Leaving Little America on February 5 we attempted to reach the coast in the second survey area, between Mt. Siple and the Thurston Peninsula. After much punching into the now new-forming ice, and listening to the disappointing reports of returning reconnaissance flyers, we regretfully gave up and headed for Marguerite Bay on the Palmer Peninsula. Here we visited with the Ronne Expedition and his British neighbors at Grahamland. On February 28th we headed north, aiding Ronne's "Port of Beaumont" through the pack to open water; then leaving their slower craft, we set course for Peru and our first glimpse of civilization in four months.

ANTARCTIC SURVEYING*

E. L. Merritt, U. S. Naval Photographic Interpretation Center

MR. PRESIDENT, Ladies and Gentlemen, Guests, and Fellow Members: I don't know of a group of people to whom I would rather speak than the American Society of Photogrammetry, and I don't know of a subject I would rather speak on than surveying in Antarctica.

The accomplishment of any large survey operation is preceded by the development of an operational plan. Under normal circumstances this plan is based on facts determined from reconnaissance. Planning a survey operation without the benefit of reconnaissance and without a complete guide is very difficult, and is a tremendous responsibility when lives and equipment are involved in the execution of the operation. This is particularly true of a survey conducted in Antarctica. Generally, there is sufficient latitude and flexibility in a survey operation to permit errors in judgment without serious jeopardy to men, equipment, and over-all objectives. Where there are many unknown variables, it is necessary to anticipate, and therefore prepare for, an operation in its entirety, down to the most minute detail. This has been a fundamental principle with all explorers.

I want to emphasize at the start that our responsibility of making the survey observations was, relatively speaking, an easy one. It was not difficult primarily because of the precedents established by, and the sacrifices made by such men as Scott, Shackleton, Mawson, Amundsen, Wilkes, Admiral Byrd, and others. Moreover, if we had not had efficient, sturdy ice-breakers commanded by Naval Officers experienced in the lore of ice-navigation, we would never have cut the distance between ship and survey point down to the safe range of the helicopter. If we had not had helicopters aboard manned by skillful Naval pilots, at least half of the survey points would have been inaccessible to us by any other means of transportation.

With your permission I am going to digress a moment to bring out a point—a bit of fundamental philosophy that I believe is vividly embodied in the story of Antarctic exploration. The philosophy is this: The present state of knowledge embodies all the sacrifices and all the contributions of our predecessors. Our mission was made less difficult because of these sacrifices and these contributions.

Let us briefly review Antarctic exploration. Ross, figuratively and literally being the first to break through the Antarctic ice pack, blazed the trail to all subsequent observations of the Antarctic coastline. He established the precedent for navigating through the ice pack; and further, up to and including his date,

* By permission of the Commanding Officer, U. S. Naval Photographic Interpretation Center. Paper read at American Society of Photogrammetry Annual Meeting, Washington, D. C., January 13, 1949.

Antarctic exploration was limited to navigating ships through the ice pack and shipboard observations. Ross, Wilkes, and others are representative of the first phase of Antarctic exploration.

Then commencing with Borchgrevink and Scott, and including Amundsen, Shackleton, and Mawson, we have a second phase consisting of an extension of the first phase in the form of land exploration by sledging parties and an almost religious collecting of data on clothing, diet, transportation, glaciology, meteorology, geology, and many related physical sciences from winter bases ashore. The precedent established in the first phase became the spring-board to the new set of facts established by the land-based type of exploration. During Shackleton's expedition, the first efforts were made to use motorized transportation on the Antarctic continent, to use wool and wind-proof burberry clothing in place of fur, and to use Manchurian ponies for drawing sledges on the trail. During Mawson's expedition man-hauling was tried with some success. Amundsen found dogs to be the best means of drawing sledges, as attested by the fact that he outdistanced Scott in the dash for the South Geographic Pole.

Finally we have the third phase of Antarctic exploration which incorporated the best of the precedents established in the previous two phases plus many innovations, the greatest of which was the aircraft. I think we can generally agree that Admiral Byrd is the greatest exponent of what might be called modern exploration. He was the first to employ the airplane for ice reconnaissance and for Antarctic exploration on a large scale utilizing both land and ship-deck bases. I feel that he anticipated the use of the helicopter in conducting the test of the autogyro during the 1933–34 expedition at Little America. He extended the beginning efforts of Shackleton, Scott, and Mawson to use motorized transportation over ice.

In reviewing the records of these men, three facts are indelibly impressed on my mind. First, each successive expedition made full utilization of all previous exploration experience; secondly, each successive expedition extended geographic knowledge beyond previous extensions; and thirdly, each successive expedition systematically verified, where possible, data observed by previous expeditions. For example, we find Scott utilizing Ross' Antarctic experience, extending Ross' observations inland, and verifying Ross' observations. Later we find Shackleton utilizing, extending, and verifying Scott's observations, and Scott returning still later and pioneering beyond Shackleton's greatest efforts. Contemporary with Scott's last expedition, Mawson was extending and verifying Wilkes' observations. In many cases the explorers gave their lives to extend the horizon of observed data. Antarctica is a saga of men who gave their lives to extend and verify observational data and methods—the story of men who either suffered indescribable hardships or died to enlarge the periphery of truth. This is why I sincerely believe the story of Antarctic exploration to be a symbol of truth, a magnificent example of the scientific method apparent in all progress and all research for the purpose of progress.

It is interesting to note here that from a very early date, photographic plates have been considered the infallible proof of the explorer's observations. As the science of photogrammetry developed, the explorer's geographical observations became correspondingly more faithful and more extensive. Photogrammetry as a tool of geographic exploration culminated in Operation Highjump and Task Force 39. The mission of Task Force 39 was also one of verifying previously observed data and in many cases extending beyond previously observed data. As I stated earlier, however, our problems were confined almost exclusively to those of surveying and transportation and therefore were not comparable in difficulty to those of our predecessors.

At this point I will briefly describe some of the problems encountered. Two factors were considered in the selection of any specific photographic detail to be surveyed: (1) accessibility, and (2) the quality of intervisibility. A point that was ice-free and snow-free and that could be reached by motor launch was preferred to one that required traveling over ice or snow. Of those points neither ice-free nor snow-free, the ones accessible to the weasel were preferable to those accessible only to the helicopter. The most common obstacles to weasel transportation were a high, deeply crevassed continental ice shelf and too wide and too numerous tidal cracks between the fast ice and sea ice bordering the continental ice shelf.

The second factor falls into three subdivisions which I shall give in the order of their suitability as astronomic stations: (1) a well defined station having intervisibility with distant features, (2) a well defined station having no intervisibility with distant features, and (3) a main station without detail having intervisibility with distant features.

From what I have just stated regarding the criteria for selecting detail to be surveyed, you might receive the impression that all survey points were selected only after we reached the ice pack. This is actually far from the truth. Mosaics were constructed from the Highjump photography by the Hydrographic Office. On these mosaics, all potential survey points were circled and numbered by the Hydrographic Office before we left Norfolk. Upon arriving in the area of survey operations, we employed the previously mentioned criteria in determining which of the many indicated points would receive first priority, second priority, or would be omitted entirely in the event of unforeseen difficulties.

Now I will touch briefly on the preparations for a survey in terms of weight, equipment priority, survival gear, and sequence of landing, along with the problems that made obtaining control very difficult for the observer. Time from Norfolk to the first point was spent in studying the Highjump photography for the most suitable of the selected survey points, assembling and conditioning the equipment, and planning the sequence of transporting equipment ashore.

I shall discuss specifically the following problems: (1) transportation of equipment, (2) application of the helicopter to triangulation, (3) acclimatization of survey gear, (4) factors affecting the precision of astronomic observations, (5) chronometers and chronometer error, related to horizontal and vertical control, (6) subtense bar baselines, (7) large diameter instrument mounts, (8) altimetry, and finally, (9) station identification.

1. *Transportation of Equipment*

During the anchorage at Samoa, a test flight was made in the helicopter to determine what equipment and personnel could be taken ashore on each of the different flights. It was soon realized that the weight-carrying capabilities of the helicopter alone fixed the items that could be taken ashore on the first and second flights. Position observations were considered the most important from the beginning; consequently, astronomic equipment and observers would of necessity comprise the first flight ashore. No other transportation was considered, because (1) both the weasel and the motor launch were capable of carrying the entire party and equipment in a single load, and (2) the helicopter was the only means of transportation not requiring a special set of conditions other than suitable flying weather.

The advantages of the helicopter for transportation of equipment and personnel on this type of survey are fairly obvious. Since ground reconnaissance is impossible and since office reconnaissance through the study of photography gives no information regarding the change in ice conditions, the aircraft must be capable of a deliberate controlled landing in the smallest possible area. This eliminates all but the helicopter type of aircraft.

The maximum load is the maximum permissible total weight of the pilot, passengers, cargo, baggage, and fuel. The maximum load of the helicopter was 1,129 pounds. Based on the test flight in Samoa, a check-off list was made that was used on each of the helicopter-transported points in which the survey parties participated. The pilot weighed 220 pounds and the required number of gallons of gas weighed a minimum of 480 pounds, which meant that the helicopter was 160.5 pounds overweight on the first load and 214 pounds overweight on the second load. This was possible largely because of the increase in the helicopter's lifting capacity in the Antarctic atmosphere.

2. *Application of the Helicopter to Triangulation*

An attempt was made to employ the helicopter to extend control by two observers' cutting the helicopter simultaneously from oppsoite ends of a baseline when the helicopter was hovering over a natural feature selected from a mosaic. The method was unsuccessful at Bunger Islands because of the absence of communication between observer and pilot. The second trial was conducted at Little America with but meager success, for the same reason plus several minor ones. The observer was unable to determine when the helicopter was hovering and when it was moving in a straight line away from the observer. Without communication, the observer had no knowledge of when the helicopter was supposed to be over the point. It was felt that observing the helicopter with theodolites from fixed ground positions would be a suitable method of extending photo control rapidly if some means of intercommunication between observer and pilot had been employed.

3. *Acclimatization of Survey Gear*

Large temperature changes in a short space of time alter the rate of chronometers and have a detrimental effect on the accuracy of precise instruments. In order that the equipment used ashore would not undergo a violent temperature change from ship to shore and vice versa, all survey gear was lashed on the port side of the boat deck a month before the first landing was made.

4. *Factors Affecting the Precision of Astronomic Observations*

The greatest single obstacle to moderately accurate position, latitude, and azimuth observations, outside the fact that high precision cannot be obtained from measurements made on the sun, was tripod instability when the observations were conducted on snow or ice, and the resulting difficulty of keeping the level bubble centered. Had the temperatures been around zero or lower, it might have been possible to freeze the tripod in place, but, at the existing temperatures, the pressure of the metal tripod leg tips against the ice was sufficient to cause additional melting and subsequently differential sinking of the tripod. No matter how carefully the various instruments were leveled, the level bubble would have crawled half the length of the vial before a single set could be completed. This difficulty was most critical with the zenith measurements for position and latitude. Each graduation of the Wild T-2 level vial is 4 seconds. Four seconds of arc multiplied by from four to six graduations throws the position off nearly a half-mile. Ration boxes, skis, snowshoes, and various pieces of plywood were placed underneath the tripod legs at subsurface level in an effort to reduce the pressure per square inch exerted by the instrument. These various devices were unsuccessful simply because they displaced too much area and therefore were affected more readily by differential melting and the movement of the observer about the tripod. The pressure of the observer's feet against the snow exerted a force downward and outward that was unavoidably transferred to the tripod supports.

Thus it was realized that what was needed in place of a device having a wide displacement was one having a very small displacement and depending rather on linear depth to provide sufficient friction surface to resist downward pressure of the tripod legs. On this premise three metal stakes were made of 1-inch copper tubing. They were cut into 30-inch lengths with one end hammered into a wedge shape and the other fitted with a reducer to receive the tripod leg tips. The stakes provided minimum resistance to downward pressure exerted by the observer's feet and maximum resistance to the downward pressure exerted by the instruments.

In using the stability stakes, it is necessary first to set the tripod up to find out about where to sink the stakes by the holes made. The stakes are then sunk to just below the surface with a slant that will roughly correspond to the tripod legs produced. These stakes were used to support the tripod during a continuous 24-hour astronomic observation made at Little America, and the level bubble did not deviate from center any more than when the tripod was mounted on rock.

Sun visibility as a problem was second only to tripod stability. Sir Douglas Mawson calls the Australian sector of Antarctica the "Home of the Blizzard" and claims it to be the windiest place in the world. Our experience would seem to substantiate his claim. At the first point the sun was observable three hours out of five days. During that time, the sun was frequently visible to the naked eye but not visible through the telescope. Generally, at all landings the entire range of filters was used. When the sun was brightest, the black filter was used; when thin clouds moved between the sun and telescope, the black filter cut out too much light and the red filter had to be used. A few more clouds required a change from red to blue, and still more clouds from blue to green, and so on down to the point where the clouds themselves provided a filter and the sun was viewed without the aid of a filter.

At first, I was baffled by the phenomenal change of the sun's well defined disk when viewed with the naked eye to simply a more brightly illuminated area in the sky when viewed through the telescope. Additional observations showed that snow flurries high in the sky evidently dispersed the light but but did not refract the light. Magnification amplified the dispersion of light and therefore gave the effect of a brightly illuminated area rather than a well defined disk.

5. *Chronometers*

A review of exploration prior to the advent of modern exploration shows chronometers and reliable determination of time to have been one of the most acute problems. The Hamilton chronometers used were mounted in metal, moisture-proof, non-magnetic, shock-proof carrying cases. This chronometer is one of the many items of astronomic equipment developed for field use by the Ground Control Division of the U. S. Army Engineer Board during the latter part of World War II. In general, this chronometer not only maintained a satisfactory rate aboard and ashore, but also a much better rate than the Gimbal-mounted chronometers. I stated previously that the chronometers were lashed on the weather decks a month before the first landing was made. These chronometers were exposed to severe blizzard conditions ashore with no apparent effect on the chronometer rate.

Chronometer Error

No time signals were obtained ashore. Weight limitations of the helicopter precluded the inclusion of a suitable radio receiving set in the list of equipment. Generally, the chronometers were compared with the continuous time signals put out by the U. S. National Bureau of Standards just before going ashore and immediately after coming aboard. To further insure that the chronometers would not be affected by inside warmer temperatures, earphones attached to an extension cord were passed through a porthole from radio to weather decks where the chronometer was lashed in place; in this manner, the chronometer error was determined at approximately the same temperatures existing ashore. Observations for position at unequal and dangerously large zenith distances did not justify obtaining chronometer error with a chronograph; nor would weight limitations of the helicopter permit taking a chronograph ashore.

Horizontal and Vertical Control

Control was extended locally by cutting natural features from the terminal stations of a random baseline measured with a Wild subtense bar. Where feasible, intermediate control was established by making a round of horizontal overlapping exposures on glass plates at the same terminal stations with a Fairchild Camera Transit. Vertical control was extended from the astronomic station by trigonometric methods, and the elevation of the astronomic station was determined by simultaneous readings on two matched Wallace and Tiernan altimeters.

6. *Subtense Bar Baseline*

Normally three men are required to measure a random baseline with one Wild T-2 theodolite and two subtense bars. One bar is used as a backsight and the other as a fore-sight. By a procedure of leap-frogging, only the back-sight bar tripod is moved for each successive leg. In this manner each distance angle is observed reciprocally and the necessity of establishing intermediate bench marks is removed. In snow-free areas, the bar traverse was rapidly accomplished, required a minimum of personnel, and gave sufficient precision. These advantages, however, were lost in crevassed areas because a man secured to each of the three observers by a 120-foot rope was required. We soon realized that a 100-foot chain was more suitable in crevassed areas because the separation of front and rear chain-man was just slightly less than that of the 120-foot alpine rope. In this manner, two men could measure a baseline, providing security for each other, where six were required with the subtense bar on the same type of surface. Furthermore, the more crevassed areas were correspondingly more inaccessible, and therefore the weights of separate pieces of gear received more consideration. A chain weighs about 2 pounds, whereas two bars and two tripods total 56 pounds. This is equivalent to ten days' rations for one man—an important consideration where the permissible amount of food covered only five days per man.

In general, the bar is not the most satisfactory means of measuring a baseline in crevassed areas where weight of equipment and number of personnel must be reduced to a minimum. Then, too, tripod instability introduces errors in the horizontal angles that are not critical in the azimuth measurements but are very critical in the distance measurements.

7. *Difficulty with Large Diameter Instrument Mounts*

At those stations where the amount of detail warranted obtaining supplemental control, a camera transit was used. One of the main difficulties encountered with the camera transit is the large thread mount on the case base and on the tripod head. The threads collected minute quantities of moisture which froze to both the case head and the tripod head. In temperatures between $+10°$ and $+20°$F., two men would be able to remove the instrument from its case base only after tapping it and applying heat provided by a lighted Coleman stove. Then after the station was occupied, the observer and recorder were confronted with the same problem all over again. This problem was never experienced with the Wild theodolite, in case or with the center screw on the tripod. The Wild is held in place on its case mount with three rectangular bakelite slides; the slides seldom froze, and when they did they were easily snapped free. Similarly, the center screw of the Wild being sufficiently small in diameter, any freezing was easily broken free with normal rotation strength of one hand.

I believe there is considerable advantage in instruments used in polar surveys being tripod- and case-mounted like the Wild T-2.

8. *Altimetry*

Lack of time, weight limitations, and a large permissible error precluded both the use and the necessity of differential leveling as a means of obtaining elevations. Furthermore, at half the stations the physical barrier of an ice shelf, sea ice, and crevasses, made running any kind of level line from sea level datum impractical, even if the former objection had not existed. For this reason, it was feasible to determine the elevation of the main stations by two precise Wallace and Tiernan altimeters being observed simultaneously: one aboard at a known elevation and one ashore at the main station. Since it was impossible to predict when the observer ashore would be taking a reading, it was necessary that the observer aboard commence reading soon after the helicopter took off and continue to read at convenient specified intervals until the helicopter returned. Thus the observer ashore read the altimeter and temperature soon after landing so that the altimeter could be returned with the pilot. Each helicopter flight provided a pair of altimeter readings that were obtained by matching the time of the readings ashore with the corresponding time of the continuous set of readings aboard. The difference in altimeter readings corrected for temperature and added to the elevation of the altimeter aboard was the calculated elevation of the main station ashore. From four to six independent values were obtained at each point reached by helicopter. These values did not have a spread exceeding 10 feet. To say that the main station was accurate to 10 feet would be absurd; but at least there was a consistency among the independent values at each point.

Two-base altimetry investigated by Professor Kissam of Princeton and Professor Church of Syracuse had no application here. The two-base method requires that a third mobile altimeter be bracketed by simultaneous readings on two additional altimeters: one at a lower known elevation and another at a higher known elevation. No elevations ashore were known at any of the helicopter points.

9. *Station Identification*

Positive identification of the stations eatablished on Highjump photography was undoubtedly the most difficult problem confronting the shore party leaders. The difficulty was alleviated in a measure at those stations established in snow-free areas. In featureless snowbound areas identification of the control points on Highjump photography was next to impossible. It was difficult because the detailed ice features had altered or vanished and only the most generalized outline of last year's pattern remained. That is why the area of the control was not too difficult to identify. Generalized configuration of the shoreline is approximately the same from year to year, while the individual crevasses and icebergs change from month to month; if they did not change, the sameness of ice features and lack of contrast in exposures of snow would make pin-pointing an ice feature extremely difficult.

At Station Elaine, the station identification was not achieved until after all phases of the survey operation were completed and then only after encircling the main station at a radius of 10 miles on foot, with photographs in hand. It is rather an empty feeling to realize after the survey is completed and it is nearly time to return, that you don't have the vaguest idea where the stations are on the photography. Four of us spent $6\frac{1}{2}$ continuous hours identifying Station Elaine on the Highjump photography. And we haven't to this day located Station Edisto on the Highjump photography.

I believe I have covered the problems that gave me the greatest difficulty. In closing, I would like to say that I am indebted to the Hydrographic Office, and in particular to Mr. Medina, for the opportunity to participate in an Antarctic survey. I am also grateful to Mr. Lundahl for inviting Mr. Medina's attention to my interest in exploratory surveying. If you have enjoyed listening a fraction as much as I enjoyed participating in the operation, I am indeed happy.

TRIMETROGON PHOTOGRAMMETRY—SOME USAGES IN THE PREPARATION OF THE CANADIAN AERONAUTICAL CHART

Cecil B. C. Donnelly, D.L.S. Chief of the Aeronautical Chart Section
Legal Surveys Division, Surveys and Mapping Bureau, Ottawa

EDITOR'S NOTE: The following paper is an adaptation from Mr. Donnelly's address at the Annual Meeting of the American Society of Photogrammetry, January 13–14, 1949. During his address Mr. Donnelly used numerous slides to describe procedures used in Canada. Although this paper is not illustrated, the descriptive information concerning the procedure is retained. Mr. Donnelly prefaced his address with an expression of appreciation to United States personnel for their cooperation in the early development of trimetrogon photography and its compilation.

THE flight lines for trimetrogon photography used in the preparation of Canadian Aeronautical Charts are meridians spaced 16 miles apart at the mean latitude of the operation map. Meridians are employed to simplify the operation of the solar navigator, with which trimetrogon aircraft are equipped. This obviates the necessity for time corrections made necessary when flying angularly to the meridian.

As an example of the flight accuracy attained by the use of the solar navigator in the hand of a skillful operator, several flight lines as long as 170 miles have been flown with a maximum plumb point deviation of $\frac{1}{2}$ inch from a straight line joining the terminal plumb points.

Complete film reports accompany each roll of film received from the R.C.A.F. The data shown include camera number and focal length, magazine number, the type of film, emulsion and filter used, exposure time, the geographic coordinates of the beginning and end of each flight, and visibility and haze conditions during the flight. The reports also give altimeter readings reduced to elevations above mean sea level.

The fiducial marks are fixed to the camera body and are thus an integral part of the optical system. They are located precisely in the focal plane. A con-