Geology and geophysics in the Patagonian Andes: R/V *Hero* cruise 84-4

Editor's note: Hero cruises in Chile's 200-nautical-mile zone were conducted with the assistance and permission of the Chilean government. In June 1983 representatives of the U.S. and Chilean governments signed an agreement that outlines a cooperative plan for research conducted aboard the Hero. To fulfill one requirement of this agreement, NSF publishes the final reports of these cruises in the Antarctic Journal. Hero was the National Science Foundation's antarctic research ship from 1968 to 1984. During the austral winters, when ice prevented work in the far south, Hero operated in the Subantarctic and along the southern coasts of South America.

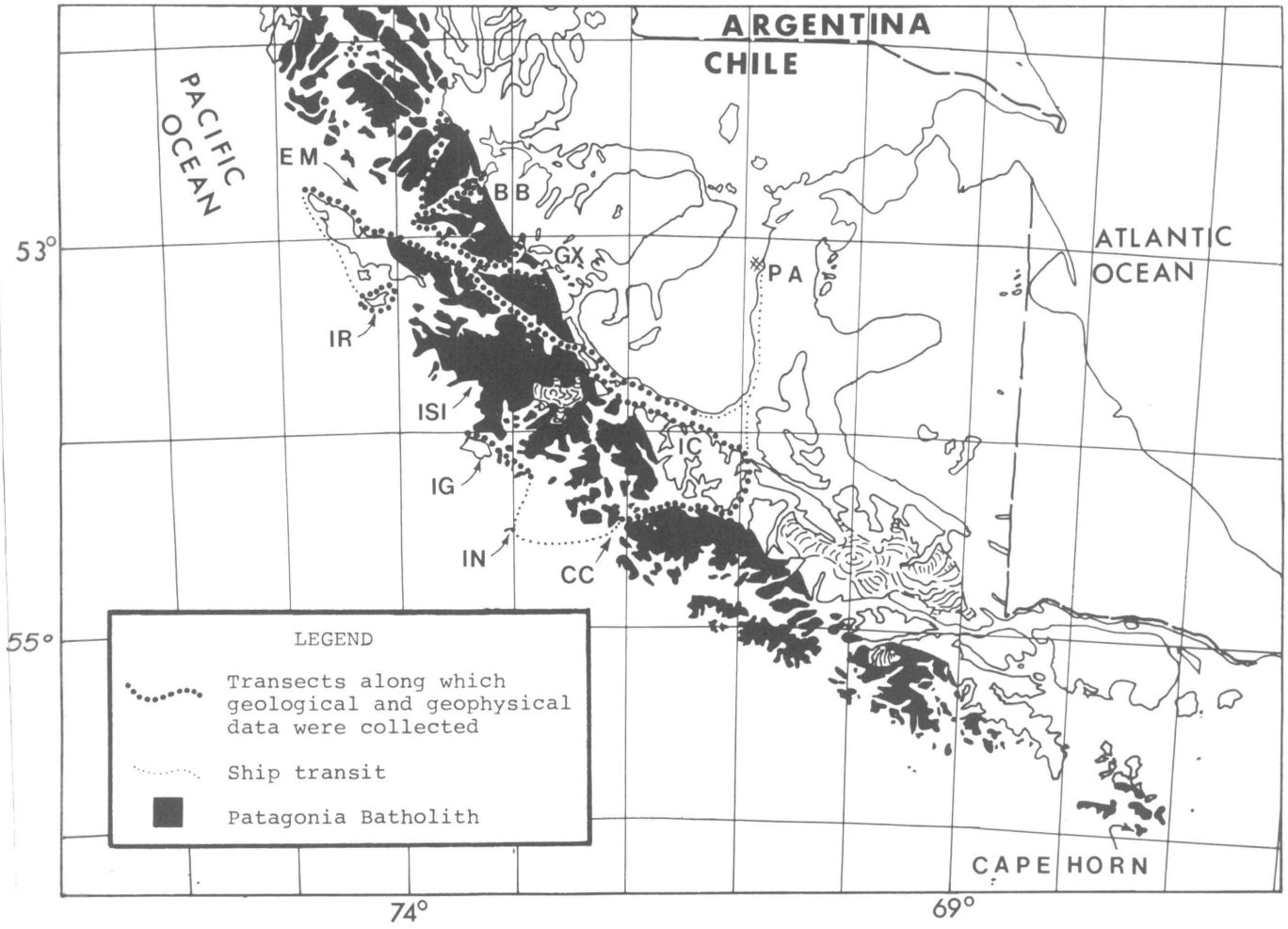
Between 14 June and 5 July 1984, the science party on R/V *Hero* studied the geology and geophysics of the southernmost Chilean Andes. This cruise (along with cruise 84-5) culminated 3 years of field work designed as the initial stages of two major investigations of the region. Our objective was to collect data on aspects of the geological and tectonic evolution of the southern Andes. Specifically, we are studying this region's history of uplift and crustal distortion, the petrological and geochemical evolution of the Patagonian batholith, and the regional gravity field. To meet these objectives, we conducted reconnaissance geological mapping, collected numerous rock samples for laboratory analysis, and made over 250 gravity measurements.

Geology of the study area

Because of its remoteness, most of the region studied has never been mapped in any detail, and much of it has never been visited by geologists. As a result of our investigation, significant changes were made in the mapped distribution of rock units in the region. The major lithologic units encountered were:

- Late Paleozoic (?) metasedimentary rocks
- rocks of the Mesozoic Patagonian batholith
- rocks of the Cretaceous Rocas Verdes igneous complex
- rocks probably correlative with the Cretaceous Vahgan Formation of Tierra del Fuego

Ship track of R/V *Hero* during cruise 84-4. Abbreviations in this figure are EM = Estrecho de Magallanes; BB = Bahia Beaufort; IR = Isla Recalada; GX = Golfo Xaultegua; ISI = Isla Santa Ines; PA = Punta Arenas; IG = Islas Grafton; IN = Isla Noir; IC = Islas Clarence and Capitan Aracena.



- volcanic rocks either related to the Patagonian batholith or to the Late Jurassic Tobifera Formation

A thick, structural sequence of steeply dipping, tightly folded shale and graywacke sandstone was mapped on Isla Deslacion, Isla Recalada, Islas Grafton, and Isla Noir (see figure). One single outcrop of bedded radiolarian chert, mapped on Isla Recalada, may help to date this sequence paleontologically and suggests that this sequence correlates with a regionally extensive Late Paleozoic(?) basement complex in the southern Andes. The extremely remote exposures on Grafton and Noir previously were mapped as batholith (*Mapa Geologica de Chile*, 1980); undoubtedly this interpretation was based on information from aerial photographs. Because we were probably the first geologists to land on these remote islands, our discovery significantly extends the southernmost known distribution of this basement complex along the outer continental shelf.

Minor changes were made in the position of geologic contacts on the *Mapa Geologica de Chile*, particularly in the fjords on the northeast coast of Islas Clarence and Capitan Aracena (see figure). Units mapped in this region include metasedimentary rocks probably equivalent to the Yahgan Formation of Tierra del Fuego, metavolcanic rocks probably related to the regionally extensive Tobifera Formation, and metamorphic rocks probably correlative with the Late Paleozoic(?) basement complex. The relatively high metamorphic grade and strong tectonic fabric of these rocks (previously unreported) suggest that a zone of intense late Mesozoic deformation, known to exist to the southeast in Tierra del Fuego, extends into the region.

We concentrated most of our work during cruise 84-4 on mapping and sampling of the Patagonian batholith (see figure). Although this region of the batholith represents only a small portion of the entire body (which is over 2,000 kilometers long and up to 100 kilometers wide), it was one of the major gaps in our reconnaissance mapping program. Approximately 200 samples were collected from the batholith for geochronological and geochemical analysis. Fission-track, potassium-argon (K-Ar), and uranium-lead (U-Pb) age determinations will be done on many of the samples to determine ages of intrusion and cooling from which uplift rates and times will be estimated. Together with geochemical analyses (major, trace-element, and isotopic), this age information will help us determine the petrological and geochemical evolution of the batholith and the underlying crust and mantle.

Although this portion of the batholith is not mapped in detail, sampling over a wide area enabled us to define the considerable lithologic variation that exists within this formation. Rock types encountered include gabbro, diorite, biotite and hornblende-biotite granodiorite and tonalite, biotite granite, two-mica granite and leucogranite. One garnet-bearing, two-mica granitic gneiss was mapped along a portion of Estrecho de Magallanes. Granodiorite and tonalite are the volumetrically dominant lithologies. The less silicic phases (diorite and gabbro) appear to be early phases that are intruded by and contained as xenoliths within the later granodiorite and tonalite. True granites are uncommon, except for a large pluton mapped in Golfo Xaultegua.

Numerous diabase dikes cut many of the younger plutons in the batholith; some dikes appear to be contemporaneous with older plutons (or late synplutonic). Most of the plutons in the batholith are massive or only weakly foliated, although a few are strongly foliated and even gneissic. These strongly foliated plutons are either very early plutons that underwent deformation during the Cretaceous Andean deformation or are younger, post-Andean plutons that were affected by post-Andean localized (shear) deformation.

Mesoscopic fault and fracture data were collected along the cruise transects. We observed two main orientations of brittle faults. One set trends north-south, has steep dips, and has dominantly left lateral separation. The other set trends generally east-west, has steep dips, and has dominantly right lateral separation. Fracture systems are more irregular but in many cases have the same orientations as the fault sets. Late mafic dikes are present throughout the study area and commonly are parallel to one or two fracture sets. Samples from some dikes were collected for age dating to constrain the timing of fault and fracture development.

Along portions of the south coast of Estrecho de Magallanes (see figure), an extensive sequence of tectonites was mapped where batholithic rocks previously had been mapped. This sequence consists predominantly of strongly deformed greenstone of the Rocas Verdes igneous complex (which has ophiolitic affinities to the southeast in Tierra del Fuego). Other mylonitic lithologies include orthogneiss, greenstone, and metasedimentary rock. Taken together, these tectonites probably represent deep exposure of a ductile shear zone along the major lineament defined by this northwest-southeast segment of the straits. Although this lineament often has been assumed to be a fault zone, these exposures represent the first direct evidence that such a fault exists. To determine the time of movement along the fault, we collected samples for age dates from late dikes that cut the mylonites.

Gravity measurements

Besides reference stations, we established 261 gravity stations in the study area. Although further data reduction is necessary, we are able to draw some preliminary conclusions. On profiles run transverse to the Andean Cordillera, a significant gravity anomaly appears to coincide with the distribution of the Rocas Verdes igneous complex. Two profiles run along either side of Estrecho de Magallanes suggest that this segment of the straits is coincident with a discontinuity in the regional gravity field, because the north side of the straits has systematically lower values than the south side.

Conclusions

During *Hero* cruise 84-4, we made numerous geological and geophysical observations in one of the last regions of the southernmost Andes to be visited by geologists. These included reconnaissance mapping of the Patagonian batholith and surrounding country rocks, structural mapping of fault and fracture sets, collection of numerous gravity data, and collection of numerous samples for laboratory analysis. We made several significant discoveries, including:

- radiolarian chert-bearing Late Paleozoic(?) basement on the Pacific coastal islands
- a belt of mylonitic rocks along the Estrecho de Magallanes lineament
- gravity anomalies coincident with the Rocas Verdes igneous complex and the Estrecho de Magallanes lineament, and systematic fault separation on two regional fracture sets

These data, when combined with data from past *Hero* cruises in the southern Andes, will add significantly to our understanding of the complex geological evolution of this remote and poorly known region. From these data we are beginning to develop models for the origin of the Patagonian batholith, for the geological consequences of oceanic ridge-trench interaction, and for the mechanisms of uplift and segmentation in Andean-type orogens.

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region. For more than 15 years geology, as well as other disciplines, has greatly benefitted from *Hero*'s presence in the region. We hope that the spirit of scientific endeavor will continue in this vein.

—Eric Nelson and Bob Bruce (Geology Department, Colorado School of Mines, Golden, Colorado 80401), Randy Forsythe (Department of Geological Sciences, Rutgers University, New Brunswick, New Jersey 08903), Dave Kammer (Geology Department, University of Houston, Houston, Texas 77001), and Ramon Moscoso (Servicio Nacional de Geologia y Mineria, Santiago, Chile).

R/V *Hero* cruise record, 1983-1984

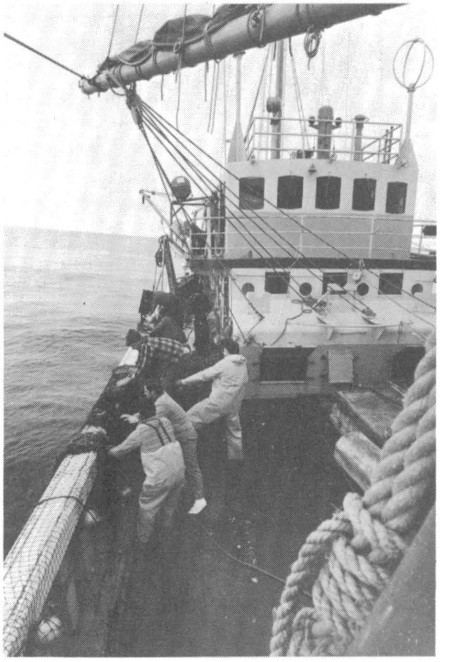
Between December 1968 and October 1984, the National Science Foundation operated the research ship *Hero* as a floating laboratory in conjunction with the U.S. antarctic station Palmer on Anvers Island. *Hero*, operated by the Foundation's support contractor, currently Antarctic Services, Inc., a subsidiary of ITT, concluded its antarctic career after the October cruise.

During the austral summer the 38-meter-long wooden research ship was an ocean platform for biologists, ocean scientists, and atmospheric researchers and transported geologists and other scientists to sites near or along the Antarctic Peninsula. The ship also brought personnel, equipment, and supplies to Palmer Station from ports in South America.

Although *Hero* operated in antarctic waters (south of 60°S) only between November and April, the ship stayed in the Southern Hemisphere throughout the year. During the austral winter months, U.S. scientists along with scientists from other countries used *Hero* to study the southern oceans and land features along the southern coast of South America. In these months the ship operated out of Punta Arenas, Chile, and Ushuaia, Argentina.

Hero left Palmer Station for the last time in April 1984; during the next 5 months geologists used the ship to investigate the Chilean canals. On 8 October 1984, *Hero* began its final voyage back to the United States. The decision to retire the ship was made because the main timbers are infected with progressing dry rot. The Foundation considered the ship no longer safe for operation in harsh antarctic waters. *Polar Duke*, a new ship leased by ITT/ANS for the Foundation, replaced *Hero* in January 1985. (See the September 1984 *Antarctic Journal* for a description of the *Polar Duke* and its capabilites.)

The following, which completes the record of *Hero*'s cruises, includes cruises conducted between June 1983 and October 1984. Lists for earlier years were published in *Antarctic Journal* issues May/June 1975, March/June 1978, and March 1983.



NSF photo by William Curtsinger.

Scientists and crew members retrieve a net while aboard *Hero* in the the mid 1970s.

The number and date of each cruise appear first; these are followed by the research area, the name (or names) and affiliation of the chief scientist, and a brief description of the type of research conducted.

Cruise 83-4. 1 June to 29 June 1983. Punta Arenas, Chile, and return via Chilean Tierra del Fuego from Seno Almirantazgo to Diego Ramirez Islands. Ian Dalziel (Lamont-Doherty Geological Observatory of Columbia University). Geologic