained in the southwest branch in depths of 1,000 meters revealed sharply crested linguoid ripples oriented normal to the canyon axis. Urgent ship repairs necessitated our departure before further observations could be made.

Having passed the southeast tip of Tasmania, a course was set for the basin west of Kerguelen. This course took us across the Tasman Fracture Zone, which forms the western margin of the Tasman Plateau. We took the opportunity to dredge and photograph the precipitous escarpment. Our dredge recovered two large hauls of crystalline, acidic, and basic rocks that tentatively suggests that the plateau is of continental composition.

Breakdown and return

On November 6, while we were dredging a tempting escarpment on the Kangaroo Fracture Zone, the engine room flooded, causing extensive electrical damage and disabling the ship.

Repairs were sufficiently advanced by November 9 that we could resume our underway program and again set a course for the basin west of Kerguelen. However, late on the 11th, a bearing failure forced the ship to abandon its scientific program and slowly return to an Australian shipyard on one engine.

Disappointment

While in Melbourne, Australia, we were informed that for lack of time we must abandon our planned research. We were requested to plan and execute an exploration during the remaining scheduled period, which would terminate at an Australian port.

Although we cannot deny our bitter disappointment, we were still hopeful of being granted another chance on a later cruise to take *Eltanin* to our planned area west of the Kerguelen Plateau. In any case the use of as able and well equipped ship as *Eltanin* for more than 3 weeks presented an exciting opportunity for research.

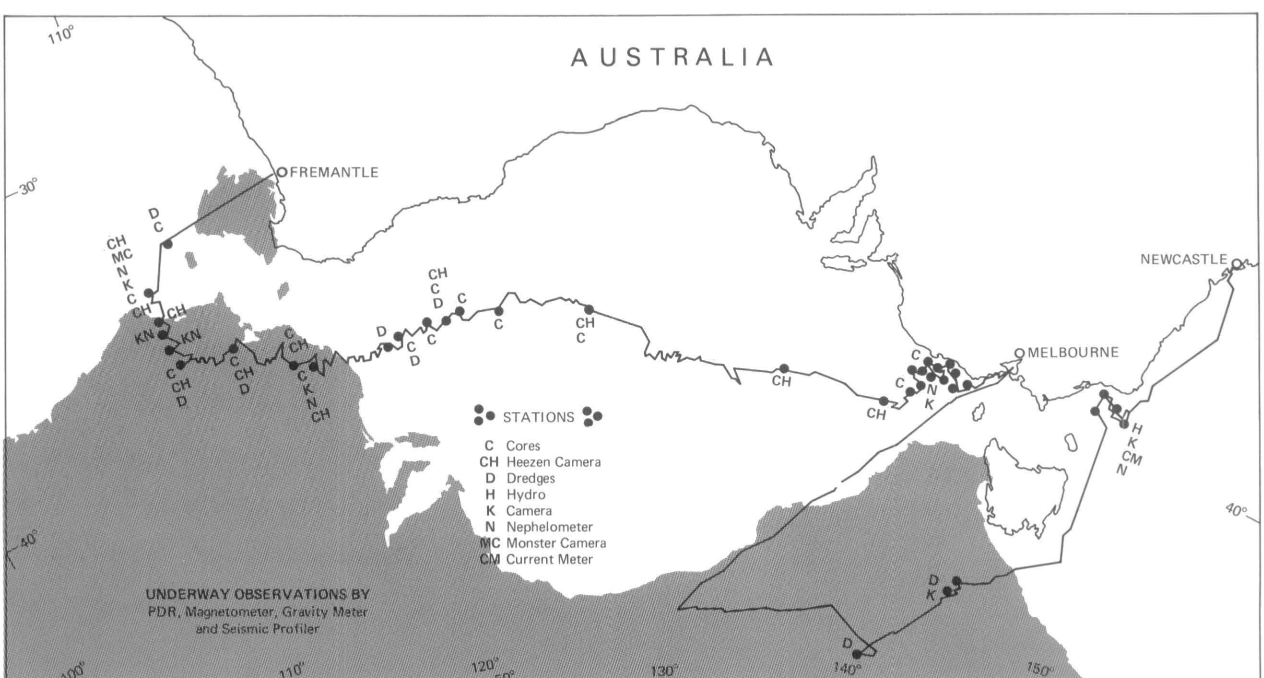
New objectives

We eventually decided on a plan that featured an investigation of a series of problems along the flank of the Mid-Oceanic Ridge, the Diamantina Fracture Zone, and the Naturaliste Plateau. The principle objectives of the new program were: (1) the investigation of possible contemporary activity in selected Victorian submarine canyons, (2) the investigation of possible contour current activity on the Australian continental rise, (3) the determination of the location and trends of fracture zones on the northern flank of the Mid-Oceanic Ridge and on the continental margin, (4) the mapping of the seaward limits of the Great Bight Abyssal Plain, particularly in relationship to tectonic trends, (5) investigation of possible occurrences of Tertiary carbonates on topographic highs, (6) tracing the tectonic trends of the Diamantina Fracture Zone, (7) sampling possible basement exposures on fracture zone escarpments, (8) investigating the age and history of the Diamantina Fracture Zone, (9) exploration for contour current effects on the continental rise adjacent to the Naturaliste Plateau, and (10) sampling ancient outcrops and perhaps basement on the Naturaliste Plateau.

This ambitious plan provided a series of pertinent objectives to be developed during the 26-day passage from Melbourne to Freemantle. The 100 observations made at 66 omnipurpose stations together with the underway observations allowed us to contribute substantially to all the above objectives.

Victorian submarine canyons

Three days were devoted to study of several small and one large submarine canyons that cut the con-



***Eltanin* Cruise 55**

tinental slope of Victoria. Cores, photographs, nephelometer traces and 3.5 kilohertz echograms were the principal tools. The 3.5 kilohertz echograms indicated a great thickness of soft sediments on the canyon walls. None of the camera stations revealed any evidence of current lineations, ripples, or scour. Since the sediment cores are taken in a plastic liner and there are no provisions on *Eltanin* for splitting the liner, we were unable to examine the cores for stratification. As far as we were able to ascertain, however, the cores consisted predominately of unstratified hemipelagic gray muds. None of the cores apparently penetrated pre-Pleisticene sediments. Although it is not possible to ascertain if contemporary current activity is taking place in the canyons, it certainly is not producing dramatic effects.

Continental rise contour currents

A series of hyperbolae of varying sizes tangent to the otherwise smooth surface of the continental rise were recorded on the 3.5 kilohertz echogram. These features were very similar to certain features observed in the North Atlantic that we had been accustomed to attribute to contour current activity. A series of photographs taken in the area on the Victorian continental rise, however, revealed no contemporary current evidence. We entertained the hypothesis that the microphysiography was indeed the result of contour current activity but that the current system had ceased to exist or diminished greatly in magnitude since late Quaternary time. According to this explanation a thin layer of mud now covers the current-constructed bottom forms that provide the familiar echo patterns. When the cores are split we may be able to test this hypothesis further.

Fracture zones in the Australia Basin

Virtually all the sounding lines run by *Eltanin* during the 4-year investigation of the basin south of Australia run north-south. The collated topographic and magnetic profiles allowed the rough localization of probable fracture zones that offset the topographic and magnetic features, but, by the same token, such a pattern of tracks could not demonstrate the exact location, spacing, or form of the fracture zones, since the fracture zones run north-south and, therefore, were not crossed by the sounding lines. Studies in the relatively better surveyed North Atlantic suggest a spacing of 20 to 30 miles for fracture zones, although it is by no means clear that spacing is consistent throughout the world. We hoped to find a series of fracture zones that may have been inundated by the turbidite deposits that created the Great Bight Abyssal Plain. With that extra indication one might be able to establish trends with the limited time available. We were only partially successful in making positive identifications of fracture zones versus ridge/rift textures. We might have had better luck farther south, for our track established that the Great Bight Abyssal Plain extends much farther south than previously had been suspected. Several prominent linear highs were shown to extend in an east-west direction for 8 to 10 miles, and in several instances the nearly north-south orientation of fracture zones could be established positively. On the lower continental rise off Victoria the Tasman Fracture Zone and Kangaroo Fracture Zone systems can be seen to extend across the continental rise, causing the ponding of sediment that apparently is being transported from northeast to southwest across the continental rise.

Tertiary carbonates

One cannot expect to obtain Tertiary carbonates in the deep basin, for abyssal clay too thick to penetrate by piston coring blankets the carbonates. On seamounts, however, currents and slumping limit accumulation, and it is sometimes possible to core a reduced and somewhat incomplete sequence that extends far back in geological time. For this reason we searched for a seamount that rises above the present carbonate compensation depth. On December 11 we found one, and from this peak we recovered a 10-meter core from near the 3,600-meter summit. The core penetrated a few centimeters of recent carbonate ooze, then several meters of barren abyssal clay, and a few meters of Oligocene ooze. The core cutter was embedded in weathered basalt. We had completed a hole through the Quarternary, Neogene, and part of the Paleogene into basement. This core directed our interest to the problem of fluctuations in the carbonate compensation depth in the antarctic area south of Australia.

Most of the 30 subsequent cores obtained during the cruise were directed towards further elucidating this problem. It was found that cores taken in depths as great as 4,800 meters recovered an upper thin layer of carbonate ooze overlying red clay. In depths as little as 3,600 meters we obtained a somewhat thicker layer of late Quaternary and recent ooze overlying red clay. In two instances the core penetrated the carbonate ooze, red clay, and abyssal ooze into early Tertiary basement. There have been previous indications of a shift in the compensation depth north of the antarctic polar front, but we suspect that Cruise 55 was the first to take the opportunity to devote 30 coring stations to the problem. There appear definitely to have been a recent depression of the carbonate compensation depth from the vicinity of 3,600 meters to a present level of somewhat greater than 4,800 meters. The differences in carbonate compensation depth being roughly similar to the present day differences between the carbonate compensation depth found in the Atlantic and the Pacific. We speculated that the change in current intensity suggested by our continental rise investigation might also be related to a recent weakening of abyssal circulation in the area.

Diamantina Fracture Zone

About a decade ago HMS *Diamantina* reported an exceptionally deep sounding obtained some 600 miles southwest of Cape Naturaliste. Shortly later RV *Vema* traced a 6,500 to 7,000 meters deep for over 100 miles in areas somewhat east of *Diamantina's* discovery. In the same year the Russian ship *Ob* reported a sounding in excess of 7,000 meters farther west in the base of the Broken Ridge.

Following a study of these and other profiles we proposed that the deep soundings lay along a fracture zone that runs along the south side of Broken Ridge and the Naturaliste Plateau and extends east across the basin south of the Great Australian Bight. Evidence even seemed to suggest a continuation with tectonic features of South Australian Victoria and Bass Strait. As additional sounding runs were made by *Eltanin* and other ships entering and departing Freemantle, the original speculation was confirmed. However, except for the initial studies by *Diamantina* and *Vema* in restricted areas west of the Naturaliste Pleateau, no systematic investigation of the fracture zone had been attempted. The Diamantina Fracture Zone is a curious feature since its trend is approximately perpendicular to the trends of the modern Mid-Oceanic Ridge fracture zones in the area. Were it not for the complete absence of seismic activity it might be tempting to consider it a deep sea trench. Indeed, the name Diamantina Trench is sometimes used.

The long linear feature is characterized by high altitude relief with both shallow peaks and excessive depths. We encountered the feature near 125°E. near the western end of the Great Bight Abyssal Plain. At this longitude the deeps were occupied by thin arms of the abyssal plain, but as we proceeded westward the plain ended, making it much more difficult to trace the rugged peaks and troughs. We were able to trace a prominent deep as a single linear feature for over 300 miles. At about 115°E. the trends were broken and we were unable to carry the key features farther to the west. The individual trends we were able to trace confidently run from east-northeast to west-southwest, whereas the overall trend of the Diamantina Fracture Zone runs west-northwest, suggesting that the zone is composed of *en echelon* features of limited extent.

Twenty piston cores were obtained from the slopes and crests of the ridges. Eight dredge hauls were made. Unfortunately, most of the steepest slopes face south. *Eltanin's* single A-frame is on the starboard side. The area is one of nearly continuous westerlies. This combination of circumstances makes it nearly impossible to dredge a south facing scarp. Fortunately, an atmospheric high passed by on our last day in the Diamantina Fracture Zone, and the consequent shift of winds allowed us to dredge on a south-facing scarp. Among the numerous manganese nodules, we recovered slabs of weathered, manganese-coated basalt.

What little evidence we obtained on the basement thus was completely consistent with an oceanic origin. The recovery of one Oligocene and one Eocene core from the tops of the peaks suggests that sedimentation began in this area at approximately the same time that the crust was formed if one accepts the isocrons estimated from paleomagnetic anomoly correlations. Thus it appears that the Diamantina Fracture Zone is a feature of the oceanic crust that was created very early in the history of that crust and probably before the present north-south trend of the fracture zones was established.

Naturaliste Plateau

Old maps and papers refer to a now discredited feature known as the Amsterdam-Naturaliste Ridge. Our studies a decade ago showed it to be an invalid conglomeration of parts of four major features—the Mid-Oceanic Ridge, Ninetyeast Ridge, Broken Ridge, and Naturaliste Plateau. The latter is broad, with a smooth surface but steep sides; it lies in depths of 1,000 to 3,000 meters and extends some 300 miles west of Australia. Seismic reflection profiles had indicated that a cap of sediment 200 to 1,000 meters thick lay beneath the smooth surface of the plateau, but suggested that outcrops of deeper layers and perhaps the acoustic basement as well may occur on the steep escarpments which bound the plateau.

We knew that very steep escarpments lay along the south flank of the Naturaliste Plateau from previous expeditions. We also knew that with our starboard A-frame and normal weather conditions we would not be able to dredge from south to north. So we went to the west side of the Naturaliste Plateau in hopes of finding some steeper escarpments, although previous tracks in the area gave scant hope of finding any. When we arrived at the southwest corner of the Naturaliste Plateau we found that indeed the scarps were not sufficiently steep to give hope of obtaining rocks. We cored into Neogene sediment and made some photographs, but shortly we decided to proceed to the north side of the plateau in an area where one echogram had indicated a very steep scarp. On arrival we found that the scarp was even steeper than previous expeditions had suggested. We lowered a dredge and recovered large slabs of manganese up to 15 centimeters thick, some created in the form of ripple marks. On the base of some of these slabs we saw deeply weathered crystalline rocks that contribute to the acoustic basement. The rocks were of continental affinities, suggesting to us the Naturaliste Plateau is a subsided part of the Australian continent and not an exceptionally thick segment of oceanic crust as had been suggested recently.

News and notes

Ross Ice Shelf Project

Scientists interested in participating in the Ross Ice Shelf Project are invited to write Dr. R. H. Rutford, Coordinator, RISP, University of Nebraska-Lincoln, 135 Bancroft Hall, Lincoln, Nebraska 68508. This management office has been established through a contract with the National Science Foundation.

Plans for the Ross Ice Shelf Project evolved from the interest of scientists from several countries who believe that a number of scientific problems could be solved if a hole were drilled through the Ross Ice Shelf to sample the ice, the underlying water column and biome, and the bottom sediments. An *ad hoc* committee of the National Academy of Sciences Committee on Polar Research evaluated the project's scientific goals, and its recommendations led to establishment of a RISP steering group under the Committee on Polar Research. Recognizing this U.S. progress, the Scientific Committee on Antarctic Research established a group of specialists on ice shelf drilling with representation from seven SCAR nations. This group met at the twelfth SCAR meeting in Canberra in August 1972 and made recommendations to the RISP steering group.

The steering group and the management office at Nebraska have been developing a science plan, and a draft copy is available. Investigators in geophysics, glaciology, geology, marine biology, oceanography, and engineering have indicated interest in the project.

The aims of the Ross Ice Shelf Project are to investigate the physical, chemical, biological, and geological conditions in the shelf ice, in the water mass beneath the ice, and in the soft sediments and bedrock at the bottom of the sea. The specific objectives as envisioned by the steering group are to seek answers to these questions: (1) What is the history of the Ross Ice Shelf? (2) What is the history of the waters beneath the shelf? (3) What is the nature of the fauna and flora beneath the shelf? (4) What is the history of the Ross Sea Embayment? (5) What can be learned from study of this area that can help in the understanding and interpretation of the glacial and climatic history of Antarctica?

During the 1973-1974 austral summer a geophysical survey and surface glaciological program, supported by helicopters, is planned for the eastern part of the Ross Ice Shelf. Initial drilling is scheduled for the 1974-1975 field season.

Third international Gondwana symposium in Canberra

The third international Gondwana symposium will be held in Canberra, August 20-25, 1973. Sponsored by the Australian Academy of Science and the International Union of Geological Sciences, the meeting will be concerned with the late Paleozoic and Mesozoic relationships between the southern continents.

Planned papers fall in six categories: paleogeography, flora, environment and origin of coal deposits, age and stratigraphical relations of glacial deposits, advances in stratigraphy and paleontology, and tectonics, igneous activity, geochronology, structural geology, and nature of the continental margins.

Although the registration deadline has passed, persons may request abstracts, proceedings, and other printed matter by sending Aust$25 to Secretary, P. O. Box 216, Civic Square, ACT, 2608, Australia.

Symposium in Leningrad on ice and snow studies

The Arctic and Antarctic Research Institute is planning a symposium on physical methods of ice and snow studies that will be held in Leningrad, October 1-6, 1973.

Papers will be presented and discussed on electromagnetic and optical methods of studying snow, ice, and water properties and mechanical properties of ice and snow. Attention will be given to recent studies of ice and snow microstructure, their mechanical and electromagnetic properties, and modern apparatus for glaciological studies.

Persons wishing to attend or present papers should write the Symposium Organizing Committee, Arctic and Antarctic Research Institute, 34, Fontanka, Leningrad 192104, USSR.

Symposium in Melbourne on polar meteorology

A symposium on meteorology of the polar regions will be held during the first special assembly of the International Association of Meteorology and Atmospheric Physics in Melbourne, Australia, January 14 to 25, 1974. Three half-day sessions will concentrate on antarctic problems, including fluxes of heat, water vapor and momentum over snow, sea ice and land ice, and the Polar Experiment.

Abstracts of contributed papers should be concise and informative and should occupy one typed page with a margin of 4 centimeters on the left side and 3 centimeters at top and bottom; they should reach the coordinator by August 1, 1973. Notification of acceptance or rejection will be mailed about September 1, 1973.

Submit abstracts to Professor S. Orvig, Secretary, ICPM, Department of Meteorology, McGill University, Burnside Hall, P. O. Box 6070, Montreal 101, Quebec, Canada.

Polar oceans conference planned for spring 1974

The Scientific Committee on Oceanographic Research and the Scientific Committee on Antarctic Research will sponsor a polar oceans conference in Montreal in the spring of 1974. The dates are May 6 to 11.

A steering committee for the conference is inviting papers under four headings: polar water masses, ice, productivity, and climatic change. Space for contributed papers is limited. Further information will appear in *SCOR Proceedings, SCAR Bulletin,* and elsewhere.

Interested scientists should write Professor M. J. Dunbar, Atlantic Oceanographic Laboratory, Marine Sciences Directorate, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.

Soviet polar literature submitted for translation

The Polar Information Service, National Science Foundation, has submitted the following Soviet polar literature for translation into English through the Special Foreign Currency (Public Law 480) Program:

Academy of Sciences of the U.S.S.R. 1971. *Fundamentals of the Biological Productivity of the Oceans and Their Exploitation.* Moscow, Nauka Press. 295 p. (Cosubmitted with National Marine Fisheries Service.)

Academy of Sciences of the U.S.S.R. 1972. *Antarctica Commission Reports No. 11.* Moscow, Nauka Press. 224 p.

Arctic and Antarctic Scientific Research Institute. 1964. *Meteorological Conditions in the Arctic During the IGY and IGC* (Transactions, volume 266). Leningrad, Hydrometeorological Publishing House. 164 p.

Arctic and Antarctic Scientific Research Institute. 1970. *Ice Forecasting Techniques for Arctic Seas* (Transactions, volume 292). Leningrad, Hydrometeorological Publishing House. 220 p.

Arctic and Antarctic Scientific Research Institute. 1972. *Investigations of the Physical Nature of the Icing of Vessels* (Transactions, volume 298). Leningrad, Hydrometeorological Publishing House. 178 p.

Arctic and Antarctic Scientific Research Institute. 1972. *Automation of the Gathering and Analysis of Scientific Information to the Ocean/Atmosphere Interaction* (Transactions, volume 301). Leningrad, Hydrometeorological Publishing House. 139 p.

Deryugin, K. K. 1968. *Soviet Oceanographic Expeditions.* Leningrad, Hydrometerological Publishing House. 234 p.
Dolgina, I. M. (ed.) . 1971. *Meteorological Regime of the Non-Soviet Arctic.* Leningrad, Hydrometeorological Publishing House. 227 p.
Yegiazarov, B. Kh. 1972. *Text to Accompany the Tectonic Map of the Polar Regions.* Leningrad. 88 p.

SAE Information Bulletin vol. 8, nos. 1-3, published

The English translations of *Soviet Antarctic Expedition Information Bulletin* numbers 79, 80, and 81 (1970) have been published. The three numbers constitute numbers 1, 2, and 3 of volume 8 of this continuing series, which is translated and published under a grant from the National Science Foundation.

Copies may be ordered for $7.50 each from the American Geophysical Union, 1707 L Street, N.W., Washington, D. C. 20036.

Marine sediments folio is published by AGS

Marine Sediments of the Southern Oceans, the 17th folio in the *Antarctic Map Folio Series,* has been published.

Drawing largely from data collected by USNS *Eltanin,* H. G. Goodell, R. Houtz, M. Ewing, D. Hayes, B. Naini, R. J. Echols, J. P. Kennett, and J. G. Donahue compiled the nine plates (seven in color) and 18 pages of text. The plates show surface sediment types, ferromanganese deposits, bottom photographs, sediment thickness in the Indian and Pacific Ocean sectors, and distribution of foraminiferal fauna and planktonic diatoms.

Folio 17 may be ordered from the American Geographical Society, Broadway at 156th Street, New York, New York 10032, for $11 plus $1 for postage and handling. A National Science Foundation grant partially supports the series.

Staff changes at the Office of Polar Programs

Mr. Robert B. Elder came to the Office of Polar Programs from the U.S. Coast Guard in June 1972 to be ocean projects manager. Mr. Alex Schwarzkopf, who came from the National Aeronautics and Space Administration in July 1972, is planning officer. Mr. Guy G. Guthridge, formerly acting director of the Polar Information Service, was named director in April. Dr. Victor T. Neal returned to Oregon State University in February 1973 after a year's sabbatical during which he was OPP's program manager for ocean sciences. Dr. Gunter Weller, on sabbatical from the University of Alaska, has temporarily assumed Dr. Neal's duties in addition to his existing responsibility as program manager for meteorology.

Two active-duty U.S. Navy officers were assigned in July 1972 for a tour of duty with the Office of Polar Programs. Commander Eugene R. Doering is assistant field projects manager, and Captain Robert L. Logner is staff associate for policy and plans. Also, U.S. Air Force Captain Peter J. Anderson, with the *Operation Deep Freeze* office until July 1972, is assistant information officer.

Admiral Charles W. Thomas dies

Retired Coast Guard Rear Admiral Charles W. Thomas and his wife Lorinda died March 3, 1973, in an automobile accident in Ushuaia, Argentina. Admiral Thomas's long-time involvement with the Antarctic began in 1946.

He graduated from the U.S. Coast Guard Academy in 1924 and served on destroyers and cutters in the North Atlantic in the late 1920s and early 1930s. In 1943 he commanded the cutter *Northwind* on an expedition to northwest Greenland and Jan Mayen Island. Also during World War II, he commanded the icebreaker *Eastwind.* From 1945 to 1946 he commanded the Greenland Patrol.

Admiral Thomas commanded the icebreaker *Northwind* during *Operation Highjump,* escorting three ships into the Ross Sea to establish Little America IV at the Bay of Whales. Later, he reestablished the Bering Sea Patrol and commanded the Coast Guard yard at Curtis Bay, Maryland.

For the IGY period, Admiral Thomas was chief of staff of the planning group to implement naval support for the U.S. antarctic expedition. In 1955 he was chief of staff of Task Force 43 and, later, was task unit commander of *Operation Deep Freeze I.* Using *Eastwind,* he aided delivery of cargo to Little America V, explored the Victoria Land coast, and selected the site for Hallet Station. The next year, he set up Hallett and Wilkes Stations.

Admiral Thomas retired from the Coast Guard in 1957. He became director of the University of Washington's study of arctic sea ice in 1958 and joined the Museum of Comparative Zoology at Harvard in 1960. Later, he was professor of science at Nathaniel Hawthorne College in New Hampshire.

Admiral Thomas had wide interests and wrote extensively on polar navigation, sea pollution, and undersea research. His 1951 book *Ice Is Where You Find It* recounts his arctic and antarctic experiences through 1950. "Two species of antarctic rotifers," in this journal [VII (5) : 186-187], is based on collections he made at Wilkes Station in 1956.

At the time of his death, Admiral Thomas was ice pilot and lecturer on *Lindblad Explorer,* a tourist ship that had just returned from the Antarctic Peninsula.

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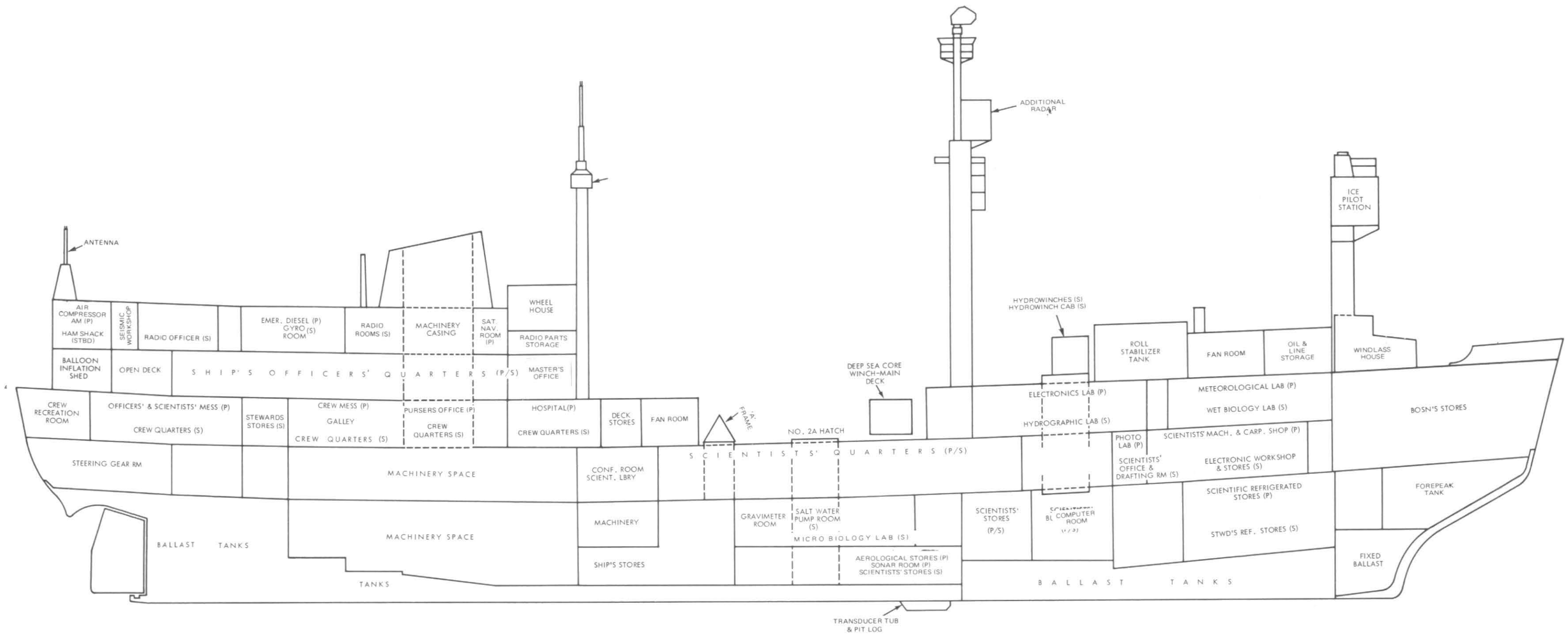

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