THE PREPARATION OF A RECONNAISSANCE MAP COVERING THE COASTS OF WILKES LAND AND ADJACENT COASTS IN ANTARCTICA

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General.

As an illustrative example, there is described here the preparation of a reconnaissance map for the coasts of Wilkes Land and vicinity, in Antarctica. The assembly and analysis of preliminary data are taken up in roughly the same order as that in which they are discussed in Part 1 (1).

Actually, the mapping project of which this was a part covered a revision of the coastal areas lying to the east and the west of Wilkes Land, as well as those of Wilkes Land proper. In its entirety, it included all coastal regions of the Antarctic Continent from about Lon. 86° 00' E. to 143° 30' E. This is the portion which fronts on the Indian Ocean. Its west end lies just west of Gaussberg, in the Wilhelm II Coast, and its east end just within the western limits of George V Coast. It embraces in order, from west to east, the coasts now known as Wilhelm II, Queen Mary, Knox, Budd, Sabrina, Banzare, Claire, Adélie, and the west end of George V Coast, roughly an expanse of about 1,400 miles.

It is not possible, within the confines of the present paper, to include a map showing the general limits and details of the whole project. These are now delineated on two new charts:

(a) U. S. Hydrographic Office Chart 2562; 1 :11,250,000; 3rd ed., Oct. 3, 1955.

(b) American Geographical Society « Antarctica » chart in four sheets; Sheet 4, 1 :3,000,000; 1st ed.; February 1956.

Fig. 1 of Part 1 illustrates, to a very small scale, the outline of the coasts from about 95° E. to 150° E. An excellent overall picture of the areas mentioned here, and their relation to the remainder of Antarctica, is given by the layout on pages 436 and 437 of the October 1947 issue of the National Georgraphic Magazine.

Previous Exploration and Background Information; Available Maps and Charts.

The region described was first visited in January 1840 by the French expedition under J. S. C. Dumont d'Urville, who roughly charted the coast from about Lon. 133° E. to 142° E. The United States Exploring Expedition under Lt. Charles Wilkes, USN, visited the area in January-February 1840, making two sketches of the coast in about Lon. 106° 18' E. and 140° 16' E. This expedition roughly charted a discontinuous series of coastal landfalls between about 95° E. and 142° E.

(1) See *Intern. Hydrog. Rev.*, Vol. XXXIII, No. 1, May 1956, pp. 141 and ff.

At the turn of the present century, a small section of the coast in the immediate vicinity of Gaussberg, an isolated coastal nunatak, was charted in February 1902 by the German expedition under Dr. Erich von Drygalski. The position of Gaussberg was determined astronomically to lie in 66° 48' S., 89° 19' E. Running surveys were made during 1912-1914 by the Australasian Antarctic Expedition under Sir Douglas Mawson in the coastal areas between about 88° E. and 101° E., and between about 137° E. and 152° E. The position of Cape Denison on George V Coast was determined to lie in Lat. 67° 00' S., Lon. 142° 40' E.

The principal maps and charts resulting from these explorations, containing *original data* of value to the modern mapper, were :

(1) U. S. Navy Historical Chart 70, « Chart of the Antarctic Continent Shewing the Icy Barrier Attached to it, U.S. Ex. Ex., Charles Wilkes, Esq., Commander, 1840 » ; U. S. Navy Hydrographic Office, Washington, 1875ff. Scale 1 : 4,350,000 (approx.) on the Antarctic Circle.

(2) Dumont d'Urville, J., « Voyage au Pôle Sud et dans l'Océanie sous le commandement de J. Dumont d'Urville », Gide et Cie, Paris, 10 volumes in 5 books.

(3) Wilkes, Charles, « Narrative of the United States Exploring Expedition », Lea and Blanchard, Philadelphia, 1845; 5 volumes.

(4) Vincendon-Dumoulin, C. A., « Atlas hydrographique du voyage au Pôle Sud et dans l'Océanie sous le commandement de J. Dumont d'Urville », au dépôt général de la Marine, Paris, 1847; 57 charts.

(5) Drygalsky, Erich von, « Deutsche Südpolar-Expedition, 1901-1903, Scientific Reports », Berlin, 1905ff.

(6) Davis, J. K., « With the *Aurora* in the Antarctic, 1911-1914 », London, A. Melrose, Ltd., 1919.

(7) Mawson, D., « The Home of the Blizzard », J. P. Lippincott Company, Philadelphia, 1915; 2 vols.

(8) Mawson, D., « Geographical Narrative and Cartography, Australasian Antarctic Expedition, 1911-1914 », Scientific Reports, Series A, Vol. 1, Government Printer, Sydney, 1942.

(9) U. S. Navy, Task Force 68, 1946-1947, Flight Index Sheets, Western Sector (« Polar Air Navigation Charts » prepared by Navy Hydrographic Office in which Inverse Mercator Projection plotting grids were superposed on Army Air Force 1 : 3,000,000 Long Range Air Navigation Charts).

(10) U. S. Navy, « Report of Operations, Second Antarctic Development Project, 1947-1948 », Task Force 39, U. S. Pacific Fleet, Washington, 1948; one volume.

(11) Expéditions Polaires Françaises. « Expédition en Terre Adélie, 1949-1951 » ; also « Expédition en Terre Adélie, 1950-1952 » ; série scientifique, rapports préliminaires, E.P.F., Paris, 1952; Nos. 14 and 20, respectively.

(12) In the course of the work, there was received from the Expéditions Polaires Françaises a provisional map entitled « Terre Adélie », published by

the Institut Géographique National in 1952, embodying new data derived by them from an analysis of the USN Operation Highjump photographs. This map was not actually received until 26 October 1953.

The coasts of Wilkes Land were, in the 1947 version of U.S.H.O. chart 2562, in the same extremely sketchy condition as when Wilkes left them, over a hundred years before. This was the situation when U. S. Navy Operation Highjump, Task Force 68, undertook to make aerial photographs of the whole coastal area in January-February 1947. The Western Task Group, under Captain C. A. Bond, USN, covered the coastal area between Lon. 86° 00' E. and 143° 30' E., a large portion of the offshore ice, and selected portions of the continent with a practically continuous array of trimetrogon aerial photographs.

It may be pointed out that the reconnaissance mapping project described here was begun at least five years after the Operation Highjump aerial flights and photographs were made. The mapper had no hand in the planning of the flights and was often handicapped in assembling factual data, because of the dispersal of the flight personnel and the extremely low priority of the subsequent mapping projects in the agencies concerned with storing and preserving the material.

In January and February 1948, U. S. Navy Task Force 39, in Operation Windmill, visited a portion of this area and established nine astronomical control stations along the coast between Lon. 89° 49' E. and 110° 26' E. This group also obtained vertical mapping photographs of two ice-free areas in the Bunger Hills [Nat. Geogr. Mag., Oct. 1947, pp. 452 and 475], lying in about Lon. 100° 55' E., and in the Windmill Islands (about 110° 26' E.).

Three French expeditions under the direction of Expéditions Polaires Françaises, which were stationed on Adélie Coast during 1950-1953, surveyed portions of that coast and obtained astronomical control at eight stations in the area between 136° 42' E. and 142° 40' E. However, the westernmost control point available to the authors during the plotting of the reconnaissance map was Lion Islet (to the north of Pétrel Island) in Lon. 140° 01' E. The astronomical fix at Rock X, in Lat. 66° 20' S., Lon. 136° 42' E., was not known until the map was essentially complete.

Available Ground-Control Data.

Without going into detail at this point, a brief review of the geographic data shows that ground control was available only at the ends of the coastal area under study, namely in the regions from Lon. 89° 19' E. to 110° 26' E., and from Lon. 140° 01' E. to 142° 40' E. The gap from Lon. 110° 26' to 140° 01' was, as indicated in Fig. 1 of Part 1, entirely without ground control.

Final correction of the 1948 ground-control data was made by the U. S. Navy Hydrographic Office following publication of the official report of the Second Antarctic Development Project, otherwise popularly known as USN Operation Windmill.

As mentioned previously, the position of Rock X in Lon. 136° 42' E., as determined by the French in December 1952, was not received in this country until after the Wilkes Land reconnaissance map had been essentially completed. The field position in Lon. 138° 43' E., reached by the French in December 1951, was not utilized in this compilation, as no distinctive features lay in this immediate vicinity. Thus the success of compiling a reconnaissance map for the portion of the coastal area between Lon. 110° 26' E. and 140° 01' E., lacking ground control completely, was dependent upon the identification of a continuous chain of distinctive points or landmarks along the coast and a graphic extension of the plot from the control points into and across the uncharted gap.

General Data on Mapping Flights.

The photographic flight tracks had been plotted by USN Operation Highjump photographic personnel to a scale of 1 : 3,000,000 on Army Air Force Long Range Air Navigation Charts. These plots, based entirely on dead-reckoning data, gave:

(1) The starting and finishing times of each film run;

(2) The direction of flight along the plotted path;

(3) The observed drift (incomplete coverage);

(4) The wind force and direction;

(5) The estimated ground speed;

(6) The estimated air speed;

(7) The airplane altitude;

(8) The radio altitude (height above terrain);

(9) The temperature;

(10) Remarks, such as: climbing, camera failure, radar fix, sun fix.

The general plan followed by the USN Operation Highjump pilots was to make short photographic runs essentially parallel to the coast. Whenever a significant bend in the coastline was noted, the cameras were shut off while the airplane changed its course by making a complete outside circle (in a direction away from the turn in the coast if they were flying over water), abreast a prominent landmark which had been photographed at the end of the first part of the run. The pilot then attempted to follow a new course essentially parallel to the next segment of coast line. The second photographic run would begin early enough to include the prominent landmark which had been photographed at the end of the first run. If this maneuver was carefully executed, one or more vertical photographs in the second photographic run would intersect and overlap one or more verticals in the first run.

The approximate length of the « photographic » portion of each flight track, that is, the portion during which the cameras were running, was obtained from inspection of the flight-log data and from a combination of the recorded ground speed of the airplane with the elapsed time that the cameras were in operation. This length, as computed for each photographic run, was laid down at a scale of 1 : 1 million on a small sheet of paper, which for purposes of discussion will be termed a corrected flight-track sheet.

Although many of the uncorrected photographic flight tracks were shown by straight lines in the index sheets prepared by USN Operation Highjump personnel, nearly all the « straight » tracks proved to have significant jogs and curves when corrected by the procedures to be described subsequently.

Fortunately, in addition to the photographic runs tied together by the common landmarks previously mentioned, many of the tracks on entirely separate flights crossed each other. If this occurred while the cameras were in operation on each run, the actual crossing point (on the earth) could be found by a careful search for a given feature on one or more verticals of each run. The serial numbers of the prints on each run which showed the geographic feature(s) photographed on both sets of verticals gave clues as to just where along each flight track the crossing took place.

The flight tracks covered in USN Operation Highjump are shown in the map on page 467 of the National Geographic Magazine for October 1947. This layout is somewhat complicated, however, by showing the tracks to and from the base ships, as well as the actual photographic flight tracks. Photographic coverage was limited primarily to the immediate coastal areas; coverage of interior areas was generally limited to short, intermittent, photographic runs.

Direction of Camera Relative to Airplane.

All the regular aerial photographic exposures were made by 3-unit trimetrogon camera assemblies, fixed in the airplane, as shown in diagram 2 of Fig. 2 of Part 1. The camera axes were assumed to lie all in the same transverse plane, normal to the airplane axis.

A not inconsiderable number of « views » were made at low altitudes with hand-held cameras; one such view is reproduced in Fig. 16 of Part 1. In general, these views were used for delineation of the topography and not for map plotting. They were particularly helpful in scattered areas where heavy cloud cover partly or wholly obliterated significant topographic details.

Times of Exposure, Numbering, and Identification of Photographs.

For the 3-unit trimetrogon camera assemblies used on USN Operation Highjump, the instantaneous data for all three cameras was taken photographically on what is known as a « gremlin » recorder. This is a photographic instrument which records on 6-inch by 6-inch units of roll film the time, the airplane altitude, and the airplane roll or tilt (right or left) at each instant that the trimetrogon cameras are actuated simultaneously.

The altitude readings correspond to the airplane altitude above sea level as a reference, by uncorrected barograph. Sporadic readings were made by the flight personnel of the height above the ground (or the ice) underneath, using the electronic altimeter.

There is no direct or automatic tie between the « gremlin » record and the individual film rolls in the three cameras. All are started at the same time and they presumably keep step with each other.

After exposure and developing, the *first* and *last* negative on each roll (for each photographic run) was marked in india ink with identifying data as follows:

(1) Print number;

(2) View direction, either left, right, or vertical in trimetrogon assemblies, but often a general compass direction, such as south or southeast, in hand-held obliques;

(3) Mission (or flight) number;

(4) Roll number;

(5) Section of operations. The Wilkes Land coverage was the responsibility of the Western Task Group of USN Operation Highjump;

(6) Date;

(7) Time of exposure, Greenwich civil time;

(8) Calibrated camera focal length;

(9) Airplane altitude.

Each successive negative was marked with a consecutive aerial number, followed by the number of the photographic run in that particular mission. Thus the negative of the print reproduced in Fig. 9 of Part I was marked « 33/1 »; that of Fig. 12 as « 124/1».

The term « run » indicates a period during a photographic flight when the cameras are operating. Should the cameras be stopped at times during a photographic flight, the latter would consist of two or more « runs », numbered in sequence. The precise times that the cameras are in operation is noted in the flight log, though occasional errors occur, understandably, because of adverse temperature conditions.

Selection and « Pointing » of Landmarks.

The map compiler should, by examination of existing maps and records, by repeated examination of the aerial photographs, and by working over the preliminary master plotting sheet described subsequently, become as familiar as possible with the area before the detailed analysis of the photographs and the map plotting begin. The greater the number of important geographic features that can be recognized early in the compilation process, the faster will be the mapping progress.

The general practice in the bearing system of graphic analysis and map plotting is to select landmarks which appear in a large number of photographs. The positions of these distant features, when derived with reasonable accuracy by three or more intersecting rays from different air-exposure stations (positions along one or more photographic flight tracks where photographs are taken), serve as extensions of the original ground control. However, in selecting distant landmarks it must be borne in mind that the angles between the intersecting rays become increasingly smaller as the distance to these landmarks increases. It is often difficult to estimate the precise point at which these longer rays intersect. On the other hand, the error involved in the use of intersecting rays increases when the landmarks selected for plotting purposes lie too close to the flight tracks and too close to each other. Small discrepancies in the positions of the intersecting rays accumulate with distance along the flight path, even when the preliminary plotting scale is large. Unfortunately, the mapper must take the landmarks as he finds them.

For the USN Operation Highjump photographs, taken landward toward the high interior of Wilkes Land, the selection of usable landmarks or indeed of identifiable features for bearing-plot or triangulation purposes posed an extremely difficult problem. Notwithstanding that most of the « hinterland » is covered by a thick continental icecap containing innumerable rolling « hills », there are stretches of hundreds and hundreds of miles in this region without distinctive or individual features. The building up of an extensive pattern of bearing lines

Fig. 19

Typical USN Operation « Highjump » Aerial Photograph showing Sea Ice and Bergs in Foreground, Coast Line, and almost featureless « Hinterland » beyond.

This photograph was taken in a southerly direction, toward the high interior of the continent, from the position marked « 22 » on the eastbound flight track of Fig. 20. It shows ice-filled Victor Bay, at the west end of Adelie Coast, in about Lon. 136° E. At the extreme left of the photograph is the Commandant Charcot Glacier. The shore line is clearly visible, despite the conglomeration of large and small bergs, sea ice, and open water filling the bay. The heavily crevassed regions in the center middleground indicate steep slopes rising from the shoreline and high land immediately behind.

for carrying the ground topography forward from an area of known control points, such as had been found so successful in making the reconnaissance map of Byrd's Eastern Flight from Little America on 5 December 1929 (Geogr. Rev., Apr. 1933, Vol. XXIII, No. 2, map opp. p. 208), was out of the question.

It became necessary, therefore, in the mapping process, to try crawling forward by short steps, as it were, hoping by this means to check (or modify) the uncorrected flight-log data. There was a distinct lack of nunataks or rock outcrops or off-lying islands in much of the area, particularly in the large central sector where the ground control did not exist. This meant that a laborious study of distinctive ice-crevasses, small protrusions on the coastal ice cliffs, and indistinctly defined coastal features lying beneath the continental ice had to be undertaken to provide a continuous set of geographic features by which to carry the plotting forward from point to point. Fig. 19, showing the Victor Bay portion of Adélie Coast, just west of Commandant Charcot Glacier, is typical of one of the better photographs with which the authors had to deal.

Normally the map compiler, interested primarily in the permanent land areas, would show little or no interest in sea-ice conditions in the polar regions which vary from year to year because of the seasonal melting and crystallization. In many cases, however, the only objects identifiable in a series of Wilkes Land aerial obliques were ice features of this kind, useful for map delineation as of the date of the flight but of questionable permanent value. Compilation of numerous small sections of the map was, of necessity, based upon the identification and consequent plotting of features such as tilted icebergs which protruded above the still-frozen sea ice fringing the coast.

Identification of « pass points », representing identifiable points common in two or more adjacent or nearly adjacent photographs which are used to tie together the photographs in one segment of a flight, and which are set down on preliminary marking plots of the map, proved to be very difficult, particularly with the vertical photographs. Distinctive crevasses and tilted icebergs in the frozen sea ice were used for pass points whenever possible. However, greatest reliance had to be placed upon elongated snowdrifts left by the last blizzard wind in the lee of small ice ridges known as kavler or zastrugi. Nearly all of the observed snowdrifts were oriented parallel to one another, as deposited by the prevailing southeast wind, and they resembled each other rather closely. This tedious inspection procedure has been simplified within the past year by the development of a new electronic reproduction process which permits much clearer prints to be made from existing negatives.

Only one set of good prints was available for much of the Wilkes Land coastal area and the adjacent coasts photographed by the USN Operation Highjump personnel. It was important, therefore, that the main portion of each print selected for analysis be left unmarked so that the topographic details would not be defaced or obscured for later inspection.

The pass points and other features selected for mapping purposes were numbered in sequence in the order of their selection. They were « pointed » by short arrows, drawn in pencil with a parallel ruler, and so aligned above each feature that the pencil marks would extend only a short distance down the upper edge of the point and would still remain well above the apparent horizon. Fig. 9 of Part I shows pointers which could be drawn rather close to the features, identified because of large areas of uniform ice shelf and sea ice. Over 900 geographic features in all categories were selected, numbered, and pointed in the large group of photographs covering the area of the reconnaissance map.

The most important part of this operation was the positive identification and pointing of the exact local features where astronomical observations were taken by the ground-control parties. Where, as in the present case, much of the ground control was obtained during the season following that in which the photographs were made, selected prints can and should be marked by the ground-control parties to show the exact position of the stations occupied. Examination of the Bunger Hills region in the photographs reproduced on pages 452 and 475 of the October 1947 issue of the National Geographic Magazine reveals an exasperating sameness about all the land topography. No detail plotting could be attempted until the ground parties had marked a set of these aerial photographs with their ground-control positions.

Print Sizes and Airplane Altitudes for Highjump Oblique Aerial Photographs.

The framed field in the trimetrogon cameras used by USN Operation Highjump measured 9.00 by 9.00 inches. In this connection there is one very important caution to be observed in case the mapper wishes to have additional prints made by personnel who are not well trained and well indoctrinated in this work. The wet paper prints cannot be rolled out for drying else they will stretch, resulting in a frame size that is larger than the screen in the camera. A grid of the correct size will give erroneous readings on a print that is too large.

Similarly, a grid constructed on film may be expected to shrink with time (one or more years) so that it will give erroneous readings if applied to a print of the correct dimensions. This is the reason for the use by some mappers of more accurate but more cumbersome grids printed on glass plates.

The range of focal lengths of the individual cameras used by USN Operation Highjump to take photographs over the Wilkes Land and adjacent areas was very narrow, from 152.2 mm. to 153.5 mm., equivalent to 5.9921 to 6.0433 inches. The calibrated focal lengths F of the cameras averaged 6.000 inches, and this value was used when calculating the data for the bearing and coordinate grids.

The range of airplane altitude during the several flights over the area covered by this reconnaissance mapping project was from 5,200 to 12,100 ft. However, most of the photographic runs were made at approximately 10,000 ft.

Details of Making and Using Bearing Grids and Plots.

Bearing grids were constructed for the combinations of airplane altitude and marginal distance as listed:

Altitudes, feet	6,000	Marginal distances, inch	1.375
	9,700		1.375
	10,400		1.4375

The grids in question, one of which is shown over an oblique aerial photograph in Fig. 9 of Part I (for $h = 9{,}700$ feet and $m = 1.375$ inch), cover angles of well over 30 degrees on each side at the true horizon and approximately 40 degrees on each side at midheight of the print. Bearings can easily be approximated to half-degrees; with a little care and experience, to the nearest 0.2 degree.

Use of the bearing grid in the analysis of oblique aerial photographs, and the coordinate grid as well, required that the position of the apparent horizon be determined by visual inspection on each such photograph. Since at an altitude of 10,000 feet the visible horizon at sea is distant some 115 nautical miles, it is sharp only in extraordinarily clear weather.

Hazy skies and cloud strata caused considerable difficulty in locating the apparent horizon in the photographs of the Wilkes Land coasts and adjacent areas. In many cases the best that could be done was to (1) determine the highest possible position of the apparent horizon, then (2) determine the lowest possible position on the print, and (3) estimate its probable position between the two.

As might have been expected it was easier to determine the apparent-horizon position in seaward views, where water or sea ice was present, than landward views, where the continental ice blended with the sky in the far distance.

Not only should the apparent-horizon (AH) marks on the bearing and coordinate grids be placed over the apparent horizon on the print, but the vertical centerline of the grid should lie over the principal point at the geometric center of the photographic print. This point is determined by the intersection of two short, lightweight pencil lines drawn between the pairs of opposite fiducial marks registered on every negative by the fixed screen in front of it. In the aerial photographs of the First and Second Byrd Antarctic Expeditions these marks were at the corners. In the USN Operation Highjump photographs they were at the midpoints of the sides, indicated in Fig. 16 of Part I and Fig. 19 of this part.

In case the marginal distance on the particular print being analyzed is not exactly the same as that of the bearing grid applied to it, the apparent-horizon lines (marked AH on the grid) are applied over the apparent horizon on the print, leaving some offset between the print center and the grid center. Care is taken, however, to place the bearing line for zero angle (the vertical trace of the principal plane on the grid) over the geometric center of the print.

About 800 bearing plots were made for the Wilkes Land project, using data derived from these bearing grids. Most of them were small, because of the lack of prominent and identifiable geographic features at medium and large distances.

Details of Making and Using Coordinate Grids and Plots.

Despite the existence of large areas of water or sea ice in many of the photographs, several preliminary « arm-chair flights » over the coastal terrain to be mapped revealed no areas of appreciable extent where coordinate plotting would offer the best method of preliminary map delineation. While extremely useful for small areas, it would have been tedious and laborious for the whole project. Later experience revealed that coordinate grids were most valuable for estimating distances from the plumb point to ice edges, to shore lines, and to other features lying at sea level.

Theoretically, the determination of correct distances in this manner calls for the use of plotting grids constructed for exactly the correct airplane altitude and marginal distance. However, lack of contrast and definition often made it difficult to « spot » accurately the feature being examined. Inability to see or to make sure of the apparent horizon on the print, when obscured by haze and clouds, necessitated an estimate of the marginal distance. Small changes in altitude involved changes in distance and position that were ridiculously small compared to the overall precision of the map.

It was decided, therefore, that despite a variation in marginal distance m of from 1 1/8 inch to 1 9/16 inch, and a variation in altitude h of from 5,200 to 11,200 ft, coordinate grids would be constructed only for the variables listed:

Altitudes, feet	6,000	Marginal distances, inch	1.375
	8,500		1.1875
	9,700		1.375
	11,500		1.375

On the coordinate grids made for the Wilkes Land project, one of which is illustrated in Fig. 12 of Part 1 (for $h = 9{,}700$ feet and $m = 1.375$ inch), distances along the principal plane of the camera could be read to tenths of nautical miles up to about 5 miles from the plumb point. Beyond that, and up to 10 miles, they could be read in half-miles or less; from 10 to 25 miles to about the nearest mile. Additional lines could have been added for reading distances at more than 25 or 30 miles from the plumb point but, placed close together, they would have interfered with the visibility of features on the print under the grid. At an airplane altitude of 9,700 feet, a marginal distance of 1.375 inch, and a depression angle θ of slightly over 29 degrees, the intersection O_G of the optical axis with the ground plane lay at a distance of 2.86 (nautical) miles from the plumb point. The field of view in the foreground and middleground is indicated in Fig. 12 of Part 1.

For the reconnaissance plotting described in this part of the paper, the coordinate grids were, as previously mentioned, used primarily for determining the distances from the plumb point (or the airplane track) to ice cliffs and other features along the shore, when viewed from seaward or when the shore line was visible.

Preliminary Master Plotting Sheet.

A sort of preliminary or master plotting sheet was first constructed, upon which there was sketched the existing map information, the approximate photographic flight tracks, the ground-control points, and the known geographic features.

The Lambert conformal conic projection, with standard parallels at Lat. 55° S. and 65° S., was selected because it maintained azimuthal directions and bearings better than any other projection suitable for this region. In this type of projection the features on the earth are drawn on the expanded surface of a cone which has its vertex on the earth's axis and which passes through the sea-level surface at the two standard parallels. Between these parallels the cone lies just under the sea-level surface and beyond them it lies just above that surface. The parallels of latitude are drawn on the map as perfect circles, with radii corresponding to the slant height of the cone at each parallel. The meridians are these radii, exactly normal everywhere to the parallels.

A scale of 1 : 1,000,000 was selected for several reasons. At the start of the project it seemed likely that the Aeronautical Chart and Information Center would express interest in incorporating the results of this study in revised editions of sheets 1751, 1773, 1774, 1775, and 1776 of the World Aeronautical Chart series at this scale and projection. Further, the ground-control data had been plotted by USN Operation Windmill personnel on this projection at a scale of 1 : 1 million.

Check and Rectification of Control Points and Photographic Flight Tracks.

It should be taken for granted by field personnel that all data turned over by them for the preparation of a map are to be thoroughly checked as a part of the map-making project. This is as true for a reconnaissance map as for any other kind. There are too many hazards involved in the observations of these data, especially in the polar regions, to leave the field worker with confidence that he has made no mistakes. Further, the field man, working in virgin country, knows nothing of its peculiarities, or what effect the strange conditions encountered may have on the accuracy of his work. By the time the mapper starts on his portion of the project he has the accumulated information from all the workers that were in the field.

Control points whose coordinates are proudly presented as accurate to tenths and hundredths of second of arc may have to be thrown out because the first phase of plotting with the aerial photographs shows them to be ten or more miles out of position. There is the case of the Prestrud data relating to the position of Scott Nunataks, on the Edward VII peninsula to the northeast of Little America. The fact that the text description and the chartered position of part of Prestrud's route differed by one whole degree of longitude left the mapper with considerable doubt as to the accuracy of the remainder of the data. Flight tracks may be represented as lying along the landward side of a shore line, when even a cursory examination of the oblique aerial photographs made on that run, looking toward the land, show the shore line in the foreground and are positive proof that the track was over water.

Two interesting situations of this kind arose in the plotting of the USN Operation Highjump flight tracks along the Wilkes Land coasts. At about Lon. 122° E., just east of Henry Bay at the east end of Sabrina Coast, the same geographic feature was found in the vertical photographs on three separate photographic runs. At a point just south of the Windmill Islands, at the west end of the Budd Coast, three flight tracks crossed over an area small enough so that another geographic feature was visible in the verticals of all three photographic runs. Nevertheless, the common intersection point in the first case lay 4 or 5 miles from each of the three flight tracks, as plotted from the dead-reckoning data. In the second case the common point lay between 13 and 14 miles from each of the tracks. Judged by distances from the base ship these variations are not unduly large but the geographic positions of the features visible in the photographs taken along these tracks cannot be reconciled until the shifts are made.

The relative positions of the vertical photographs showing the common intersection point, as compared to all the photographs taken during the run, indicate approximately where along each track the crossing took place.

A further discussion of flight-track intersections is found in a subsequent section entitled « Importance of Flight-Track Plotting ».

Simplified or Uncontrolled Mosaic Plotting Procedure.

With no recognizable distant landmarks on which to triangulate by the bearing method described in Part I and illustrated in Fig. 18 of that part, and with a series of identifiable coastal features that lay too close to the flight tracks for carrying the ground control forward in accurate fashion, a new method of reconnaissance plotting had to be devised. This indicates the ever-present need for the map compiler to maintain a flexible approach to his problems, and to develop additional techniques when necessary. One method employed for the long eastern coastal area of Fig. 1 of Part 1, devoid of any ground control, was the use of the vertical trimetrogon photographs to verify or correct the shapes of the dead-reckoning flight tracks.

The basic compilation in any one area, such as that covered by Fig. 20, was begun by laying out the vertical photographs in the principal photographic run in that area in what is called here a simplified or « uncontrolled » mosaic pattern. The mosaic is formed, in the usual manner, by laying out and superposing a series of verticals, matching the pass points and other features in the overlapping portions, as indicated in Fig. 5 of Part 1. It is « uncontrolled » in that it is uncorrected for any horizontal tilt to which the airplane (and the vertical camera) may have been subjected. As indicated for Case 1 of Fig. 5, in addition to swing or yaw in the horizontal plane, the airplane (and camera) may have had lateral tilt caused by dipping of one wing or the other, or longitudinal tilt caused by movement of the airplane nose, up or down. In photogrammetric engineering, rectification of this tilt is normally accomplished by photographic or machine methods. For the Wilkes Land compilation, in the nature of a reconnaissance map, rectification was limited to a visual attempt to match corresponding images while laying down and aligning the series of verticals on a floor composed of large square cork slabs. While, on the face of it, this method appears crude and leaves much to be desired in the way of photogrammetric rigor, it proved in fact to give results that were surprisingly good, as is explained presently. To be sure, the procedure required patience and accumulated experience on the part of the operator (the junior author) but the results appear to demonstrate that an acceptable layout can be achieved in this manner.

Before laying down the mosaic, the approximate length of the photographic flight track was computed from the recorded ground speed of the airplane (from the uncorrected flight log) and the time interval during which the cameras were operating. This length was laid down at a scale of 1 : 1,000,000 (the same as the preliminary work sheet) on a small transparent sheet.

Two direct measurements were made while the uncontrolled mosaic was still in place on the floor. The amount of lateral drift and the amount of crab or deviation of the airplane axis from the airplane track were determined at a number of significant places along each flight, using as a basis the dead-reckoning track of that flight. This measured drift and crab were then transferred, at the proper scale, to the small transparent sheet, giving in effect a corrected flight-track pattern at the same scale as the work sheet. Included in the « significant places along each flight », previously mentioned, were points where the crab appeared to be excessive, so that when bearing plots were laid down at these points along the track they would be oriented in azimuth at positions which were correct or nearly so.

Brief mention should be made of the two cases where, at the time of exposure of the vertical photographs, the airplane was flying (1) over open water or (2) over open-water areas with loose floating ice. In both cases the relative positions of the individual vertical photographs had to be tied in with information derived from the corresponding oblique photographs in the same flight. A rough estimate can be made regarding the general direction of the flight and the approximate amount of drift, in the case of a close concentration of identifiable floating icebergs, because practically no ice movement occurs during the few moments that a given

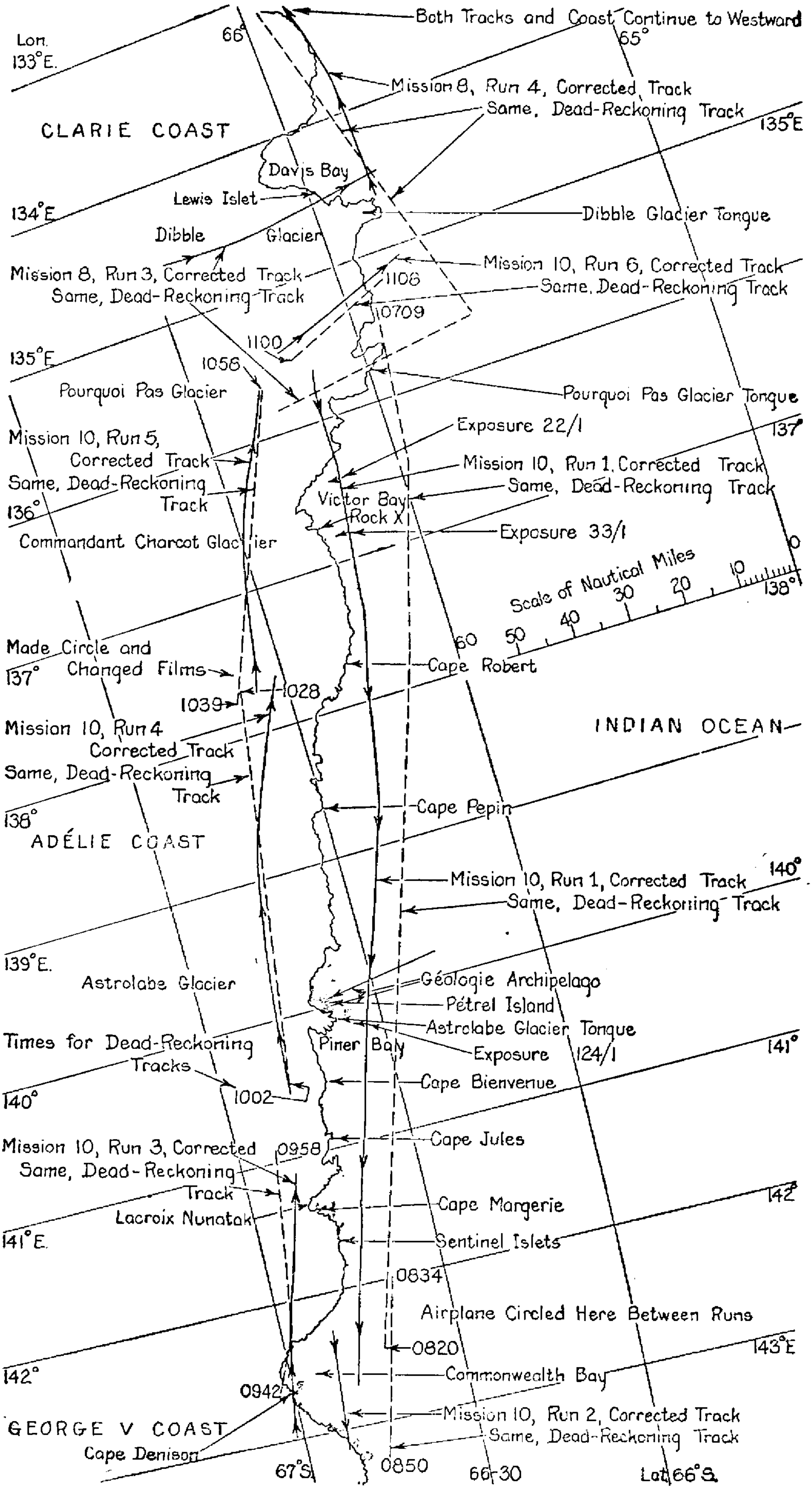

Fig. 20.

Sketch of the Adelie Coast, with portions of the adjacent coasts, showing uncorrected and corrected flight tracks and principal coastal features.

The uncorrected (dead-reckoning) tracks are in broken lines, the corrected tracks in full lines.

The north side of the map is arbitrarily placed on the right instead of at the top to permit the whole layout to be reproduced on one page.

iceberg lies within the combined field of a few adjacent vertical photographs. However, the lapse of slightly longer periods, such as between the outgoing and return portions of a flight, prevents the matching of image points because of the relatively swift movement of the ocean currents in some regions.

Comparison of the corrected flight tracks (solid lines) with the dead-reckoning tracks in Fig. 20 (broken lines) shows that significant position differences occur between many of the pairs of flight tracks. Perhaps even more noticeable are the differences due to large drift corrections between the dead-reckoning tracks and the corrected flight tracks.

Compilation Methods Employed for the Coastal Region Between Lon. 130° E. and 143° E.

A summary of the typical basic techniques employed in the compilation of the reconnaissance map of the coasts of Wilkes Land and the adjacent coasts can be embodied in a description of the methods employed in compiling that portion of the map between Lon. 130° E. and 143° E. This comprises the Clarie and the Adélie Coasts, carrying the Australian name Wilkes Coast and the French name Terre Adélie, respectively.

Inspection of the dead-reckoning tracks and flight index charts of the USN Operation Highjump photographic runs made in this area indicated that Run 1 of Mission (or Flight) 10, made on 26 January 1947, presented the best photographic coverage of the area. As shown by the broken line of Fig. 20, it began at 0709, ran in an east-southeasterly direction, and ended at 0820. One of the longest photographic runs made in the Wilkes Land area, it extended along Adélie Coast for about 178 nautical miles, from the vicinity of Pourquoi Pas Glacier to the entrance of Commonwealth Bay. Visual check of the 190 individual sets of photographic prints indicated that the Adélie Coast area could be mapped adequately from this offshore run.

There was consolidated sea ice under most of the run, so continuity was established by the vertical photographs, largely from inspection of tilted icebergs such as those pictured in Fig. 19. This was critical for the first half (west end) of the run, for which ground control was not available. Good continuity was established in the right oblique photographs showing the coastline to the south, except at the very beginning of the run, where the airplane flew over the land.

The vertical photographs for this run were laid out on the floor, as described in the preceding section. A flight-track pattern was prepared showing the drift, crab, and relative scale within the run itself, as well as the approximate scale computed from the flight-log information. Auxiliary plotting sheets were prepared on transparent paper showing all the ground-control points and the meridians and parallels of the map grid. It was apparent that progressive revisions of the existing area map would have to be made and it was believed desirable that the plotting sheets also serve as overlays.

At the start of the project a small working group of right oblique photographs had previously been selected from this run, in which landmark continuity had been established. The photographs in the latter half (east half) of the run, showing the ground-control stations as established by the French and the Australasian expeditions in the area between 140° 01' E. and 140° 40' E., were reviewed, and a few additional photographs were selected at the key locations along the flight track which were most nearly opposite the ground-control stations.

Right oblique photograph 164/1 was selected as one of these because it showed the Sentinel Islets, in 66° 47' S., 141° 12' E. Of all the features whose positions were reliably known this was closest to the flight track. The air-exposure station for photograph 164/1 was determined by coordinate-grid and bearing-grid methods to lie 3.6 miles, in a direction 12 degrees east of north, or 12 degrees true, from the Sentinel Islets. This air position was then laid down on the plotting work sheet. Both types of grid were used with successive photographs close to the east, and close to the west, to determine the directional trend of the flight track in this immediate area.

This process was then used to locate the positions of air-exposure stations, as well as the directional trend of the flight track opposite:

(1) Cape Denison in 142° 40' E.;

(2) Cape Margerie (site of the French Port Martin base) in 141° 24' E.;

(3) Cape Jules in 140° 56' E.;

(4) Cape Bienvenue in 140° 31' E.

(5) Pétrel Island (site of the French Géologie Archipelago base) in 140° 24' E.

The scale of the entire flight track pattern for Run 1 was adjusted in accordance with the plotted positions of these six corrected air-exposure stations. Having adjusted its shape, scale, and position, the flight-track pattern for Run 1, with all its air-exposure stations, could be considered as generally correct. This permitted the positioning of landmarks all along the run through the use of the bearing and coordinate grids. With a good network of geographic features established, the topographic details can be added by using the appropriate grid.

The position of Run 2 on Fig. 20 shows about a 10-mile overlap at the east end of Run 1. Instead of lying slightly to the north of that run it lay actually about 5 miles to the south, at the time 0834. Run 2 was only about 21 miles long, extending to the east side of Commonwealth Bay. According to the flight log the airplane continued eastward to the east side of the Mertz Glacier Tongue, but the photographs taken between 0852 and 0905 were omitted from the official record because of poor light conditions.

The airplane then changed course about 180 degrees and headed generally west-northwest, flying back (to the southward) of the coast. Run 3, beginning at 0942, fortunately passed directly over Cape Denison, the Australasian base site of 1912-1914. Since the base position had been astronomically determined, it was used to great advantage in delineating the coastal features near the head of Commonwealth Bay. The west end of Run 3 passed close south of Lacroix Nunatak and terminated about 8 miles southwest of Port Martin, the French 1950-1952 base on Cape Margerie.

Run 4 lay from 6 to 12 miles inland from the coast and was separated from the west end of Run 3 by a four-minute gap representing about 12 miles. Data from these photographs were used to supplement the map information obtained from seaward on Run 1. However, they were less important in the compilation process because of the abrupt change in ground slope near the coast and the consequent difficulty of identifying low-lying islets and capes nestled behind steep coastal ice cliffs or steep continental slopes. Whenever it was possible to identify any landmarks shown in the vertical photographs, as in the rare instance in Run 3 when the photographic run passed directly over the known position of Cape Denison, the positions of such landmarks were used to orient and position that part of the photographic run.

At the end or Run 4 it was necessary to change film in all the cameras, so the airplane made a circle between 1028 and 1039 before beginning Run 5. The uncorrected flight log showed Run 5 as continuous with Run 4 but actually the former began about 4.3 miles southeast of the ending of the latter. Run 5 was, like Run 4, used only for supplementary mapping purposes. It terminated at 1058, near the head of Pourquoi Pas Glacier, in about Lat. 66° 20' S., Lon. 135° 30' E.

It was necessary to identify and position the landmarks which lay between the tracks of Runs 3, 4, and 5 and the coast. The positions of most of these landmarks, common to the photographs of both inland and offshore runs, were computed largely by bearing plots. The air-exposure stations of these three runs were then resected from the positions of the intermediate features. As indicated in Fig. 18 of Part 1, resection by the bearing-plot method is undertaken by assuming the approximate position of an air-exposure station and plotting rays from three or more known landmarks, by a trial-an-error process, until a minimum of three rays intersect at a common point for each feature. Though two intersecting rays will indicate the computed position of a feature, as at point 21 and point 301 on Fig. 18 of Part 1, a minimum of three intersecting rays is deemed advisable. In locations where key features are critical, either because of the lack of numerous landmarks or else the massive size of some particular feature, it may be wise to verify the positions of such features by six to a dozen intersecting rays.

The start of Run 6, the last photographic run in Mission 10, was determined to lie about 7 miles northwest of the termination of Run 5. Here, as in all other runs of this mission, there were no intersections of flight tracks whatever. Correlation of these two runs, at the eastern end of Clarie Coast, meant that an intensive study of ice crevasses had to be made. There was also the matter of correlating Run 6 and the start of Run 1. Only two substantial and identifiable features could be found in the photographs to serve as links between the end of Run 5 and the start of Run 6, and between Run 6 and the start of Run 1. These two « features », which could scarcely be called landmarks, were:

(a) A small group of crevasses en echelon, shown in the right obliques of Run 6 as well as in the right obliques of the first few frames of Run 1.

(b) A corner of the coastal ice cliffs common to the right obliques of Run 6 and the first few left oblique photographs in Run 1.

Lack of Large Shadows in the Wilkes Land Regions.

Unfortunately, there were relatively few opportunities of checking azimuths by the sun-line techniques described in Part 1, not only in the area represented by Fig. 20 but in all the other areas covered by the project. The combination of high airplane altitude and low relief always eliminates long shadows and accurate sun lines. In the rare instances where good shadows were observed beside rock features of moderately low relief, the positions of adjoining features had invariably been determined by astronomical means. Such was the case with Gaussberg, far to the west on Wilhelm II Coast, the Bunger Hills at the west end of Knox Coast, and the Windmill Islands off the western end of Budd Coast.

Mapping Procedure for Gaps in Photographic Coverage.

Run 3 in Mission 8, made on January 8, 1947, represents an example for another problem that can arise. This run was indicated in the uncorrected flight log as lying 7 to 12 miles east of Run 6 in Mission 10, made in a general north-south direction directly over Pourquoi Pas Glacier. However, comparison of the photographs in both photographic runs proved that Run 3 in Mission 8 lay about 29 miles westward and from 10 to 15 miles west of Run 6 in Mission 10. This shift, coupled with the break between Runs 5 and 6 of Mission 10, left significant gaps in the topography which had to be filled in from relatively few photographs. Fortunately, many of the crevasses in Dibble Glacier were sufficiently distinctive so that they could be sighted from both roughly parallel runs. Another assist was received from the presence of a large hummock or ice-drowned hill which causes the icecap to rise in this position. This hill lay near the coast and almost under the flight track for Run 3 of Mission 8.

Every area covered by aerial photography has its unusual features. The Antarctic probably has more than most, at least more that are unfamiliar to the mapper. Experience with the present project proves that wide use of a simple stereoscope is highly desirable in a reconnaissance study. There are many places where icebergs resemble rocks, or the reverse. Even melt-water ponds can easily be confused with rock outcrops. One of the basic contributions of a reconnaissance map, aside from the primary relative association of features, is the correct identification of features so that returning field or air parties may be properly guided and ground control sites can be quickly selected.

Importance of Flight-Track Plotting.

While the ultimate aim of the mapper is to produce a reconnaissance plot or chart, his real goal, technically speaking, is to lay down a set of accurate, reliable airplane tracks. He knows that, once he has the correct path over the ground followed by the aerial camera(s), he will be able sooner or later to set down the features shown on the photographs in their correct places on the map.

In an area such as most of the Wilkes Land region where prominent landmarks are noticeably lacking, the intersection of two photographic runs is highly important. A typical example was the crossing of Runs 3 and 4 of Mission 8. The sketch of Fig. 20 shows these two photographic runs intersecting each other at nearly right angles over an area of consolidated sea ice near the entrance to Davis Bay. In addition to making flight-track patterns for each photographic run, the junior author also constructed patterns on small, transparent sheets of paper showing the actual angle of intersection between overlapping runs, such as the two runs mentioned. This angle can be measured directly by comparing the two photographs which show the greatest amount of overlap. The junior author found, however, that the visual method of superposing one photograph upon the other and transferring the angle of intersection by a parallel ruler was sufficiently accurate, especially as experience was gained during the project. This angle of intersection, when determined correctly, gives many clues as to the approximate location of the adjacent geographic features in relation to the area as a whole.

The flight-intersection patterns, together with the flight-track patterns, can be slipped under the transparent mapping work sheet and shifted manually until the best possible combination of flight tracks is determined by a trial-and-error process.

The flight tracks, in a small area, are lightly indicated on the work sheet and are corrected by the use of bearing and coordinate grids until the flight-track positions meet all the conditions inherent in a group of interlocking photographs. This trial-and-error process, with subsequent recheck by both grid overlays, may have to be repeated many times until no further corrections are determined necessary.

Perhaps the greatest satisfaction in the delineation of the whole Wilkes Land and adjacent coastal areas was the discovery of the point where two flight tracks intersected close behind Cape Poinsett on Budd Coast in 113° E. The flight-track plotting indicated such a crossing but it was not until the photographs of this area had been reviewed five separate times before proof of this crossing was found. Four parallel crevasses, seen through a heavy cloud layer, marked the common point between the only two photographic runs covering this area.

As an indication of the accuracy with which a reconnaissance map of this type can be constructed, take the position of Rock X on the east side of Victor Bay. The sketch map of Fig. 20, copied from the transparent work sheet used by the junior author, shows this rock in Lat. 66° 17' S., 136° 43' E. The French position, astronomically determined, and received *after* the sketch map was completed, places Rock X in Lat. 66° 20' S., Lon. 136° 42' E. A revision of the sketch map of Fig. 20, to conform to the latter position, would swing it to the left in azimuth. In other words, it would be rotated about the known positions at the east end and moved some 3 miles farther south at the Rock X position. Since the difference in longitude at Rock X is only about 0.4 mile, the scale of the map, in a direction parallel to the coast line, is very nearly correct.

Supplementary Notes.

Since the text in the foregoing sections was written and submitted, two significant corrections of the preliminary reconnaissance sheets prepared by the junior author have resulted from the recent photogrammetric compilation of a preliminary map series by the U.S. Geological Survey. Brief mention of these two corrections is included at this time merely to point out the kind of errors that can occur in preliminary reconnaissance studies.

(1) A major portion of the Clarie Coast between Porpoise Bay in 130° E. and Dibble Glacier in 135° E. was found to lie some 9 miles farther south than the 1955 preliminary study. One-third of this error was noted in the preceding description of the recent astronomically determined location of Rock X. The remaining error is due largely to the overcorrection of the amount of drift of the photographic reconnaissance aircraft from its dead-reckoning course. No significant landmarks occur in this area and only an intermittent number of small crevasses, of the type suitable for reference purposes, appear in the vertical photographs of this reconnaissance run.

(2) The second major correction applies to portions of the Budd Coast between the head of Vincennes Bay in 109° E. and the Cape Poinsett area in 113° E. The head of Vincennes Bay was found to lie some 11 miles farther northward, while Cape Poinsett at the eastern end of Budd Coast was found to lie some 14 miles farther southward. Heavy cloud cover in the photographs showing the head of Vincennes Bay caused some errors to be introduced. Although additional analysis of any preliminary reconnaissance map invariably permits cartographic corrections, the major correction in the Budd Coast area required a small

clockwise rotation of the photographic flight tracks, which trend in a general northeast-southwest direction.

The photogrammetric study by the U.S. Geological Survey utilized six scattered astronomical positions for island features in the Windmill Islands group. The earlier preliminary study described here was limited to a single fix on Holl Island at the southwestern end of the Windmill Islands group. Here again is another excellent example of the many handicaps encountered in reconnaissance mapping. Due to the rapid disbanding of the task force of 1947-1948 and to the failure to document the complete scientific investigations, the existence of the other five astronomical positions was not made known to the present authors. What is even more appalling, the data on these five positions, after having been used as described at the beginning of this paragraph, cannot now be found! It is fairly certain, however, that on the basis of this information, the position of the Hatch Islets noted in Figure 16 of Part I of this article in the May 1956 issue of the *Review* should be corrected to read Lat. 66° 49' S., Lon. 109° 12' E.

APPENDIX 1

THE SOLID GEOMETRY OF SUN LINES, SUN AZIMUTHS, AND SUN ALTITUDES

For the illustrative case, involving the combination of sun lines, sun azimuths, and sun altitudes as related to shadows or images of the sun, Fig. 21 is drawn with a single large shadow and a single sun line. This avoids the complication of multiple objects and shadows and of multiple sun lines intersecting at the point p_3. Actually, it has not been found possible, from a single sun line, to work out the numerical values of the angles and distances set down in this appendix except by a process of trial and error. This is discussed subsequently.

The sun is assumed to be behind the plane of the camera negative, with the camera pointing down sun. The isometric drawing for the case where the sun is in front of the plane of the negative has been prepared by the authors but it is not reproduced here.

Rather than to work out examples of several cases where the computed altitude of the sun can be used to obtain missing information or to check other data, the three-dimensional geometric relationships are illustrated graphically in the figure and set down mathematically in the notes which follow. With these relationships the prospective mapper may set up the problem with the particular known quantities at hand and solve for the remaining unknown quantity. Even though a particular problem may have to be solved by trial and error, the geometric relationships remain the same.

The position of the camera lens S, the optical axis of the camera, the camera negative, the plumb point M, the plane of the inclined camera negative, the direction and trace of the true horizon, the ground trace of the principal plane, and the intersection Q of the plane of the camera negative and the vertical line through M and S are the same as the corresponding features in Figs. 8, 10 and 13 of Part 1.

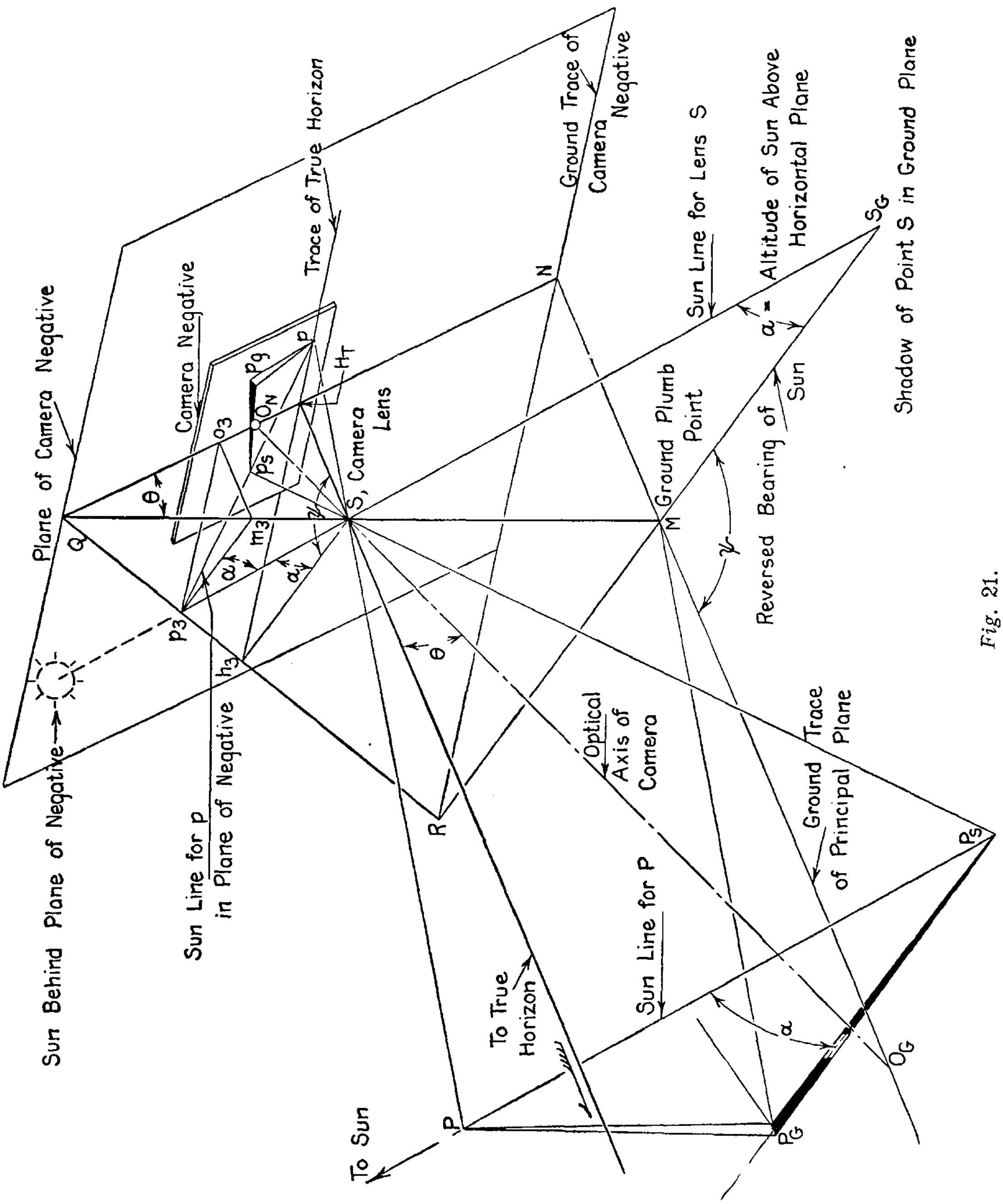

Fig. 21.

Isometric drawing representing the solid geometry of the oblique aerial photograph having a single large shadow and a single sun line.

Assume that there is in the field of the camera a large pole or mast which casts a shadow, having its top at P and its base at P_G. The shadow extends from P_G to P_S so that PP_S is a sun line for this feature. The corresponding three points on the camera negative are p, p_g and p_s. The position p_3 is found on the plane of the negative, extended beyond the negative limits as may be necessary, by the intersection of all sun lines in the field of view.

A ray from the sun passing through the position S of the camera lens intersects the plane of the camera negative at p_3 and falls upon the ground plane at the point S_G. The latter is the position of the shadow of the airplane on the ground. A vertical plane through S_G M, S, and Q intersects the ground plane in the line $S_G MR$. It intersects the inclined plane of the camera negative in the straight line QP_3h_3R, and passes through the sun behind the plane of the negative. The angle between the ground trace $O_G MN$ of the principal plane and the vertical plane through S_G, S, p_3, and the sun is the angle ψ between the principal plane of the camera and the reversed bearing of the sun. In the ground plane it is represented by the angle $O_G MS_G$; in a horizontal plane through the camera lens S and the trace of the true horizon it is represented by the angle h_3SH_T; in a horizontal plane through the point p_3, intersecting the plane of the negative in p_3o_3, it is represented by the angle $p_3m_3o_3$.

Since the lines $P_G P_S$, $S_G MR$, and Sh_3 all lie in horizontal planes and are parallel to each other, since they lie in vertical planes that are likewise parallel to each other, and since the sun lines $P_S P$ and Sp_3 are parallel to each other in space, the altitude α of the sun is represented, as indicated on the diagram, by the three equal angles $P_G P_S P$, $MS_G S$, and h_3Sp_3.

The following three-dimensional geometric relationships obtain:

(1) Relating to the reversed bearing ψ of the sun with the principal plane, $\tan \psi = h_3H_T/SH_T = p_3o_3/m_3o_3$.

(2) Relating to the altitude α of the sun above the horizontal, $\tan \alpha = m_3S/m_3p_3$. This makes use of the equal and opposite angle shown in the figure.

(3) Assuming that the angle θ has been determined from the marginal distance m and the airplane altitude h, and that the focal length F is known, $O_N Q = F \cos \theta$ and $O_N H_T$ is $F \tan \theta$.

(4) The line p_3o_3 is drawn parallel to the true horizon and the distances o_3p_3 and o_3Q are measured. Then $o_3m_3 = o_3Q \sin \theta$, whence $\tan \psi = p_3o_3/m_3o_3$.

(5) In the horizontal triangle $m_3o_3p_3$, $m_3p_3 = o_3m_3 \sec \psi$. In the principal plane $QS = Q_N Q \sec \theta = F \operatorname{cosec} \theta$.

(6) The distance $Qm_3 = o_3Q \cos \theta$ and $m_3S = QS - Qm_3$, whence $\tan \alpha = m_3S/m_3p_3$.

If there is but one sun line in the field of view, and if the sun's altitude can be computed by a knowledge of the local mean time of exposure and the estimated geographic position, successive positions for the point p_3 along the sun line pp_S extended have to be assumed until the angle α is found to be equal to its calculated value. The value of the reversed bearing is then determined by finding the angle from the relationships given.

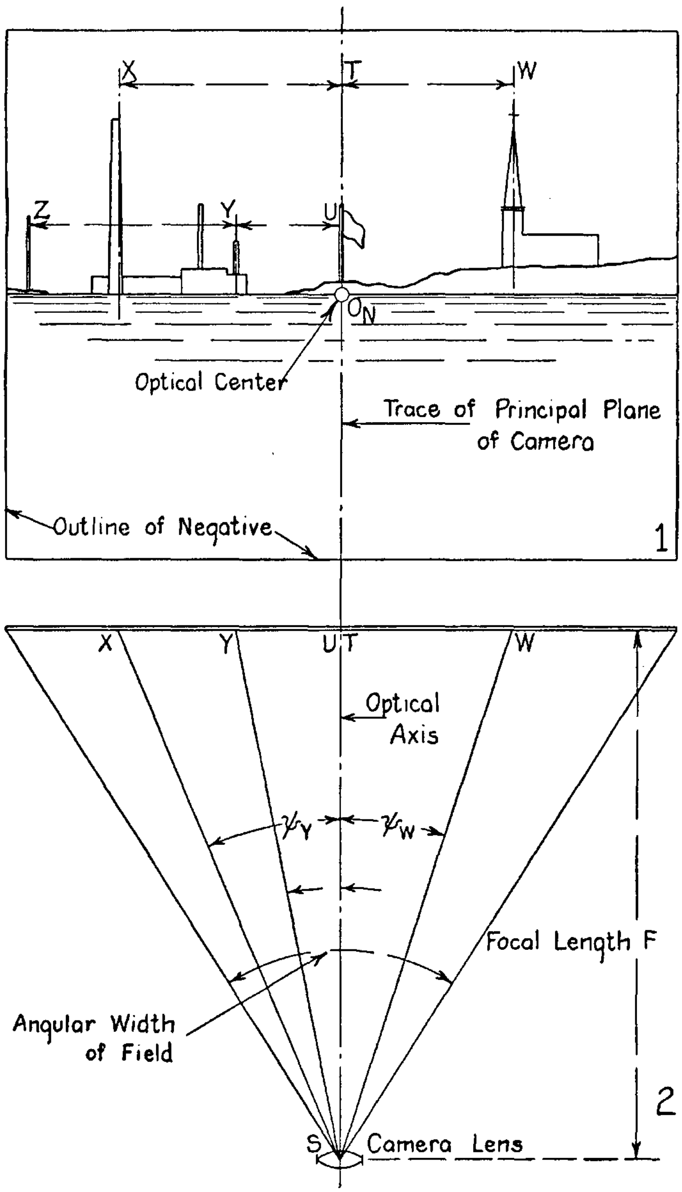

Fig. 22.
Sketches illustrating method of determining approximately the focal length of any camera.

If p_3 is determined by the intersection of several sun lines, the altitude is determined from the foregoing and then compared with the altitude α calculated by suitable celestial-navigation methods.

APPENDIX 2

FINDING THE APPROXIMATE FOCAL LENGTH OF A GIVEN CAMERA

To find the focal length of a camera which has been employed for taking aerial « views », it is first necessary to obtain the camera itself. The lens assembly can be removed and its focal length determined accurately in an elaborate apparatus, but there is described here a much simpler method, sufficiently accurate for most reconnaissance mapping.

Select a position in the open where a number of tall, clearly defined, vertical objects are visible in the field of view, preferably at a distance of a mile or more. Place the camera on a firm rest, with its optical axis horizontal. Point it, as nearly as can be done, at some characteristic marks such as the flagpole at U in diagram 1 of Fig. 22. The focus is placed at infinity setting and the diaphragm stopped down for clear detail. Take a few exposures, shifting the camera slightly in azimuth between each exposure so that its optical axis is pointed directly, as nearly as can be determined, at some one of the vertical structures.

Then with a theodolite or other suitable surveying instrument, set up close to the camera, measure the horizontal bearing angles between all the principal vertical objects, such as Z, X, Y, U, and W in diagram 1 of Fig. 22. Arithmetic addition and subtraction give a check on the horizontal angles between any selected combination. If a surveying instrument is not available a navigator's sextant is used, held on its side so as to measure horizontal angles.

From the unstretched photographic contact print — or better, from the negative itself — measure the distances XT, TW, UY and UZ. Then from the trigonometric relationship $F = (TW) \cot \psi_W$, calculate the value of F for each angle that has been observed visually, reckoned from the optical axis O_N. An average of the several derived values of F is sufficiently correct as a focal length for infinity setting to permit the construction of any type of plotting grid.