The interior of a crevasse is far from an ideal working location—temperatures down to —10° C., falling icicles, collapsing snow bridges, and even melt water from the surface.

Scientific curiosity and defense needs inspire a study of the occurrence and behavior of crevasses in glaciers.

Living On Cracked Ice

by C. J. Pings

During the International Geophysical Year there was considerable publicity covering the exploration and scientific activities of the United States in the Antarctic continent. Actually, of course, our nation was much involved in arctic research before the Geophysical Year, and continues to be even now, after the close of that formal program. Personnel from a number of universities, including those from Caltech's Geology Division, from the U.S. Coast and Geodetic Survey, and from several independent research institutes have a continuing scientific interest in the arctic regions. In addition, several branches of the Department of Defense support both basic and applied programs of arctic research.

Scientists are mainly interested in arctic regions because they pose an interesting collection of unsolved problems in the earth sciences. In addition, since about 1950, our defense needs have dictated the necessity for maintaining operational air bases and radar warning stations in the far North. If one takes a spherical look at the earth, the Thule air base in Northern Greenland, for example, represents one of the closest points of access to the interior of Russia, with the exception of continental Europe.

I am primarily familiar with the activities of the United States Army Corps of Engineers through their Cold Regions Research and Engineering Laboratory (CRREL) at Hanover, New Hampshire. Much of the exploration and field work of CRREL has been carried on since 1953 in various regions of Northern Greenland. The Thule Air Base at 76° north latitude in Greenland is maintained under an agreement with the Danish Government, which permits the United States to carry out glaciological activities in a substantial portion of the northwest sector of that island.

The accessibility afforded by an operational airstrip only 900 miles from the North Pole has made Northern Greenland an optimum area for arctic field research. Personnel and moderately heavy equipment can be brought in by airlift. It is possible in addition to move very heavy equipment by ship during the approximately six weeks each summer when the Thule harbor is ice-free. The airstrip has been of further value as a base for aerial reconnaissance, and particularly for helicopters for moving personnel to otherwise inaccessible areas on glaciers and snow fields.

In the early years of the Corps of Engineers' activities in Northern Greenland, the field activities were actually staged from the Thule Air Base. However, in 1954 the Corps constructed Camp Tuto at the edge of the icecap, about 13 miles inland from Thule. Every year since then Camp Tuto has grown in size, and the facilities have been improved until now it serves as an extremely useful base camp for projects operating for several hundred miles out onto the icecap. In addition to Camp Tuto the Corps of Engineers maintains at least one operational camp a substantial distance out on the ice sheet. The present icecap facility, located 100 miles out on the glacier, is the site of much of the experimental activity of CRREL.

In addition to these permanent facilities, smaller temporary camps have been set up at various locations as they were needed by the individual research projects. These are conventionally supplied and maintained from Camp Tuto, sometimes by airdrops, sometimes by surface with weasels, caterpillars, or other tracked vehicles.

The wide variety of problems that have been attacked by the personnel supported by CRREL in these various field camps, and in the laboratories at Hanover, has been dictated sometimes by scientific interest and sometimes by the need for a solution to a practical problem. Quite frequently an activity has contributed both to scientific understanding and to progress on an applied problem. One very interesting and successful engineering program carried out over a period of a number of years involved tunneling into a glacier and hewing out a number of large rooms. This was done to study the problems of tunneling in ice and to observe the strength of walls and ceilings in the shafts and rooms. However, in addition, these operations made it possible for some of the physicists to obtain samples of ice crystals which had been subjected to an unusual history of pressure and strain while present in the moving glacier. As a further bonus, one of the rooms served for a while as a very convenient field laboratory for carrying out some physical tests on ice samples without the need for elaborate refrigeration. Another activity involved setting up a drilling rig and sinking a hole into the icecap. The engineering motivation was to define the problems of drillings in ice and hopefully to find their solution. Here again, however, the scientists profited from the activity by studying the subsurface cores, resulting in definite stratigraphic correlations based on annual banding in the glacier caused by the seasonal freeze-thaw cycle.

In 1955 I was a member of a six-man group of scientists headed by Mark Meier, then a graduate student in Caltech's Geology Division, which went to Northern Greenland with the objective of carrying out some scientific and engineering studies on the occurrence and behavior of crevasses in glaciers. I returned to Greenland again twice in 1956 and once in 1957 to continue some aspects of this study. In addition to Meier, our 1955 party consisted of Jean Hoerni, then a research fellow in Caltech's Division of Chemistry and Chemical Engineering; William Melbourne, a graduate student in astrophysics; James Conel, a graduate student in geology; and the late Paul Walker, an undergraduate from Occidental College.

Concealed crevasses

Crevasses in glaciers have long been a troublesome problem to people traveling in arctic regions or over mountainous snow fields. These giant cracks in the ice presumably have developed due to the movement of the glacier. Sometimes an area will be so badly broken up on the surface by a mesh of intertwining crevasses as to make it completely impassable. However, the most insidious aspect of crevasses is that they are frequently concealed by thin bridges of snow, which may cover pits in the ice up to 100 feet deep. These snow bridges are frequently created across a crevasse during a blizzard or a high windstorm. It is quite surprising to find a crevasse five to six feet wide completely bridged over by a snow bridge only a few inches thick. These concealed cracks in the ice have claimed the lives of a number of arctic explorers, both in Greenland and in Antarctica.

As of today there is still no adequate means to detect the presence of these concealed crevasses except by the visual observation of obviously open segments of the snow bridge. Actually, when our project entered the crevassed areas, we sought the concealed crevasses by using a probe rod. This was a ⅜-inch steel rod about 10 feet in length with a sharp point. If we could physically drive this rod into the snow in front of us to a depth of about 8 feet without it dropping, we could then assume that the area immediately in front of us was safe for passage. However, to proceed with any assurance of safety it was necessary to do this probing every two to three feet. Progress under these circumstances was indeed slow.

There has not been much scientific work reported on the occurrence and behavior of crevasses. It was hoped that our project would be able to make some observations and measurements that might identify areas of likely occurrence of crevasses, and give indication of their probable depths, rates of opening and closing, and perhaps something of the mechanism of the growth and collapse of the snow bridges which so often conceal them. It seemed obvious that we ought to attempt to correlate the occurrence and behavior of the crevasses with gross features such as the underlying bedrock topography, the rate of flow, the stress field at the surface of the glacier, and perhaps seasonal fluctuations in precipitation and ambient temperature. We were free in addition to make any contributions that might suggest improved methods of crevasse detection. However, at the time, this did not seem a likely prospect, since other parties had been in the field actively testing devices and schemes such as sonar, radar, and electrostatic systems.

Advanced planning

Anyone responsible for the progress of a research program in a laboratory appreciates the difficulties of anticipating all needs of equipment and supplies required for uninterrupted research. The problem is amplified manyfold if the activities are being carried out in a field camp, especially in a location as distant and as remote as a glacier in Northern Greenland. All of our instruments and supplies had to be crated and shipped ahead of us by air in early May 1955. As a matter of fact, even more advanced planning had been required in order for the Corps of Engineers to supply us with snow weasels and cargo sleds, both of which had been brought in by ship the previous summer.

Our project personnel were flown into Thule by the Military Air Transport Service in the third week of June 1955. We spent about 10 days in Camp Tuto unpacking our equipment, checking our instruments, drawing arctic clothing, and arranging for food and fuel. When we finally left to set up a field camp, our caravan consisted of two snow weasels and three wanigans. The snow weasels are small tracked vehicles about the size of an automobile; as a matter of fact, they are powered by a conventional 6-cylinder automotive engine. Although it may be merely legend, I am told that the weasel was developed late in the war for use in swampy terrain. It turned out to be quite impractical for this use, but someone discovered that it worked very well on snow fields and glaciers. The weasel is not a powerful vehicle, but it is capable of hauling about five men, and of towing a moderate load at the same time. The wanigans were simple plywood structures constructed on one-ton cargo sleds. We used two of them for sleeping quarters and the third as a field laboratory for our instruments and our records. These wanigans were primitive, but they were snug protection from the occasional blizzards. They proved vastly superior to tents.

Traffic in Northern Greenland usually avoids crevasses, and with good reason. However, our objective was to study them, so it was necessary to set up our camp in the middle of a crevasse field. From aerial reconnaissance a badly crevassed area about 15 miles out onto the icecap had been selected for study. We entered the area deliberately and carefully, and after considerable scrutiny we were able to pick a safe campsite between the crevasses.

Our party contained some expert mountaineers and some complete novices, including myself. Therefore, even after we had set up a secure camp, we deferred scientific activity for several days while Meier conducted class to acquaint us with safety procedures in moving about the crevasse field, and to teach rope techniques which would be necessary when some of us started to enter the crevasses. We also discussed techniques and procedures that would be necessary should there be an accident requiring a rescue from a crevasse. These precautions paid off, since we spent the entire summer living and working in the crevasse field without a single accident.

In order to make any progress we had to narrow the scope of our investigation. We decided finally that we would pick out one crevasse and concentrate our detailed studies upon it. This was coupled with examination of the bedrock profile, velocity measurements, and general superficial observations on an area of considerable extent on both sides of this crevasse. We did make enough control measurements on several other crevasses to convince ourselves that we had not selected a freak for our detailed study.

Assorted investigations

Although there were some activities shared by all of the party, for reasons of intrinsic scientific interest, various members of the party concentrated on different investigations. Meier and Conel measured the velocity of the surface of the glacier over a considerable area embracing the study crevasse plus several parallel crevasses on each side. As early as possible in the summer of 1955 they set out a grid of vertical stakes in the glacier surface, forming as nearly as possible a rectangular grid. After these stakes had been positioned approximately, their location was precisely established by triangulation with a theodolite. The stakes were surveyed a second time late in August of 1955, and the measured changes in position were sufficient to make a fairly detailed mapping of the strain vectors on the surface of the glacier.

The results confirmed that the glacier was not only moving, but that, at the surface, movement was definitely non-uniform. The occurrence of the crevasses seemed to be well explained in terms of the measured stress concentrations. From these observations Meier noted that, parallel to the existing crevasses, there existed a locus of stress concentration which indicated a likely future crevasse. As a matter of fact, a new crevasse was indeed discovered at this location in 1959, when personnel reentered the area.

With the assistance of a seismological crew from the Air Force Cambridge Research Center, Meier planned and carried out a series of seismic shots in order to establish the location and configuration of the bedrock underlying the study area. Interpretation of these data was assisted somewhat by the availability of a few gravitometer studies obtained in a previous season. These measurements seemed to indicate some slight undulations in the bedrock surface under the study area. Although the data were too sketchy to be absolutely convincing, they appeared compatible with an often quoted model for crevasse formation which suggests that the surface of the ice checks or cracks as the glacier stretches over a slightly rounded region on the bedrock.

Bill Melbourne and I spent much of the summer clambering in and out of the study crevasse. He was making strain measurements in order to establish the rate of opening of the crevasse, while I was conducting some thermal studies. To our knowledge there had never been any careful quantitative measurements of the rate of opening and closing of crevasses, though there were some interesting legends of gaping crevasses suddenly opening in front of skiers' eyes, and the converse tales of crevasses suddenly snapping shut, much to the embarrassment of anybody who happened to be in them.

Rate of opening of crevasses

Melbourne was able to get some interesting and conclusive data on the rate of opening of the crevasses by application of a strain gauge technique. He stretched strain gauge wire across the width of the crevasse and anchored it very securely with ice pitons in each wall. He strung a number of these wires at various depths in a vertical plane and then ran lead wires from the two ends of each of these wires to the surface of the glacier. One by one these could be hooked into a bridge circuit which measured the resistance of the wire. With appropriate calibration, changes in the resistance of each wire gave the changes in lengths, and hence a measure of the widening of the crevasse.

The crevasse studied in detail seemed to be opening as a wedge about an apex 65 feet below the surface, with a rate which was equivalent to a movement of the walls of about 2 inches per week at the surface of the glacier. From another nearby crevasse Melbourne obtained evidence that the crevasses also close with comparable rates.

In addition to those measurements, in 1955 we observed what appeared to be a new crevasse of substantial length, but apparently only several inches wide at the surface. This particular crevasse was observed again in 1956 and 1957, and each time it showed a considerable increase in width until it was

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several feet wide in 1957. We are thus rather firmly inclined to reject as old-wives' tales the legends of catastrophic opening or closing of crevasses.

I was personally assigned the job of making some temperature measurements in the walls of the crevasses. We thought it would be informative to better understand the heat flow characteristics in the glacier near the crevasse, especially since there had been some speculation that transient thermal expansion might have some effect on the collapse of the thin snow bridges. We drilled thermocouple wells up to 15 feet back into the sides of the crevasse. In each of these wells we installed a number of thermocouple junctions, the leads from which were all run to the surface of the glacier. Additional thermocouples were mounted at assorted locations on the walls of the crevasse and in the snow bridge.

The interior of the crevasse was not exactly an ideal working location. It was moderately cold, with temperatures ranging to −10° C. There was a considerable hazard from icicles falling from the wall and from fragments of snow and ice falling from a snow bridge or over the edge of the crevasse. In addition, on a warm day, considerable melt water from the surface ran over the edge of the crevasse. It is particularly unpleasant to be showered with water while working in an environment that happens to be about 10 degrees below freezing!

Some of the strain gauge and thermocouple installations were made at the bottom of the crevasse, where we could stand on reasonably solid ice while working. However, we were anxious to install both types of instruments at a number of assorted depths between the surface and the bottom of the crevasse. At the beginning of the summer we attempted to do this work while clinging to a rope ladder anchored at the surface. This proved to be difficult to the point that productivity was negligible. Therefore we were particularly pleased when the Corps of Engineers was able to supply us with a 15-foot aluminum assault bridge, long enough to straddle the crevasse in which we were working. This bridge included a small hand-operated hoist works which permitted us to position a bos'n chair at any desired depth within the crevasse. Either Melbourne or I spent much of the summer strapped in that chair dangling in the crevasse while we installed our instruments.

Altogether we installed about 65 thermocouples at various locations in and near the crevasse. These were arranged so that we could read the temperature by using a potentiometer at the surface. Sufficient readings were obtained in 1955, and again in the summer of 1956, to permit us to map the temperature distribution around the crevasse, including the transient response to seasonal changes in the ambient temperature. These data were sufficient for computation of the heat flux vectors near the crevasse and in the snow bridge.

As an interesting illustration of the results that sometimes come out of scientific measurements, our temperature data provided the incentive for some of the personnel of CRREL to investigate a new scheme of crevasse detection. While inspecting our data, Lyle Hansen of that organization noted that our results indicated differences between the temperature of the snow surface over the undisturbed glacier and the temperature of the snow bridge over a crevasse. This temperature difference was slight, but it appeared that it might be sufficient to be detected by some recently developed infrared cameras. This has led to further studies and development of a thermal crevasse detector which exploits an infrared camera mounted in an aerial mapping plane. Although this work is still in progress and is partially classified, I can report that there is some prospect of a crevasse detector that may eventually replace the 10-foot probe rod.

Although our party obtained a few useful results, our efforts were brief and provided only a mere beginning to a better understanding of the mechanism of occurrence and growth of crevasses. As with many other problems involving arctic phenomena, a combination of scientific curiosity and defense needs will motivate still further productive research on crevasses and their detection.