Ross Ice Shelf Project

Drilling in and below ice will reveal physical, chemical, biological features

JAMES H. ZUMBERGE

College of Earth Sciences
University of Arizona

The Ross Ice Shelf Project as presently conceived will involve the drilling of a hole in the Ross Ice Shelf to investigate the shelf ice, the underlying sea water, and the ocean floor.

It is difficult to trace the origin of the idea for this multidisciplinary project to an individual or group of individuals, but ever since the Ross Ice Shelf was penetrated at Little America in 1958 (Ragle *et al.*, 1960), a number of scientists have speculated on the value of future ice-core drilling in the shelf. In 1968, A. P. Crary suggested in his address to the International Symposium on Antarctic Glaciological Exploration that a number of scientific problems could be solved if a hole drilled several hundred kilometers back of the Ross Ice Shelf barrier could be used to sample the underlying water column and bottom sediments (Crary, 1970).

One of the original authors of the Ross Ice Shelf Project may have been the late Harry Wexler. Dr. J. W. Brodie, director of the New Zealand Oceanographic Institute, reported in a letter to G. O. Hemmen (May 15, 1969) that "many years ago" he had discussed with Wexler the proposition of drilling a hole through the Ross Ice Shelf to sample animals and sediments in the water column and at the bottom; to measure current velocity and direction, temperature, and salinity in the water column; to measure heat flow through the bottom; and to install such permanent monitoring equipment as current meters and thermographs. Brodie recommended in his letter to Hemmen that the site of the hole be over a substantial depth of water and several hundred kilometers from the ice front.

The National Academy of Sciences' Committee on Polar Research (1970) made a number of formal recommendations that relate directly to the scientific goals of the Ross Ice Shelf Project and established an *ad hoc* planning group to look into the matter. Dr. Sayed Z. El-Sayed of Texas A&M University, chairman, convened the group in Washington, D.C., on March 27 and 28, 1970, at which time a number of ideas were presented and some recommendations were made.

Scientific objectives

As a result of the March 1970 meeting, the scientific objectives of the Ross Ice Shelf Project have emerged. Physical, chemical, biological, and geological conditions within and beneath the Ross Ice Shelf will be investigated to determine how they relate to the ice itself, the water mass, the ocean floor, and the subsea sediments. More specifically, answers will be sought to these and other questions:

1. What is the thermal regime (melting or freezing) at the base of the Ross Ice Shelf several hundred kilometers from the ice front?
2. What do the physical and chemical aspects of the water mass reveal about the origin, age, and circulation of sea water beneath the Ross Ice Shelf? Is this water mass (or part of it) stagnant with respect to the Ross Sea, or is there continuous interchange of water between them?
3. What are the biological inhabitants of the water mass? Does a living biome exist as a separate and isolated entity with its own nutrient cycle? Are all or some of the organisms beneath the shelf immigrants from the Ross Sea?
4. What are the conditions of sedimentation on the sea floor beneath the Ross Ice Shelf and how do they differ from the sedimentary environment of the Ross Sea at varying distances from the ice front? Are the sediments on the floor of the Ross Sea and the ocean bottom beneath the Ross Ice Shelf diagnostic of the absence, or presence, of shelf ice conditions?
5. What can be learned from sedimentary cores taken beneath and beyond the Ross Ice Shelf about the waxing and waning of the antarctic ice sheet and the preglacial geologic history of the Ross basin?

This list is by no means exhaustive, but it gives an idea of the intriguing scientific questions that might be answered from the project.

SCAR group of specialists

On February 27, 1970, Scientific Committee on Antarctic Research (SCAR) Circular 248 reported on progress in the United States toward formulating a plan to drill through the Ross Ice Shelf and invited the SCAR nations to indicate their interests in such a project in preparation for discussions at the 11th SCAR meeting in Oslo in August 1970.

Considerable interest in the Ross Ice Shelf Project was voiced by a number of scientists at the Oslo meeting. A paper outlining the plan was presented to the opening plenary session, to a special meeting of SCAR delegates and observers, and to the joint meeting of the SCAR working groups on geology and solid earth geophysics (Zumberge, 1970). The Oslo discussions were reported by the International Union of Geodesy and Geophysics (1970) and the Scientific Committee on Antarctic Research (1971).

As a result of these discussions, the SCAR executive appointed a specialist group on ice shelf drilling projects to offer guidance and advice to the Ross Ice Shelf steering group of the U.S. Committee on Polar Research (discussed below) and to other groups that might develop future ice shelf drilling projects. Details on the specialist group are given in Scientific Committee on Antarctic Research (1971, p. 797). Members of the specialist group are R. D. Adams (New Zealand), C. R. Bentley (U.S.A.), J. W. Brodie (New Zealand), W. F. Budd (Australia), M. Grosval'd (Soviet Union), B. L. Hansen (U.S.A.), T. Ishida (Japan), C. C. Langway (U.S.A.), R. Radok (Australia), G. de Q. Robin (United Kingdom), C. M. Swithinbank (U.K.), E. Seibold (West Germany, liaison with the Scientific Committee on Oceanographic Research), and J. H. Zumberge (U.S.A., convenor). The specialist group plans to meet at the twelfth SCAR meeting in Canberra, August 1972.

Committee on Polar Research steering group

To follow up the work of the *ad hoc* planning group, Dr. L. M. Gould, chairman of the Committee on Polar Research, appointed a Ross Ice Shelf Project steering group consisting of C. R. Bentley (University of Wisconsin), D. H. Elliot (Ohio State University), S. Z. El-Sayed (Texas A&M University), A. L. Gordon (Lamont-Doherty Geological Observatory), B. L. Hansen (U.S. Army Cold Regions Research and Engineering Laboratory), D. E. Hayes (Lamont-Doherty), C. C. Langway (CRREL), R. P. Southard (U.S. Geological Survey), N. Untersteiner (University of Washington), J. Weertman (Northwestern University), and J. H. Zumberge (University of Arizona; chairman). P. M. Smith (National Science Foundation) and L. DeGoes (Committee on Polar Research, executive secretary) are *ex officio* members.

The steering group met in Washington, D.C., on April 16, 1971, to discuss the scientific objectives of the Ross Ice Shelf Project and to review the status of the planning. The following remarks are based on the deliberations at that meeting.

General plan

It was decided to divide the Ross Ice Shelf Project into two phases: a pilot hole project and a main drilling project. The objective of the pilot hole project will be to test the feasibility of drilling a hole in the shelf and of keeping it unfrozen long enough to conduct a limited scientific program. During the drilling of the pilot hole, the diameter of which has not yet been determined, a complete ice core will be recovered. The water column will be sampled for biologic and inorganic content, and other parameters of the water mass will be measured. Samples of the bottom sediment will be retrieved, and shallow gravity coring will be attempted. Underwater television may be tried, and bottom photography may be used. The tentative site of the pilot hole is about 450 km from the ice front, at 82.5°S. 166°W., where the ice is about 500 m thick and the underlying water column 100 to 200 m thick (see map on page 261).

The main drilling project will include all experiments attempted in the pilot hole plus a capability for core drilling in the ocean floor. Additional experiments arising out of experience gained in the pilot hole project may also be conducted. The site for the main drilling project will be selected after adequate seismic soundings through the shelf have been made. The start of the main drilling project is planned for 1 year after the pilot hole is started. The ability to meet this schedule will depend on the experience gained in the pilot hole project and on such other factors as the need for specially designed equipment, funding, and logistics.

The Ross Ice Shelf Project will be augmented by the deep-sea coring program of *Glomar Challenger* if plans by the National Science Foundation to fund several legs into antarctic waters materialize.

Details of the pilot hole project and some aspects of the main drilling project follow.

Planning map

The U.S. Geological Survey is preparing a planimetric map of the Ross Ice Shelf and environs at a scale of 1:1,000,000. The map will cover the area from 77° to 88°S. between 150°W. and the Transantarctic Mountains and will include all available information from International Geophysical Year traverses, recent air photographs, radio-echo sounding data on ice thickness, and newly published shaded relief maps of the Transantarctic Mountains. The map will be drafted on a stable base and will be retained at the Survey's Branch of Special Maps, where new information will be added as it becomes available. Film positives or paper prints will be available to Ross Ice Shelf Project scientists.

Drilling technique

The U.S. Army Cold Regions Research and Engineering Laboratory will design, fabricate, and test a drill rig under the direction of B. L. Hansen. The rig will be of the compressed-air, reverse-rotary type and will use a wire-line coring device for obtaining ice cores. The hole diameter has not been established, but it will be in the 30- to 100-cm range. The upper section of the hole will be cased because of the permeability of the firn. A heated wire suspended in the hole will prevent sea water that enters the hole at the base of the shelf from freezing. Drilling time will be about 30 days in ice that is 500 m thick.

Glaciology

Considerable experience has been gained in the analysis of ice cores from the 1,391-m core taken at Camp Century in Greenland and the 2,164-m core taken at Byrd Station in Antarctica. Analytical techniques established by Langway (1970) on those cores will be used on the Ross Ice Shelf cores. In addition, volcanic ash will be sought in the cores. Gow (1963, p. 277) identified ash horizons in the Little America core at the 172-, 219.4-, and 222.8-m depths. Discovery of these volcanic ash inclusions in other ice cores from the Ross Ice Shelf would not only provide a means of correlation but also be of great value in analyzing the dynamics of shelf movement.

The basal shelf ice will be examined for evidence of sea ice accretion. Swithinbank and Zumberge (1965, p. 210) inferred bottom melting of the ice shelf near the barrier and bottom accretion of sea ice near the land margin of the shelf. In their mass balance equation for the Ross Ice Shelf, Giovinetto and Zumberge (1968) used a value of 12 g per sq cm per yr as the mean rate of sea ice accretion at the base of the Ross Ice Shelf south of a line about 150 km south of the barrier. This value was based on previous work (Zumberge, 1964), which has been questioned by Robin (Giovinetto and Zumberge, 1968, p. 265). Oceanographic studies in the Ross Sea show high salinities (34.60 to 34.90 per mill) in the bottom water (Jacobs *et al.,* 1970), and Gordon (1969, p. 183) has suggested that the highly saline waters originate beneath the ice shelf, where brine is released during the freezing of sea water to the shelf bottom. The thermal regime at the shelf-water interface some hundreds of kilometers south of the barrier will be of obvious interest to glaciologists and oceanographers. The planned site of the pilot hole, 450 km from the ice front, was selected in part to test the bottom freezing hypothesis.

Physical oceanography

In addition to questions of freezing and melting at the bottom of the ice shelf, other questions about the waters below the shelf will be answered by direct sampling and measurements through the open hole in the shelf. The oceanographic aspects of the project will include measuring salinity, temperature, oxygen, and the density-depth relationship; sampling water for turbidity, carbon-14, and chemical analyses; and measuring current. This work will be done over a few hours to a few days rather than over several weeks or months. However, a self-contained recording package may be left on the ocean bottom, or one or more units may be suspended beneath the shelf; ice that forms in the hole can be melted for retrieval of the recorders. The extent to which existing sampling and measuring devices can be used will depend on the stable diameter of the open hole.

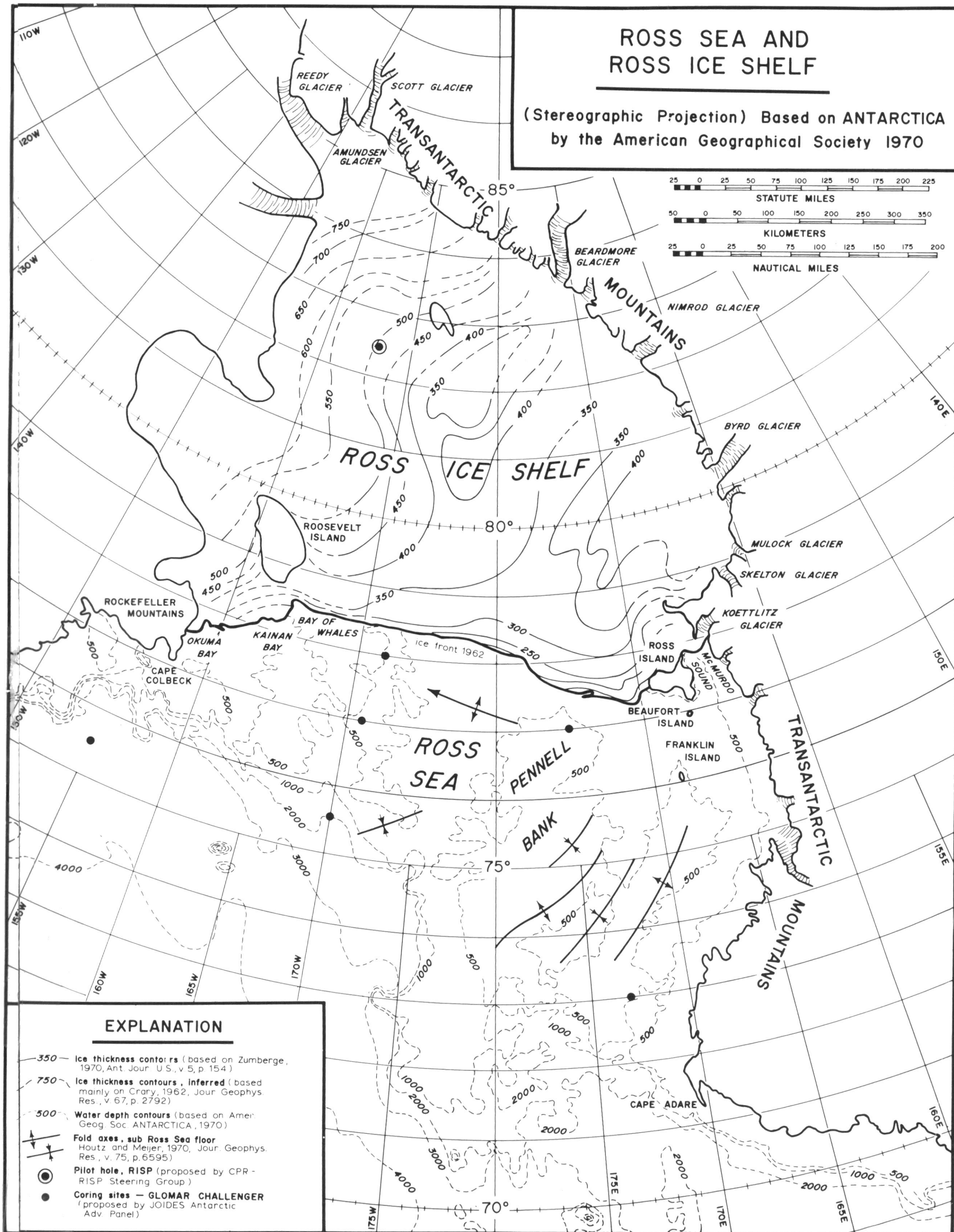
Marine biology

The cold, dark waters beneath the Ross Ice Shelf will be sampled carefully for pelagic or benthic life. Because these forms may be microscopic, large volumes of sea water will be pumped from different depths and filtered to recover planktonic forms. Microscopic bottom dwellers will be sought in the bottom sediments. Underwater television and photography will be used in the search for larger species. Contamination of the hole will be kept to a minimum to protect the integrity of the biological sampling. While there has been no speculation on the life forms that might exist in isolation beneath the ice shelf, the occurrence of highly specialized forms of life in aquatic caves suggests that marine life beneath the Ross Ice Shelf is possible.

Bottom sediments

The pilot hole project will include the sampling of bottom sediments and the retrieval of shallow gravity cores. These samples will be compared with samples from the Ross Sea in the hope that a subshelf facies can be distinguished from a Ross Sea facies. This distinction is necessary in the interpretation of cores from either beneath the shelf or the Ross Sea.

The main drilling project will include the capability of lowering the drill stem to the sea floor and retrieving cores with a wire-line coring device. The depth of penetration will depend on the nature of the sediments encountered and on the time available for coring. The latter is a function of water depth and movement of the shelf. For example, with a water depth of 200 m and a shelf movement of about 1 m



Ice thicknesses and depth soundings are in meters.

After this paper was in press, the Scott Polar Research Institute (SPRI) released a draft version of a new ice thickness map for the entire Ross Ice Shelf based on radio-echo soundings. The SPRI map shows greater detail in shelf ice thicknesses as affected by ice streams from Marie Byrd Land and by outlet glaciers from the Transantarctic Mountains.

per day, we can drill for 10 days—assuming that coring can continue until the hole in the shelf moves horizontally 5 percent of the length of the water column from the hole in the ocean floor. Because the location of the main drilling site will not be determined until after the pilot hole project has been concluded, the time available for bottom coring cannot be determined. It is assumed, however, that sufficient time will be available at the main drilling site for moderate-depth coring.

Deep coring

Since the early planning stages of the Ross Ice Shelf Project, the National Science Foundation has considered the possibility of extending *Glomar Challenger*'s drilling program to Antarctica. Plans for this extension include the drilling of a number of sites in antarctic waters. The planning committee of the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) has been advised of the desirability of deep coring in the Ross Sea to augment Ross Ice Shelf Project objectives. A JOIDES advisory panel on the antarctic ocean, established this year, has identified three sites in the Ross Sea that should be put on *Glomar Challenger*'s schedule if core drilling in antarctic waters becomes a reality. These sites are at 78°S. 172°W., 77°S. 171°W., and 75.5°S. 170°W. (see map). The points fall on the trajectory of a projected ice flow line passing through the pilot hole site and the edge of the continental shelf. These proposed drilling sites would have been covered by the Ross Ice Shelf at an *assumed* earlier stage when the ice front stood along a line from Cape Colbeck on the Edward VII Peninsula to Cape Adare in Victoria Land, some 400 km north of the present front.

Even if these sites are approved by the JOIDES planning committee, there is no guarantee that coring will be done at those exact coordinates. The final decision can be made only after extensive seismic profiling in that region of the Ross Sea. Houtz and Meijer (1970) have shown that anticlinal structures exist beneath the Ross Sea (see map). For obvious reasons, the penetration of a subocean anticline containing fluid hydrocarbons is to be avoided.

Seismic soundings

In addition to seismic profiling in the Ross Sea, seismic soundings at a number of places on the Ross Ice Shelf will be necessary to more clearly define water depths, bottom topography, and geological structures beneath the sea floor. The only information on water depths beneath the shelf is based on traverses made during the International Geophysical Year (Crary *et al.*, 1962). An airborne seismic sounding program covering selected segments of the shelf will provide information on the parts of the shelf not covered by the IGY traverses and will be vital to the selection of the drilling sites.

Tentative schedule

The magnitude of the Ross Ice Shelf Project, the multidisciplinary range of the experiments, and the participation of non-U.S. scientists demand careful planning and skillful execution of the field program. At this writing, planning for the field activities is still in a state of flux. Costs for various aspects of the project have not been estimated; not all project leaders for the specific elements of the program have been identified; the exact means of involving foreign scientists have not been worked out; and the overall managerial assignment has not been made. Decisions bearing on these questions need to be made soon.

Meanwhile, the Committee on Polar Research steering group for the Ross Ice Shelf Project has suggested a tentative timetable.

The Ross Ice Shelf planning map, in preparation by the U.S. Geological Survey, will be completed in early 1972.

Preliminary design and engineering for the drilling equipment is being undertaken by the U.S. Army Cold Regions Research and Engineering Laboratory. Drilling of the pilot hole could commence in October 1972 depending on the time needed for engineering design, procurement, and testing at the CRREL drill test facility in New Hampshire and in Greenland. Funding constraints could delay the pilot hole until October 1973.

Seismic work on the shelf could be started in the austral spring of 1972 and carried out over two successive seasons. Because the pilot hole will not involve drill-coring into the sea floor, seismic soundings are needed at the pilot hole site to establish only water depth and ice thickness.

The main drilling project could take place in the 1973-1974 austral summer, synoptically with drilling in the Ross Sea by *Glomar Challenger*. If the main project is delayed a year, the *Glomar* schedule will not be affected because there is no compelling reason to have the main drilling project coincide with coring in the Ross Sea.

When the diameter of the pilot hole is established, equipment that will be lowered through the hole can be procured by selecting from among existing items, by modifying present equipment, or by designing instruments specifically for through-the-ice sampling and measuring. This task should get under way early in 1972 so that all components will be ready for the pilot hole operation should it begin in the 1972-1973 austral summer.

The success of the Ross Ice Shelf Project will depend on how carefully all of the component activities can be fitted into a single operational schedule. If humanly possible, all participants should adhere to the master plan once it is established. However, unforeseen delays may arise, and each scientist must be prepared to adjust to a new situation on short notice. Scientists who possess this capability have been the most successful in past antarctic operations. The Ross Ice Shelf Project is not likely to alter this observation.

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R/V *Hero* Cruise 71-2 to Isla de los Estados

OLIVER S. FLINT

Department of Entomology
Smithsonian Institution

The objective of R/V *Hero* Cruise 71-2 was to survey the vertebrate, arthropod, and marine biotas of Isla de los Estados and adjacent areas of Tierra del Fuego, Argentina. Much of Tierra del Fuego has been studied, and its fauna is fairly well known. However, aside from incidental observations and collections, mostly of birds (Salvadori, 1900; Castellanos, 1935, 1937; and Beaglehole, 1961), the fauna of Isla de los Estados has not been surveyed previously.

The island

Isla de los Estados is roughly 60 km long on an approximate east–west axis and is situated across the Estrecho de la Maire from the eastern tip of Tierra del Fuego (see map). The north and south sides are cut by many fjords, some of which almost bisect the island. The topography is generally very rugged, reaching to 823 m in the Montes Bove. The northeastern corner of the island and Islas Año Nuevo are much flatter, however. The shoreline is generally steep, often precipitous, although there are a few bays with sand or cobble beaches.

The lower slopes are covered with a dense evergreen forest of southern beech (*Nothofagus*) and winter's bark (*Drimys*), often with a dense undergrowth of shrubs and bryophytes. On level areas with saturated soil or at high elevations, the land is covered with a moorland-type flora, sometimes hip-deep with rushes. Bedrock is evident everywhere, with the peaks generally barren rock.

Streams and ponds are numerous. The latter occupy glacial basins, some of which (Lago Louisato,