CONTRIBUTIONS TO THE STUDY OF ANTARCTIC SURFACE FEATURES

BY PHOTOGEOGRAPHICAL METHODS

by
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF KEYS

LIST OF MAPS

All maps are appended in a separate folder.

CHAPTER I

THE PROBLEM

If a picture was thought to be worth 10,000 words by educated men in the time of Confucius (551-479 B.C.), what value would these philosophers have placed on a photograph? How much would an airphoto stereogram which showed ten square miles of the earth's surface in three-dimensional detail have been worth to them? The chief value of stereo airphotos may lie in their nature as a medium of three-dimensional expression of landscape. In point of fact, it is doubtful that any number of words can aptly, conveniently, rapidly and completely convey to the reader the spatial relationships and the quantitative, qualitative and associative data capable of being derived from an airphoto stereogram.

Obviously it is most difficult, if not impossible, to place on aerial photography an exact value in terms of words. The usefulness of any such item depends upon how well man has learned to apply it to solve his problems. For example, fire was but a hazard to man until he learned to control it and apply it to his own needs. Similarly, although the first aerial photographs were of some use when taken nearly 100 years ago (McNeil, p. 1.02), their value has since increased in great measure as new ways have been found to utilize them in unraveling the enigmas of nature faced by modern man.

In this study there are demonstrated some of the methods by which airphoto interpretation can be applied to the problems of the geographer. Portions of the Antarctic have been selected for the demonstration, partly because the lack of field work and literature concerning these specific locations enables the photogeographical method to provide a wider variety of contributions to the knowledge of the local landscapes and partly because the investigator's first-hand knowledge of the subject, general area or analogy concerned is prerequisite to the utilization of the photogeographical method.

Antarctica is nearly twice as large as the United States. Only its fringe has been explored, and little of this has been examined in detail. Here lie the only sizable areas of the earth which have not yet been seen by man. The largest of these areas is comparable in size to the whole of the United States.[1]

Of the two existing glaciers of continental proportions in the world today, the Antarctic icecap is the better although the lesser known example. The study of the processes and the morphology of continental glaciers is significant in that through it we may obtain a better understanding of the landforms created by the continental glaciers of the Pleistocene Epoch which terminated some 25,000 years ago. These landforms are basic to much of the terrain upon which the North American and north European peoples dwell and they have had a considerable influence, not only on the utilization of the natural landscape, but on the cultural landscape and folkways as well.

Much of the theory concerning the landforms which have resulted from continental glaciation is based upon studies of Alpine glaciers or the Greenland icecap, neither of which is strictly comparable to the huge ice sheets of the Pleistocene Epoch. The Alpine glaciers are too small, too shallow and too confined for direct comparison, the Greenland icecap is

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[1]See Map 1. The maps are located in a separate folder.

ringed by mountains. On the other hand, ice masses of the Pleistocene Epoch frequently overrode nonmountainous areas to front directly on the ocean as does much of the continental glacier of Antarctica. Since the direction of ice movement and the creation of landforms from this movement are dependent to a considerable extent upon the original landforms, it is logical to assume that emphasis should be placed upon the study of topographic and ice conditions which most nearly resemble those existing on North America and Europe during Pleistocene time. These conditions exist in the Antarctic.

The Antarctic continental glacier is estimated to contain from 82 to 90.5 per cent of the volume of the earth's existing glacier ice.[2] The commonly accepted conclusion that this ice is gradually melting is generally confirmed by evidence of former, higher glacier levels and the observed retreat of individual glaciers in both hemispheres. Gutenberg (1941, p. 730), Marmer (1943) and Flint (1947, p. 429) demonstrate through the use of tidal gage records that sea level is rising at a variable rate which probably averages 2.5 inches per century. These authors attribute this rise almost wholly to a net loss of glacial ice during the same period. In the future our knowledge of glacial dissolution can be much enhanced by making studies of comparative aerial photography of glaciers over a period of time.

While a rise in sea level approximating 2.5 inches per century is not alarming, it is not inconceivable that the human mind which has learned to create rain and to explode atomic bombs might also learn how to melt vast

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[2]Thorarinsson (1940) 82 per cent; Antevs (1929, p. 43) 84 to 89 per cent; Ramsay (1930, p. 15) 87 per cent; and Daly (1934, p. 12) 90.5 per cent. Flint (1947, pp. 429-431) cites these in tabular detail.

quantities of glacial ice. Such knowledge would provide its owner with a fantastic weapon superior to any which now exists, for by its use sufficient water could be generated to immerse all of the world's port cities and coastal plains. Aside from the obvious effects upon the peoples of the world, such an event would affect the habitability of many areas for all living things, change base levels and areas of marine erosion and affect climatic conditions all over the earth.

Recent estimates of the rise in sea level attributable to melting of the earth's present supply of glacial ice include Anteve (1929) 131 to 197 feet without isostatic or other adjustments; Ramsay (1930) 180 feet without adjustments; Daly (1934) 164 feet without adjustments, less than 130 feet with isostatic adjustment; Thorarinsson (1940) 79 feet including isostatic adjustment; and Flint (1947) 65 to 165 feet without adjustment. Adjustments for isostatic reactions would tend to reduce the unadjusted figures. These same students of glaciology estimate the lowering of the sea level to accommodate the ice of the Fourth Glacial Age to be from 230 to 332 feet.

The Antarctic and, to a much lesser extent, Greenland are not easily accessible to scientists. Aerial photographic interpretation now appears to offer the best method for the preliminary scientific exploration of these regions, for the isolation of problems requiring field study and for use in the field by the occasional scientific expeditions to these frozen areas. Aerial photographs may also be used to record the findings of the field investigators as well as to map the area with sufficient accuracy for reconnaissance purposes.

Therefore, on the basis of the available aerial photography, current photo interpretation techniques, extensive research into the literature written about the Antarctic and two seasons of personal field experience there, the author aims:

1. To contribute to the knowledge of the ice forms typical of the Antarctic continental glacier in general, and to the morphology and reconnaissance geography of one typical Antarctic region in particular through the use of airphoto interpretation as a geographic technique, and in so doing
2. To investigate the use, value and limitations of airphoto interpretation as a geographic technique for the inventory and analysis of landscapes, particularly those landscapes which occur in areas of limited accessibility.

These goals will be accomplished in the succeeding chapters by an analysis of the photo interpretation technique (Chapter II); a brief consideration of the area and the application of the photogeographical method to it (Chapters III & IV); the presentation of photo interpretation keys of selected features of continental glacier morphology (Chapter V); the application of these keys and field experience in analogous areas to the investigation of specific landscapes which have not been scientifically explored by surface parties (Chapter VI); and finally, a summary of the findings of this investigation and an evaluation of the validity of photogeographical method (Chapter VII).

CHAPTER II

THE METHOD

The contributions to the knowledge of Antarctic surface features and to the reconnaissance geography and geomorphology of the Ingrid Christensen Coast which are contained in this study are presented through the medium of photo interpretation keys (Chapter V) and through the application of such keys to the aerial photographs of a specific region (Chapter VI).

Although students of several of the earth sciences and of other disciplines have prepared and are currently preparing some sets of photo interpretation keys related to their fields of interest, the formulation of keys characteristic of geographic regions and the derivation of information of geographic significance through their use are distinctly geographic techniques.[1]

Therefore, since (1) the photo interpretation method is considered an acceptable geographic technique, (2) the contributions of this study are based upon this technique, and (3) information of this character is not generally available in the geographic literature or the literature of other disciplines, this chapter is devoted to the nomenclature of photo interpretation, descriptions of the photo interpretation process, an analysis of the purpose and utilization of photo interpretation keys and an explanation of the photogeographical method.

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[1]Photographic interpretation is also recognized as a geographic research technique by the Department of Defense.

PHOTO INTERPRETATION DEFINED AND DESCRIBED

Nomenclature. The methodology of photo interpretation is of relatively recent development. Consequently, the presentation of certain definitions is required in order that the thought processes of the reader and the author may remain on a common plane. The following significant terms are first defined and later discussed according to their usage in this study.

*Photograph or Photo. A general term for a positive or negative picture, likeness or image obtained by exposing a plate, film or other medium, usually coated with certain chemicals, to the actinic effect of light.

*Aerial photograph or Airphoto. A photograph made from any kind of an air vehicle. The camera lens is normally depressed sufficiently to permit the formation of an oblique or vertical pictorial representation of the earth's surface.

*Stereogram. Two or more photographs of the same area, taken from different camera stations and oriented in such a manner as to permit the viewer to obtain a mental impression of a three-dimensional model.

Photo image. A pictorial representation of a specific object or substance, irrespective of size, which is composed of the sum of such elements as tone, texture, shadow, shape, size, pattern, position and parallax.

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*Definitions preceded by an asterisk do not vary in any significant aspect from similar definitions established by the Committee on Nomenclature of the American Society of Photogrammetry. Terms not preceded by asterisks are not defined by the committee. American Society of Photogrammetry, Manual of photogrammetry. Pitman Publishing Company, 1944, Ch. XVII.

Photo interpretation key. A device designed to aid photo readers and photo interpreters in the rapid, accurate identification of an object from the study of its photo image. The key may assume any of a wide variety of forms but generally includes both a written description and a pictorial representation of the characteristic recognition features of the object concerned.

*Photogrammetry. The science or art of obtaining reliable measurements of any object by means of photography. (The greatest portion of the photogrammetric effort is currently applied to surveying and mapping.)

*Photo reading. The simple identification or description of photo images without analysis of their meaning.

Photo interpretation. The utilization of systems, techniques or processes of analyzing photographs which enables skilled scientific or professional personnel, by virtue of their individual experiences, to produce significant, reliable and detailed information concerning the natural or cultural features of the area photographed and to determine or infer the factors which the observable presence, condition or use of these features imply.

Photo intelligence. The collected products of photo interpretation, classified and evaluated for military use.

Photogeography. Photo interpretation applied to geographical problems. More specifically, the joint employment of geographical training and experiences together with photographic interpretation techniques for the production of knowledge relative to geographical regions, landscapes or the various systematic disciplines of which geography is composed.

Discussion of nomenclature. The meanings of the terms "photograph" and "aerial photograph" seem not to be controversial. The terms "photo interpretation key" and "photogeography" are discussed in greater detail in sections of this chapter which are devoted to these subjects. For the purpose of this study, some of the other terms cited require elaboration:

Photo image. A complete understanding of the photo image and the elements of which it is composed is a requisite for those who would use airphotos for scientific purposes. Without the knowledge of the interrelationships of these photo image elements, scientific photo interpretation could not be performed. The scientific photo interpreter must take into account the sum of the elements of tone, texture, shadow, shape, size, pattern, position and parallax before he is able to identify or interpret an airphoto or the photo images of which it is composed. This procedure is most often performed subconsciously, but upon occasion, it becomes necessary to examine one or more of the elements individually to ascertain the nature of a photo image.

The difficulty of assessing a photo image is likely to be complicated by the small size of the image. One of the scales most frequently used in aerial photography which is intended for mapping and interpretation purposes is that of 1/20,000. A large portion of the United States is covered by photography at this scale. The keenness of optical and mental perception necessary to assess photo images becomes evident when one realizes that, at this common scale, an object 20 feet long on the ground is represented on the photograph by an image only one one-thousandth of a foot in length.[2] Within this small image, the interpreter may have to assess each of the elements listed above. Although many images are smaller than this, such as an individual coniferous tree, corn silo, telephone pole or glacial erratic, there are numerous images of larger size as well, e.g., corn fields, most buildings, major landforms and most stands of natural vegetation. Photo images may exist within photo images as, for example, the image of an individual conifer within the image of a coniferous woodlot. A consideration of the principal elements of the photo image follows:

Tone. Tone is the foundation upon which all other photo image elements are built; without it, no other elements could exist, since the photograph would be but one shade of gray and no images would appear. Tone, then, denotes the shades of gray in which the subjects are photographically depicted. All the shades of gray from white to black must be reckoned with. Tone is not necessarily the result of the color of the object photographed. Instead, it depends largely upon the amount of light reflected into the camera lens by the object (object brilliance), which in turn is dependent upon such factors as the angle formed by the sun, the object and the camera lens; the degree of smoothness and the orientation of the surface texture of the object; and the photographic materials and processes used. The tone in photo images of the same object may change if any one of these variables is altered. Many common objects or surface conditions, such as water, dampness, vegetation, vegetation diseases,

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[2]Photo interpreters generally measure the size of photo images in thousandths of a foot, since this measurement may be multiplied directly by the denominator of the representative fraction to obtain the actual size of the object or distance imaged. For example, a bridge 0.009 feet long appearing on a 1/20,000 scale airphoto can be readily determined by mental arithmetic to be 180 feet long (9 x 20).

tracks and so forth, are rendered in tones on infrared emulsion which differ considerably from the tones produced by these objects on panchromatic emulsions.

Tones are most frequently described by adjectives such as dark, medium or light. Small tabs cut from exposed photo prints of various tonal values ranging from black to white can be assembled in an orderly fashion to produce a grayscale to which tones in various photo images can be compared for purposes of identification. The tones in American grayscales are generally numbered from one through ten, with the numerical value increasing with the darkness of tone (Dashn, 1949). A "Graukeil," said to have 23 shades, was developed and used in Germany in 1944. Grayscales have not proved to be of significant value to date because of the many varying factors which may cause photo images of the same object to appear in different tones in different airphotos, or which may cause two similar photo images to appear in different tones on the same airphoto. At the present time this problem is the subject of an investigation by members of the geography and physics staffs at Northwestern University.

Texture. The visible detail in airphoto images is actually produced by the minute variations in tone. The term texture is used to indicate the manner in which the small constituent tonal parts of the photo image are arranged, disposed or united. Russell, Foster and McMurray (1943, MS) define texture as the number of tonal changes in any given part of the photograph. Colwell (1952, MS) describes texture as a product of the aggregate of unit features too small to be (readily) discernible (as individual features). Accordingly, the unit features of which texture is comprised must vary with scale. In large-scale photography the roof tiles, gutters and roof ridges may be observable. At successively smaller scales, however, the tiles, then the gutters and finally the ridges can no longer be individually recognized and become a part of the photo texture.

The importance of shadows in the composition of texture deserves more recognition than it has generally been accorded, for although the descriptions of the other authors do not preclude the part which shadows play in the formulation of texture, neither do they report adequately upon it. Since the objects which have perfectly smooth and level surfaces are few in number, essentially all objects photographed must cast or contain either large or minute shadows. As a result the photo images of objects like croplands containing small grain crops are frequently of fine texture because of the close spacing of the individual stems of grain and the large number of closely spaced, tiny shadows. Conversely, cornfields have a more coarse texture because of the wider spacing of a smaller number of larger shadows.

Textures are said to be fine, medium or coarse, stippled, mottled, dappled, streaked, variegated, lined, velvet or feathery. In fact any adjective which aptly conveys the appearance value of a texture may be used.

Shadow. The best times for taking aerial photography for interpretation purposes are mid-morning or mid-afternoon, local sun time. At this time the light is quite strong and the sun is at such an angle that it will cast shadows long enough to aid in the identification of photo images but not so long that they will cover an undue proportion of the adjacent photo images.

Shadow is peculiar in that it is composed of dark tones and distinct shapes and yet maintains recognition properties apart from either tone or shape. Normally shadows are found to be among the darkest tones on the photograph. They are jet black on infrared emulsions and approach that on panchromatic film. The shapes of shadows are determined by the angle of the sun, the outline of the opaque object from which they are cast and the configuration of the terrain upon which they fall.

Shadows are frequently used to measure the heights of trees or buildings. Shadows are important because they often reveal the presence of objects which otherwise might not be visible, such as telephone poles. The shapes of shadows may more nearly resemble objects as they are seen from the ground as in the case of a suspension bridge. The significance of shadow in determining the appearance of texture has been mentioned previously. Shadows are also important because they sometimes obscure the detail of objects over which they fall.

Shape. The shape of a photo image of any object is determined by its tonal edge gradient,[3] the angle of view and the elements of photographic distortion present. While some objects may be interpreted from a single element of the photo image, this is not a sound practice in the case of shape since many objects of different size or character possess the same general shape.

The eyes of men normally view the natural and cultural features of the landscape from a level of five to six feet above its surface, with occasional oblique views from positions of vantage on hilltops or in tall buildings. The vertical aerial photograph, looking squarely down upon these features, presents unfamiliar outlines and hitherto unrealized external appearances of objects which are familiar from other, more normal viewing angles.

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[3]The edge gradient is the rate of tonal change between the edge of a photo image and its background or adjacent photo images.

Size. The size of a photo image, especially in relation to a given scale or in comparison with a positively identified object imaged on the same vertical airphoto, is the characteristic which enables a distinction to be made between objects of similar shape but of differing area or volume. It is always necessary to check the scale and to correlate it with the size of the photo image in order to avoid errors of interpretation.

Pattern. The spatial arrangement of the component parts of the terrestrial landscape as shown in a photo image or the arrangement of photo images on the airphoto sometimes produces a characteristic design known as the pattern. In some instances patterns may be caused by the repetition of individual shapes or relationships. The checkerboard pattern of the farmlands in our cornbelt stands in sharp contrast to the long, narrow, striped pattern of fields in many portions of Europe and the patterns formed by the step terraces of the hilly lands in Japan and southeastern Asia. Patterns are frequently characteristic of an object or condition, e.g., the trapezoidal pattern of an artillery emplacement or the angular pattern of trellis drainage and its associated morphological conditions. Terms used to describe patterns include such adjectives as regular, irregular, random, concentric, radial, and rectangular.

Position. The spatial relationship of a photo image to its environment or its association with nearby photo images is called position or site. Since photo images which are sometimes not otherwise identifiable may occasionally be identified on the basis of position alone, this element is a significant recognition characteristic. Certain natural features, such as some species of vegetation, are confined to specific landform, soil or climatic sites. In the cultural landscape, the differentiation between the house and the barn in a local farm group consisting of two large single-gable roofed buildings without chimneys and several smaller buildings is made easy by the position of these structures in relation to the visible driveway which bypasses the house and fans out into a barnyard.

<u>Parallax</u>. The apparent displacement of the position of an object in relation to its background or any other point of reference which is caused by a change in the position of the observer is known as parallax. Normally, aerial photographs are exposed by means of an electric intervalometer attached to the aerial camera and adjusted for the altitude and ground speed of the aircraft and the focal length and angle of view of the camera so that each photographic exposure will include approximately 60 per cent of the earth's surface that was covered by the preceding airphoto. In this manner each visible object on the earth's surface within range of the camera is presented in photo image form on at least two successive exposures. The horizontal displacement of these photo images in relation to a common reference point can be measured and converted to a factor which, when multiplied by the scale of the photograph, will give the height of the object represented by the photo image as that object exists on the earth.

Of more importance, as a result of this parallactic displacement the photo analyst may view one of the two consecutive, overlapping prints with his left eye and the other with his right eye and form a three-dimensional model of the photo image in his brain. The ability to control or prevent convergence so that each eye can remain focused on a separate photograph at the same time is easily acquired by most people with good vision in both eyes. Usually, however, the photo interpreter employs a stereoscope to prevent eyestrain as well as to magnify the image size. The change in the photo image from two dimensions on a single airphoto to a three-dimensional model from viewing a stereogram increases the analyst's ability to interpret the objects in the photo images to a significant degree.

Other factors. The quality of all these photo image elements will be determined in large part by image sharpness and resolution. Image sharpness is largely dependent upon edge gradient, the abruptness of tonal change between the edge of a photo image and its background. Image resolution may be described as a measure of the amount of detail visible on a photo image; it is usually measured in terms of lines of photo image per millimeter. Image sharpness and image resolution are to a large measure dependent upon the photographic equipment, materials, processing, exposure, scale, object photographed and image movement. Colwell (1952, MS) states that the photo image is also determined in part by the reflective, sensitivity, transmission and haze interference spectrums. The effects of the quality of the emulsion and the correctness of exposure on the resulting resolution are self-evident. Image movement, caused by the forward motion of the aircraft or sometimes by the vibration of the camera during the fraction of a second necessary for the exposure has the effect of blurring the photo image. All conventional airphotos are subject to this, but to a widely varying degree. A few cameras are equipped with image motion compensators, but even these, when accurately set, cannot prevent blurr from vibration. Although the blurr caused by image movement is always present, it is seldom noticeable to the naked eye. Saunders (1941) describes how to measure image movement and to determine its effect upon the airphotos concerned.

Whether or not images of less than a given size-shape factor can be seen by the naked eye on aerial photography depends upon the photographic scale. Magnification of airphotos up to four diameters will frequently reveal images not previously visible to the naked eye. Further magnification generally produces no additional detail but brings out the graininess and merely makes the already visible images larger and fuzzier in appearance. In practice, the analyst observes the whole photo image, rather than its individual elements, and describes the object it represents. The individual elements of the photo image are merged into one impression and normally it is this impression which stimulates his mental processes, causing his response to assume a particular form.

Macdonald (1951) and Colwell (1952, MS) hold varying views on the relative values of scale and resolution in relation to the recognition of photo images. It is evident, however, that photo images of sufficiently large scale for recognition can lack the image sharpness required for identification. Likewise, photo images of high resolution value can be of such a small scale that recognition is again impossible. Therefore, the recognition threshhold must be determined by the scale-times-resolution factor at which the photo image first becomes identifiable and the scale-resolution factor above which the image is no longer identifiable.

Photogrammetry. The layman's concept of photogrammetry is akin to the meaning of the word as expressed in Webster's New International Dictionary of the English Language, Unabridged (1939), which restricts the application of this discipline to surveying in the sense of map making. According to the Committee on Nomenclature of the American Society of Photogrammetry (1944, p. 799), however, any and all operations in which measurements are made from photography are regarded as falling within the purview of photogrammetry. These categories include, aside from mapping and surveying, such operations as measuring stands of timber, measuring lands and crops for purposes of taxation, census or sale, making ballistics tests and measuring individuals for custom tailored suits when any of these or other equally varied tasks are performed by making measurements on photographs. It includes, in the view of this organization, the portions of photo reading and photo interpretation which are based upon measurements for description and interpretation. Conversely, the portion of photogrammetric map making in which selected detail is lifted for transfer to the map compilation base is photo reading. There can be no doubt as to the close relationship of the two fields of endeavor. It is not unreasonable to state that photogrammetry is the quantitative aspect and photo reading and photo interpretation are the qualitative aspects of a single art or applied science.

PHOTO READING, PHOTO INTERPRETATION AND PHOTO INTELLIGENCE

In the United States, the military services are in agreement that photo reading and photo intelligence are the processes by which the product, photo intelligence, is derived.[4]

It is unfortunate, however, that there is no civilian or scientific counterpart for the phrase "photo intelligence," i.e., a phrase which

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[4]Since most military publications in this field have been devoted to the practical training of photo readers and the production of photo interpretation keys almost to the complete exclusion of articles concerning the theory of photo interpretation, there is no widely disseminated written authority for this statement. It is interesting to note in this connection that only one of the basic terms defined at the beginning of this chapter is mentioned in the glossary of the Photographic interpretation handbook--U.S. Forces which was published in 1945 at the peak of the military photo interpretation effort, and which, though presently under revision, is still considered the principal written guide to military photo interpretation.

would apply to the collected products of photo interpretation classified and evaluated for scientific use. Photo intelligence is also the proper expression for civilian use according to the common dictionary meaning of the word intelligence, but because of the recent and continuing state of international affairs, the word intelligence is almost universally thought of as military intelligence. The term "photo data" must be ruled out since this expression is commonly used to designate information about the photography, itself, as recorded by the navigator, photographer and photo laboratory technician. "Photo information" is perhaps the best of the remaining synonyms; it is suggested here for use as the scientific counterpart for the term photo intelligence.

In military operations photo intelligence reports are distributed to staffs and commands which produce general intelligence reports or make command decisions, based in part upon the photo intelligence report and in part upon all other sources of intelligence which may be available. In the scientific world, however, the creator of the photo information is likely also to be the end consumer who will combine the information he has gleaned from the airphotos with whatever other kinds of reliable information that are available to him in order to produce his own final report or decision, thus eliminating entirely the necessity of a photo information report. This condition, however, may not prevail if civilian scientific groups engaged in photo interpretation continue to grow in terms of numbers of such groups, numbers of mature scientists and graduate students within individual groups and numbers of research projects assigned to individual groups.

In general photo reading constitutes the processes by which familiar objects of the landscape are recognized from their appearance on the airphoto; by which airphotos are oriented while in the field or in respect to maps; by which airphoto scales are normally determined and by which limited photo identification may be accomplished with the aid of photo interpretation keys. Photo interpretation constitutes the applied technique which produces these keys; the processes by which the images on the photographs are translated into factual data or terms of evidence relating to a specific field of inquiry; and the methods by which proper, accurate and significant inferences are drawn from the implications revealed by the photo images.

While the essential differences between photo reading and photo interpretation are generally agreed upon by the geographers, geologists, ecologists, foresters, engineers and other scientists who commonly use aerial photography, there are, of course, some disagreements as to the exact wording of the definitions. These concepts are best explained by an examination of the works of the more competent photo analysts in the various disciplines concerned.

R. N. Colwell (1952, MS), a forester, ecologist and military photo interpreter describes photo interpretation as:

> . . . . the act of examining photographic images of objects for the purpose of identifying the objects and deducing their significance. In accordance with this definition, virtually everyone can consider himself a photographic interpreter to one degree or another. If this were not true our newspapers and popular magazines would contain no photographs, the portraits of wanted criminals would not adorn our post office walls, the motion picture and the television industries would be non-existent, and there would be no multimillion dollar business catering to the needs of amateur photographers.
>
> However, photographic interpretation as indulged in by the amateur should not be confused with professional photographic interpretation as performed by the photogeologist, engineer, forester, soil scientist, city planner, or military photographic interpreter.[5] Each of these men usually has a solid

[5]Note that Colwell does not include the geographers among the leading professions which make use of airphoto interpretation.

> background of training and experience in his specialty. . . . it is largely by virtue of this background that the professional photo interpreter is able to identify, on photographs, objects which the amateur would either overlook entirely or would fail to interpret in their proper significance.

Colwell does not use the term photo reader. Instead, he discusses amateur and professional photo interpreters. He has emphasized one important point which is sometimes overlooked by other authors on the subject, that is that everyone can interpret photographs to one degree or another, but that this degree is usually limited to snapshots, motion pictures, video reception or in some cases such simple items as roads, lakes, and field patterns from airphotos. The determination as to whether the roads are concrete, macadam or 'dirt'; as to whether the lake is salt or fresh; and as to whether the field contains corn, wheat or rye demands professional experience, however.

H. T. U. Smith (1943, p. 54), an outstanding photogeologist, explains his concept of the relationship between photo reading and photo interpretation in the following terms:

> Photo reading refers simply to the identification of features shown on photos. Photo interpretation, however, is broader in scope, comprising both the recognition of features and the drawing of inferences as to their significance, in the list of all available information. Direct observation is supplemented by deduction, obscure or hidden features are visualized with the guidance of previous experience, and the implications of the whole picture with respect to the observer's particular objectives are ascertained as far as possible. The actual objectives of photo interpretation are many and varied. . . . All, however, have a common starting point--that of obtaining from the photos as clear and complete a picture of the land surface as possible. Further steps depend upon the observer's familiarity with his field of investigation and on the quality of his reasoning.

As if to emphasize the importance of that last sentence, Smith (1943, p. 93) states:

> The second phase of photo interpretation consists in translating the picture into terms of evidence relating to some

> particular field of inquiry, such as geologic or geomorphic history, economic possibilities, land utilization practices, city or regional planning, military tactics, etc.

It is this second phase which demands that the photo interpreter be well trained in his particular field or science or endeavor. NO MAN CAN INTERPRET EXTENSIVELY FROM AERIAL PHOTOS THAT WHICH HE COULD NOT IDENTIFY IN THE FIELD.

Gottfried Pfeifer (1946, MS p. 16), a German geographer, has this to say in his description of photo interpretation:

> Numerous single items and even entire parts of landscape are actually not identified directly from the airphoto, but rather they are inferred or interpreted. . . . .Many objects are not painstakingly identified, but interpreted from common knowledge or specialized scientific knowledge.

This citation emphasizes a point not common in the English literature on photo interpretation, namely, that it is not only the specialized scientific knowledge in one's particular field of discipline which enables him to interpret, but also that his interpretation is dependent upon his exercised powers of observation and the ordinary factors of landscape which lie outside of his specialty that he may have previously lbserved. It will be seen from an analysis of quotations that Colwell and Pfeifer merely use different words to express substantially the same attitude.

Pfeifer, E. Meynen and E. Otremba (1946, MS p. 61) are quoted as presenting the point of view that landscape interpretation is composed of three elements: perception, observation and interpretation. Perception is likened to simple photo reading or the identification of single objects on the airphoto. Observation endeavors to recognize photo images with regard to their extension in form and distribution. Interpretation inquires into the meaning of the situation and the relationships of the objects appearing on the airphoto to the environment. The results of interpretation may then be applied to the further evaluation of the airphoto.

There is a strong feeling among geographers that it is necessary for photo analysts to have an understanding of the origin, development and life cycles of the objects whose photo images they would interpret. Russell, Foster and McMurray (1943, p. 319) feel that:

> A prime requisite for the interpretation of aerial photographs is a knowledge of the processes involved in the production of the particular natural or cultural feature that is to be identified.

It was the summary opinion of about a dozen European scientists working on a series of photo interpretation projects and numbering among them professional men from the fields of geography, geology, ecology, pedology, forestry, hydrology, engineering and photogrammetry (Pfeifer, 1946, MS p. 102) that:

> . . . . conclusions [were based upon] . . . . general geographic experiences in combination with local field experiences.
>
> Previous knowledge concerning causal relations in the landscape . . . . broaden the evaluation possibilities and render better safety in evaluation according to the experience of most workers.

Belcher (1948, p. 482), a photopedologist and a highway engineer, is equally insistent upon the necessity for the interpreter to know the terrain:

> Basically, airphoto analysis depends upon a well-versed acquaintance with ground features and soil characteristics. The aerial pictures provide a means of making a deliberate and a detailed study of an area and an evaluation of the landforms by an enlarged perspective. Theoretically, the same things that can be studied in the airphotos can be examined on the ground; time and limited information prevent this. The optimum condition is represented by a judicious ground investigation guided by a photo analysis. In most instances to see a ground feature in its entirety is to understand its origin, its composition, and its influence on the surrounding terrain. When standing on the ground, man is so dwarfed in size, even by the features of micro-relief, that their outline and overall character is obscure or hidden.

> Photo analysis is founded upon observation and inference. Only features that are surficial can be directly observed; conclusions must be inferred from these. Studying the surface pattern of an area is a means of evaluating subsurface conditions. Judgment must be based on an interpretation of certain visible conditions that represent the net effect of the surface and subsurface conditions. The ability to infer correctly is based on experience and on a working knowledge of geomorphic, pedologic and ecologic principles.

Frost and Mollard (1946, p. 563) were apparently in agreement, when they wrote:

> Adeptness in airphoto mapping depends, to a large extent, upon a basic knowledge of some of the natural sciences; soil mapping experience by the correlation of field data with airphoto pattern elements; knowledge of engineering problems as they relate to soil formation and topographic position; and the ability to observe, interpret and evaluate the fine details of the airphoto pattern.

However, three years later, Frost (1949, p. 5) modified his position:

> It is not necessary for the interpreter to become a specialist in the natural sciences dealing with surface features of the earth; rather, the interpreter should be aware of the sources of literature in the related fields since this is of paramount importance in obtaining background material about a particular area.

While Frost's 1949 statement correctly points out the need to know the sources of the scientific literature and implies the need for using the literature in fields relating to the discipline of the interpreter, his apparent lack of concern with the professional background and field experience required by the interpreter himself is not in agreement with the opinions of his colleagues.[6] Aerial photographs provide no substitute for first-hand knowledge of the landscape, even though they contribute greatly to that knowledge. It will be noted that the citations of the other authors, without exception, do not express this view.

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[6]This statement may have been influenced by the fact that it was prepared for delivery before a group composed of engineering rather than earth science professional men. The members of the audience, then, had professional backgrounds, but not in the earth sciences.

Bagley (1941, p. 111) asserts:

> It is important to become acquainted with the appearances of objects by experience. Study of photographs should be accompanied by field trips with the photographs in hand and direct identification of the objects pictured. As many different types of terrain as practicable should be studied. . . .

Coleman (1948, p. 472), a civil engineer and naval photo interpreter, in pointing to the solution of a particular type of photo interpretation problem, wrote:

> It [military coast and beach analysis] is achieved by a fine blending of photogrammetric and photographic interpretation techniques with scientific knowledge in geography, geology, vegetation, soils, and engineering, tempered with a thorough understanding of amphibious tactics.

Here a new point is added to the concept. Coleman's experience has proved to him that it is necessary for the interpreter to know and understand the use to which his product will be put. This is particularly true in cases where the interpretation is to be applied to some specific use such as highway engineering, regional planning, etc.

Spurr (1948, p. 176), a forester who has specialized in teaching other foresters the use and value of photo interpretation in forestry, is of the opinion that:

> Photo interpretation ability depends upon the ease and accuracy with which the interpreter can recognize under the stereoscope objects with which he is familiar on the ground. If technical distinctions are to be made, such as species identification, the interpreter should have had the necessary technical training. For this reason forest photo-interpretation should be carried out by trained foresters.
>
> It is of the utmost importance that photo-interpreters spend sufficient time in the field with photographs and a stereoscope to develop the ability to correlate forest features on the ground and the photographs. Familiarity with local conditions will do more than anything else to improve the speed and quality of office photographic-interpretation. Field reconnaissance and field checking are usually requisites of forest mapping from aerial photographs.

It is noted that Spurr implies that the photo interpreter should first obtain his professional training before making photo analyses. This does not mean, however, that he should complete his professional training before learning the photo interpretation technique. Training in professional background and in photo interpretation techniques go best hand in hand. Each can materially contribute to the effectiveness of the other.

Competent scientists in the various disciplines in which airphoto interpretation may be used as a technique of significant value have been cited above to the effect that the photo interpreter should (1) be familiar with the techniques of photo interpretation per se, (2) be thoroughly acquainted with the knowledge and methods required by his discipline, (3) be acquainted with the subject, process or area which is to be interpreted, (4) have a working knowledge of the various earth sciences, and (5) be aware of the literature relative to his problem whether or not this literature be within the literature of his discipline. There also seems to be emphatic agreement on the fact that the airphoto analyst can interpret with reliability only those objects or conditions which he could analyze in the field.

One factor not brought out in this discussion is the necessity for allowing the interpreter sufficient time to properly perform his analysis. This principle has not been followed in military photo interpretation for obvious reasons. For scientific purposes, however, the necessity for sufficient time is axiomatic.

Requisite training. Special training or experience is needed in at least one appropriate discipline to enable the individual to properly perform photo interpretation. Airphotos are not to be considered implements of black magic. No interpreter can expect to produce from them more information or more accurate information than he could obtain from a ground survey, provided that he would take the pains to map the area concerned in as great detail as shown on the photography.[7] But the interpreter can expect to secure the information he desires within the limits of his own interpretation ability and within the limits of the kinds and degree of information which is obtainable from airphotos by use of currently known techniques. This information will be made available to him in but a fraction of the time and cost than would otherwise be the case. From the viewpoint of energy expended it is not practical to attempt to represent an area cartographically in as great detail as is provided in aerial photographs, but that does not mean that the added detail on the airphotos should be ignored; indeed, this additional detail is one of the significant values of aerial photography. An inventory must be made before a geographic analysis or map can be produced. Decisions relative to the conclusions of such an analysis or the content of such a map are based on the completeness of this inventory. Therefore, without the use of airphotos with their wealth of detail, the law of diminishing returns as applied to detailed inventorying becomes operative at an earlier stage of the investigation because of the prohibitive cost of procuring the same amount of detail through field work.

A professional geographer's training at the college level might well emphasize the systematic earth sciences with at least one venture into

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[7] In a certain few instances this statement might not hold, as for example when time is of the essence. For example, if it was desired to map the damage caused by a hurricane over a thousand miles of coastline or to determine the distribution of specific hardwoods in leaf on the first day in May in an area six thousand square miles in size, it would not be possible to compile the data necessary to make the maps in one day. Airphoto reconnaissance could easily collect the data, however, and store the information for the record until the investigation could be completed.

the field of regional geography in terms of a broad region and another for a micro-region within the larger area. This statement is based upon general agreement among photo interpreters from the several earth science and engineering fields to the effect that the important portions of the interpreter's training are in the basic fundamentals of the pertinent natural sciences; the origin, processes, characteristics and life cycles of any natural or cultural feature to be interpreted; and, since nothing exists alone in nature, the associative relationships of these features.

In addition, some training in the synthesis of the various earth sciences is necessary in order that the interpreter may be able to produce regional geographic studies and evaluate landscape. A knowledge of the sources of literature for regions and of the methods of extracting the pertinent data from this literature is imperative. Experience in the field with airphotos in hand is also prerequisite to sound photo interpretation practice. In short, the amount of training needed for a general interpreter's background is so voluminous that it precludes itself for lack of time. It then becomes mandatory for the interpreter to specialize in the disciplines in which he has been trained and to depend upon keys produced by other specialists for reading subjects which are not closely related to his specialty.

Geography and photo interpretation. Almost all photo interpreters from fields of endeavor other than geography have indicated that the interpreter must be familiar with the geography of his area of research. The appropriate committee of the Research and Development Board, composed of outstanding earth scientists from all over the United States, has designated photo interpretation a geographic research technique. In spite of such strong indications as these that the interpretation of areas and of landscapes could best be done by geographers, the members of a number of other disciplines are currently exhibiting more interest in photo interpretation than professional geographers. Geologists, foresters, pedologists, and highway engineers are producing many times the amount of research in this field performed by geographers in the United States. Although no authentic, reliable figures are known to have been compiled on the subject, it is the opinion of the author that the great majority of institutions which offer one or more complete courses in photo interpretation are presenting the bulk of these courses in departments other than the department of geography.

Next to a team of scientists from the different earth sciences, such as the teams that employed the "combination method," utilized so successfully by the Forschungsstaffel (Smith and Black, 1946, p. 402), no individual man is better qualified by professional training and experience to perform photo analyses of the general landscape than a well-trained field geographer. Geographers should take more interest in this field which lies so close to the core of their science.[8]

THE DEVELOPMENT OF AIR PHOTO INTERPRETATION

The following pages briefly describe airphoto analysis in terms of its early history, the impetus given to it by World War I, the interwar years, World War II and its present status.

Early history. The first known aerial photograph was made by Nadar (1893) in Paris in the year 1858. Taft (1938) states that the first

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[8]The Forschungsstaffel is discussed in greater detail in the next section of this chapter. The cited reference to Smith and Black (1946) gives the best account of this organization that is available to American geographers today.

American airphoto was made over Boston in 1860. It is quite likely that a number of experimental photographs were made from balloons at this time with the experimenters being entirely unaware of each other. Balloon and kite photography continued in an experimental state until the advent of the first world war. According to Newbronner (1949), even carrier pigeons were employed as aerial photographers by the Prussian military forces during this period.

World War I. In the early part of the first world conflict the Germans installed cameras in both lighter and heavier-than-air craft, an action soon followed by the Allies. The differences between the cameras, the resulting airphotos and the quality of photo interpretation of the two world wars are comparable to the more familiar differences between the numbers and capabilities of the aircraft used in the two wars. Aerial photography of World War I was used for intelligence, engineering and map-making purposes, but methodology, instrumentation and aircraft had not advanced sufficiently at that time for photo interpretation to become recognized and firmly established as an essential component of the intelligence, engineering and cartographic fields.

Nevertheless, this first nebulous acquaintance that many men in military service had with photographic reconnaissance and photo interpretation during World War I was one of the prime reasons for the significant post-war increase in civil photo analysis.

The interwar years. The applied science of photogrammetry advanced most rapidly during the two decades between the wars. A large number of aerial survey companies were formed after World War I, many with pilots, aircraft and cameras left over from the conflict. Although the great majority of these companies failed, several of them, such as Abrams

Aerial Survey Corporation and The Fairchild Aerial Surveys, managed to secure contracts and produced mapping photography of such good quality that they were able to survive and become large firms in a highly competitive business with a limited market. The private aerial survey companies, usually under government contract, and the government's own aircraft produced a tremendous amount of aerial photography, which by the end of the interwar period covered most of the area of the continental United States at scales suitable for both mapping and interpretation.

Coincident with the vastly improved source of supply for airphotos provided by the government and by the private survey corporations, was the rapid development made in photo interpretation. For the first time articles devoted to the analysis of aerial photography began to appear in small but significant numbers in the journals of the several interested professional societies. At first the articles were general in nature, such as Willis T. Lee's classic: The Face of the Earth as Seen from the Air.[9] By 1939, however, literally hundreds of articles concerned with photo interpretation in specialized fields had been published in the professional journals of archaeology, ecology, engineering, forestry, geography, geology and pedology in the English, French and German languages. For example, in 1944 the U. S. Forest Service prepared a chronological listing of 286 works, published between 1887 and 1943, relative to the

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[9]New York, American Geographical Society, Special Publication No. 4, 1922, 122 pp., 82 maps and photos. More recent Special Publications of the American Geographical Society which are based primarily on aerial photos include: No. 12, George R. Johnson, Peru from the air. 1930, 171 pp., 141 photos. No. 26, John L. Rich, The Face of South America. 1942, 301 pp. No. 25, Richard U. Light, Focus on Africa. 1944, 228 pp., 323 photos.

use of aerial photographs in forest surveys.[10]

During this period there were no professional periodicals devoted exclusively or even chiefly to photo interpretation. Near the close of the period, however, several scientific journals commenced frequent publication of articles concerned with airphoto analysis. Among these were Photogrammetric Engineering, of the American Society of Photogrammetry, published since 1935; Luftbild und Luftbildmessung, about 30 issues of which were published during the last portion of the interwar period and the first few years of World War II; and Zeitschrift der Gesellschaft für Erdkunde zu Berlin, which, although largely devoted to other matters, carried articles on photo interpretation in the volumes published since 1938.

Although photogrammetry and certain aspects of scientific and engineering photo interpretation received a great impetus from World War I, military photo interpretation for intelligence purposes came to a complete standstill during the era of peace that followed the war. Unlike other arts and specialties of modern warfare, no training curricula were provided to insure a military photo intelligence capability. In Germany, however, several works were published before the outbreak of World War II, on the military aspects of photo reading, the volume of General Fischer being typical.[11]

Among the German geographers who labored for the cause of photo interpretation during the latter portion of the interwar period, the name of

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[10] See the Bibliography of Photo Interpretation Bibliographies appended to this dissertation for complete reference to similar bibliographies.

[11] Oberstleutnant Eberhard Fischer. Das Luftbildwesen. Verlag Bernard & Graefe, Berlin, 1938, 257 pp., 150 illus.

Professor Carl Troll is outstanding. Troll, associated with the Geographical Institute of the University of Bonn, led the movement for the establishment of the Wissenschaftliche Luftbildstelle at the Gesellschaft für Erdkunde zu Berlin. He also published several papers on the subject and had Russian books and articles concerning photo interpretation translated into German. These translations were mimeographed and distributed to geographers and other scientists interested in photo interpretation.

No consideration of this period would be complete without mentioning some of the many Federal government agencies that were making extensive use of aerial photography during the 1930"s. The Agricultural Adjustment Administration was systematically photographing the nation's crop and grazing lands and the Forest Service was photographing the nation's timber reserves; the Geological Survey was producing topographic quadrangles and geological maps with the aid of airphotos and the Soil Survey was mapping the soils of the United States by means of aerial photography. In addition, such regional agencies as the Tennessee Valley Authority, began to solve their planning and resettlement problems by aerial photographic mapping and interpretation. Even state, county and metropolitan planning agencies were rapidly taking up the new medium.

World War II. The stimulus provided by World War II produced aircraft of many times the speed, maneuverability, payload and capability of the pre-war flying machines. Similar improvements were made in the aerial cameras. A wide variety of aerial cameras, many of which cost more than a thousand dollars each, were purchased by the thousands for military use. One example of the special cameras perfected during this period is the continuous strip camera (Kistler, 1946) which permitted the making of a single stereogram nine and one-half inches wide and 200 feet in length.

This particular camera is important for the study of features with linear characteristics, such as beaches, stable military fronts and lines of communication. A strip of terrain, beach, front line or road 20 miles long can be covered at 1/600 scale with one roll of film. An additional advantage lies in the fact that no differential image movement occurs during exposure so that moving objects, such as waves and vechicles can be photographed stereographically, a performance not obtainable with ordinary cameras. This feature permits study of the ocean bottom along beaches to determine depth and character. As a matter of fact, height and depth measurements from continuous strip photography are likely to be more accurate than horizontal measurements because of the inherent difficulties in synchronizing the speed of the film in the camera with the ground speed of the airplane. For this latter reason, continuous strip photography is unfit for mapping purposes. Continuous strip cameras were made possible by the development of fast, low-flying aircraft.

The tri-metrogon camera installation, especially designed for reconnaissance mapping, is another World War II development. The trimetrogon technique is especially suitable to mapping rugged terrain at a tiny fraction of the time and cost required by previously developed methods. More than 15,000,000 square miles were photographed and mapped in this fashion during World War II (Fitzgerald, 1946). The installation consists of a camera mount designed to hold three wide-angle, six-inch-focal-length lens cameras in such manner as to provide horizon-to-horizon cover at right angles to the path of flight. A German development, the Pleon lens, provides horizon-to-horizon cover in all directions with a single camera, but involves special rectification equipment to overcome the resultant distortion. Night photography instrumentation and interpretation techniques including superior flares, flash bombs and the new electronic flash units also advanced rapidly. Late in the war radar position plan indicator scope photos were used for night interpretation and interpreting through clouds and other obscuration.

The increased capabilities for procuring airphotos called for a corresponding increase in the quantity and quality of interpretation. Just previous to World War II, Germany had organized and trained a group of military photo interpreters to a degree unknown to have existed in any other country. At the outbreak of hostilities, this group was supplemented by the militarization of Hansa Luftbild, G. m. b. H., an aerial survey company into which all other German aerial survey companies previously had been forced to merge.[12] The new organization was known as the Sonderluftbildabteilung or Sobia.

The British also built their first military photo interpretation center about a commercial aerial photo survey organization, whose principal members were commissioned in the R.A.F. The United States, with a two years' warning from 1939 to 1941, did not follow this practice. Instead, officers were sent abroad to study the British methods and then returned to this country to train American military and naval personnel. Upon recommendation of these officers, the United States government which had long been employing civilian photogrammetrists, employed its first civilian photo interpreters in 1941.[13] Soon after, additional civilian and military personnel were assigned interpretation duties and at the time of the Pearl

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[12] This merger was effected by decree of the German Air Ministry on 1 January 1934, presumably to make more effective use of the technicians, scientists and specialized equipment for possible military use.

[13] In so far as the author is aware he was the first civilian specifically designated as an aerial photo interpreter by the U.S. Government.

Harbor attack a full procurement and training program was under way. Long (1947), in a description of the types of operational photo interpretation duties performed by civilian geographers for the Army Air Forces during World War II, indicates geographers were frequently superior in photographic interpretation to personnel trained in other fields of knowledge.

As the demand for interpreters increased in proportion to the increased amount of photo reconnaissance, it was constantly necessary to train new readers and interpreters. Schools were established at Hildesheim, Goslar and Kiel in Germany, at Nuneham Park, Princes Risborough and Medmenham in England and at Harrisburg, Naval Air Station, Anacostia, Camp Ritchie, Camp Lejeune and Orlando in the United States. In addition, temporary schools were frequently established within local commands of the various services of these three countries to train or refresh military photo interpreters for use within a particular theater. As a consequence of this intensive training program, thousands of individuals were exposed to the elements of photo reading and photo interpretation. Although the quality and quantity of training varied considerably from school to school, the production of such a vast number of reserve military personnel as photo readers and interpreters provided a considerable impetus to civil photo interpretation in the post-war years.

The cognizant German, British and American commands turned out quantities of hastily prepared photo reading training materials and photo interpretation reference manuals. Each of these countries also published a periodical primarily for photo interpreters and designed to bring to their attention a steady flow of new or interesting airphotos of the enemy's installations and cultural landscapes in order to maintain and improve reading and interpretation efficiency as well as to improve morale.[14] As far as is known, the contents of these military photo interpretation periodicals have never been declassified, though this may be more from lack of personnel and time to review the material than from the point of view of security.

The United States forces, in particular, published many volumes of photo interpretation keys concerned with a wide variety of subjects from landforms and vegetation to industrial and urban analysis. The British Forces turned out relatively few of these manuals, partly because of the paper, personnel and time shortages and partly because their interpretation was largely centralized, whereas that of the U.S. was widely dispersed.

As the war continued, the German military photo interpretation capability decreased while that of the British and Americans increased rapidly. The causes of the German downfall in military photo interpretation are many and varied, but most of them have to do with the adverse effects of policy decisions on high levels; the effects of commanding officers in photo reconnaissance and photo interpretation who were either not technically qualified or not sufficiently aggressive; the rapid expansion of the Luftwaffe which promoted the best qualified photo reconnaissance and photo interpretation officers out of their technical billets; and strangely enough, the German penchant for thoroughness which seldom allowed the production of a method or instrument until it had been made perfect, a fact which resulted in the Germans' employing much the same photo interpretation equipment at

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[14] These were: Germany: <u>Mitteilungen für den Luftbilddienst</u>
<u>Technische Mitteilungen</u>
England: <u>Evidence in camera</u>
United States: <u>Impact</u>

the end of the war as they had in the beginning. There were many other contributory causes, including the jealousy of the intelligence officers who finally succeeded in having the photo interpreters made entirely subservient to them.

In contrast to their military failures in photo interpretation, Smith and Black (1946) describe the notable advances in the German civil geographic organizations engaged in photo interpretation. The principal ones were:[15]

1. Wissenschaftliche Luftbildstelle, a special unit of the Deutsche Geographische Gesellschaft, located at the Gesellschaft für Erdkunde., H. Bobek, Geographer, Head.

2. Abteilung für Landeskunde of the Reichsamt für Landesaufnahme. E. Meynen, Geographer, Head.

3. Foruchungsstaffel zur besonderen Verwendung, Oberkommando Wehrmacht. O. Schulz-Kampfhenckel, Geographer, Head.

The Wissenschaftliche Luftbildstelle had a dual purpose mission: to promote aerial photo interpretation research on a world-wide basis, and to make airphoto materials accessible to scientific agencies. The Abteilung für Landeskunde was devoted solely to furthering regional geography within Germany. Among other means to this end, including a library, a map collection and bibliography, it kept an extensive airphoto collection designed primarily for developing internal scientific regional geography (Troll, 1949, p. 121).

The Forschungsstaffel zur besonderen Verwendung, Oberkommando Wehrmacht, commonly called the Forschungsstaffel, was outstanding in its photo reconnaissance and photo interpretation work applied to special military

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[15]The following civil agencies also made significant use of photo interpretation: Mil-Geo (Army), Mar-Geo (Navy), Luft-Geo (Air Force), Eisdienst (Deutsche Seewarte), Wehrgeologie, Organization Todt, Reichsforschungsrat, Photogrammetrische Abteilung (Reichsamt für Landesaufnahme), Reichsforstat.

needs, its mobility from one theater of war to another, the celerity with which it produced the required information, and its famous "combination mapping method" by which mature scientists from the different earth sciences worked in teams in performing the air reconnaissance, the photogrammetry and especially the photo interpretation necessary to produce military maps (Smith and Black, 1946, pp. 401-402).

Forschungsstaffel operations were frequently one-package affairs. The staff included photo reconnaissance pilots equipped with suitable aircraft, photo technicians, photogrammetrists and a corps of about 80 mature, well-trained scientists from the fields of geography, geology, plant association botany, forestry, pedology, etc., who worked not as individuals, but in teams in the process of securing information by photo interpretation and plotting the results in map form.

The outstanding German exponent of photo interpretation during World War II was the geographer, promoter and Nazi, Dr. Otto Schulz-Kampfhenkel, who was not only the founder and the scientific director of the Forschungsstaffel, but the official of the German National Research Council (Reichforschungsrat) responsible for all problems in geographic research. Troll still retained a very active and constantly growing interest in geographic airphoto analysis, but his efforts to advance photo interpretation were overshadowed by the aggressive activities of the younger Schulz-Kampfhenkel, a fact which is largely attributed to the latter's considerable political influence with high Nazi officials including Reichsmarschall Hermann Goering, (Fischer, 1948, p. 308; Troll, 1949, p. 126). Probably not less than two score other geographers participated regularly in the analysis of aerial photography for geographic research and military operations. More than half of these were members of the Forschungsstaffel.[16]

An interesting item to note is that with the exception of Troll, Bobek and Meynen, most of the well-known, active German geographic photo interpreters appear to have been born in the 1901-1909 era, making them about 30 years of age at the outset of World War II. This age bracket generally corresponds with the ages of photogeographers in England and the United States, where few geographers who have been seriously engaged in photo interpretation as a geographic research technique for a period of five or more years have yet reached or passed their early forties. The large proportion of photogeographers in the relatively young age brackets is a natural consequence of the comparative newness of the subject. Most geographers born prior to 1910 developed their basic research methods and field techniques before instruction in airphoto interpretation was available to them. Many geographers born after this date received military training in airphoto interpretation.

Troll reports (Fischer, 1948, p. 308) that the Forschungsbeirat für Vermessungtechnik und Kartographie selected 34 typical regions for minute ground and airphoto survey to determine the best means for their

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[16]Drs. F. Bartz, H. Bobek, W. Credner, H. Ellenberg, E. Ewald, R. Finsterwalder, Kreuger, W. Grotelueschen, E. Meynen, E. Otremba, G. Pfeifer, W. Pillewizer and S. Schmithüsen are included. In related fields, the following scientists engaged in the interpretation of airphotos closely associated with geographic research: Plant association botanists Drs. H. Gams, F. Haske, E. Hassmer, H. Hueck, and R. Tuexon; geologists Drs. H. Cloos, Splechter; pedologists K. Kuron and E. Vageler; and limnologist Dr. E. Wasmund. K. von Klebelsberg interpreted the 12,000 oblique aerial photos taken on the Deutsche Antarktische Expedition, 1938/39. Smith and Black (1946, p. 402) note that 80 such scientists were engaged in this type of work for the Forschungsstaffel alone.

cartographic presentation.[17]

Present status. After the cessation of hostilities, the military photo interpreters, who were nearly one hundred per cent reserve personnel, were almost entirely demobilized in all countries, except possibly the Soviet Union. In the U. S. and British armed forces, some photo interpretation schools have been retained on a reduced basis to avoid loss, through normal attrition, of the interpreters still on active duty. In the United States, civilian photo interpreters have been employed to complement or even to replace the military interpreters at various military installations. Civilian employment involves less cost to the government, provides the exact specialists desired and provides the important element of continuity which is lacking among the military personnel who are constantly being reassigned to other duties. On the other hand, employment of civilian photo interpreters by military establishments limits the mobility of such interpretation units.

The civilian and military interpretation personnel of the armed forces have continued to advance the technique, particularly in terms of moulded aerial photos, regional and subject photo interpretation keys, improvement of radarscope interpretation, development of television and high-speed facsimile photo interpretation and the development of new methods of reading

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[17] Troll's (1947) analysis, critique and justification of geographic science in Germany during the period from 1933 to 1945 was to be written in two parts, the first of which appeared in 1947 in the initial issue of the post-war geographic publication, Erdkunde, and which was reviewed by Fischer (1948) and in part translated into English by Fischer (Troll, 1949). Troll stated in a personal communication to Fischer (Fischer, 1948, p. 309) that part II would include ". . . . special chapters about scientific airphoto interpretation . . . . /and other subjects/. . . . specially developed in the German geography of the last ten years." In view of the wide acceptance of Part I of Dr. Troll's work, and his unquestionable standing, both as a geographer and a photo interpreter, this article, which was to have appeared in 1949, is still awaited with considerable interest.

photographs taken through obscurations.

The veteran photo interpreters who have returned to civilian life are, in many instances, applying the techniques of photo interpretation learned in the military services to their civilian pursuits.[18] Many of these, especially in England and the United States, have returned to the universities where they are teaching photo interpretation as a technique of their particular field of science or engineering.

Scientific research based upon photo interpretation is increasing annually, especially in the universities. There are numerous reasons for this, aside from the many young scientists who received World War II training in the basic technique. At present aerial photography is available from the Production and Marketing Administration of the U. S. Department of Agriculture for almost any portion of the United States. A considerable amount of aerial photography of the United States and of foreign areas is available from other sources.[19] In addition, Smith (1944, p. 729) and others have demonstrated that where precision is not required, anyone possessing a 35-mm. camera, such as a Leica or its equal, can hire a small aircraft and produce his own aerial photography.

Other reasons for the upswing in scientific photo interpretation include the large amount of literature now available, currently amounting

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[18] For example, one group of veterans who were young geologists formed an organization which offers petroleum companies a petroleum prospecting research service by airphoto interpretation on a consulting basis. The company has been an outstanding success, increasing its employees from four to more than 70 during its first five years of operation.

[19] U.S. Soil Conservation Service, U.S. Forest Service, U. S. Geological Survey, U.S. Air Force, U.S. Navy, U.S. Coast and Geodetic Survey, the governments of many foreign countries and the commercial aerial survey companies.

to thousands of individual references[20] and the financial support given to the research staffs of universities, scientific organizations and commercial companies by various state and federal government agencies. At the present time photo interpretation is being used as the principal technique in a wide variety of research projects involving several scientific disciplines.[21]

While photo interpretation itself is not a field of science, the number of scientific personnel in the United States who are actively interested in photo reading or photo interpretation number in the thousands. This number is equal or superior to the number of professional personnel engaged in any one of several of the scientific disciplines.[22] Some of the principal differences between photo interpreters and the members of

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[20] See the Bibliography of Photo Interpretation Bibliographies, appended hereto.

[21] Some of these are:

Type Study	School	Dept.	Principal Investigator
Vegetation Analysis	Boston U.	Geography	Dr. Ericksen
Vegetation Analysis	Catholic U.	Botany	Fr. O'Neill
Landform Trafficability	Cornell U.	H'way Eng.	Dr. Belcher
Sand Dune Terrain	U. of Kansas	Geology	Dr. Smith
Coastal Geography	La. State U.	Geography	Dr. Russell
Pleistocene Landforms	N'western U.	Geography	Dr. Powers
Settlement Patterns	N'western U.	Geography	Dr. Kohn
Crops	N'western U.	Geography	Miss Smith
Permafrost	Purdue U.	Eng. Exp.	Prof. Frost
Highway Studies	Purdue U.	Eng. Exp.	Prof. Woods
Regional Keys	U. Virginia	Geography	Dr. Crittenden
Coastal Landforms	U.C.L.A.	Geology	Dr. Putnam

[22] For example, all classes of membership in the Association of American Geographers, which includes essentially all of the professional geographers in the United States, did not exceed 1600 in 1950.

any of the smaller scientific professions are the facts that the former have no society or association, are unorganized as a group and are largely unacquainted as individuals or even by reputation. The photo interpreter quite properly considers himself as being first of all a geographer, geologist, ecologist, or whatever his basic profession may be.

This situation has resulted in a lack of stimulation, a lack of interest in promoting photo interpretation research and consequently in a larger share of the individual photo interpreter's research effort being expended entirely within his primary field of inquiry without making use of the photo interpretation technique. This situation has also resulted in a lack of research in airphoto analysis per se inconsistent with the number of professional personnel actively engaged in the pursuit. The lack of any specific organization or association to promote research in photo interpretation and the lack of professional publications devoted to the subject further retard interest in photo interpretation.

The long period of waiting may soon come to an end. Two international and two national societies have indicated an interest in sponsoring photo interpretation. The International Geographical Union has established a Commission on the Utilization of Aerial Photographs[23] which is now preparing a report for the XVII Congress to be held in Washington, D.C., August 1952.

At the 47th Annual Meeting of the Association of American Geographers in Chicago, March 1951, 40 members of that association gathered for an impromptu session on photo interpretation. It was the concensus of those

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[23]The Commission members are Barrère and LeMéhauté of France, von Frijtag Drabbe of the Netherlands, Linton of the United Kingdom and Stone and Roscoe of the United States. The Commission met in Paris in January 1952 to plan its report to the XVII Congress.

present that a sufficiently good program could be devised each year to ask the program committee for space for a half-day session at each annual meeting hereafter. More than enough papers on this subject were pledged for 1952.

Officials of the American Society of Photogrammetry have approached leading photo interpreters with the suggestion that a sizable portion of each issue of "Photogrammetric Engineering" be devoted to photo interpretation subjects. The offer has not been accepted, largely because of a lack of any organization of photo interpreters to make the acceptance. Nevertheless, the principal feature of the December 1951 issue of the society's professional periodical "Photogrammetric Engineering" was a written symposium on "Air Photos in Geography and Soil Science" contributed to by geographers Stone of Wisconsin, Kohn and Powers of Northwestern and Foster of Illinois, among others. At the annual meetings of the American Society of Photogrammetry in Washington, January 1952, an oral symposium on photo interpretation was held. More than 800 members of the society listened to the 15 speakers in spite of the fact that simultaneous symposia had been scheduled for other strictly photogrammetric subjects. Twice as many papers are planned for 1953.

In addition to the above, Commission VII of the 7th International Congress of Photogrammetry plans a session on photo interpretation to be held at the congress in Washington, September 1952.

Although archaeologists, foresters, pedologists, geologists, ecologists and other professions are interested in or utilize airphoto interpretation, there are no known movements afoot to organize photo interpreters within these professions.

These are some of the problems which face the photo interpreters of today:

1. The formation of a society which would either issue a periodical devoted to photo interpretation research or the sponsorship of such a periodical in one of the earth science or engineering fields in which photo interpretation is employed as a standard technique.

2. The completion and wide dissemination of bibliographies relating to photo interpretation, particularly to its methods, techniques, subject fields and regional aspects.[24]

3. The completion and dissemination of a world atlas of purchasable aerial photography.

4. The completion and dissemination of a roster of qualified photo interpreters including their primary specialties and other pertinent data.

PHOTO INTERPRETATION KEYS

The problem. Recent developments in optics, emulsions and film processing have improved resolution and increased the value of aerial photography as a tool of science, but even with the finest resolution, photo interpreters can neither adequately determine nor properly describe phenomena with which they are unacquainted. Individual interpreters cannot be trained in all the earth sciences nor can they be familiar with the myriad of cultural patterns superimposed upon the earth's surface. A device is needed to provide the individual photo analyst with the information necessary to rapidly and accurately perform the interpretation problem assigned.

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[24] Much of the ground work for this has already been accomplished. Refer to the Bibliography of Photo Interpretation Bibliographies appended to this work.

Under normal circumstances a photo interpreter can accurately recognize only the photo images of objects with which he is familiar. Analysis and interpretation of these images demand a competence in the discipline concerned. Most interpreters have received professional training and performed research in one of the engineering, military, biological or earth science professions. But a geologist, who may make his living prospecting for petroleum by photo interpretation, falters in the analysis of buildings and their structures; the architect frequently cannot differentiate between the 105-mm. howitzer and anti-aircraft emplacements; the military expert finds himself unable to estimate the production capacity of an aluminum plant from the photo images of its facilities. These difficulties all result from the lack of personal familiarization with the object analyzed, its origins, its life cycle and its associations.

It is impractical to attempt training individual interpreters in each of the many background fields. While interpreters are normally capable specialists in one field, it is often found impractical to restrict their entire research or operations effort to that single specialty. This is especially true in the case of military photo interpretation and in research projects where all of the investigators are from the same field of earth science, where complete staffing is not practical and where the team approach cannot be used.

The solution. A photographic image may stimulate an interpreter's mind in one or both of two ways: association or recall. A biologist, botanist or ecologist interpreter may determine the trafficability of a certain soil type by recognizing and analyzing the vegetation associations which grow upon it, and with which the trafficability is closely associated. This process constitutes genuine photo interpretation. An architect, however, may determine the same factor of soil trafficability if he has had the opportunity of seeing and being taught the meaning of similar images on airphotos previously examined. This is recall, a simple memory technique, a process of photo reading rather than photo interpretation.

Obviously then, while an interpreter can analyze and interpret only the subjects with which he is thoroughly familiar, a trained investigator may accurately read any photographic image, provided he knows where to find the proper photo interpretation key in the form of a similar image and its correct interpretation. The solution to the problem, then, lies in the provision of a suitable photo image reference file, containing annotated photo images of the natural and cultural objects most necessary for any given photo reader or interpreter to know. These annotated photo images are called photo interpretation keys.

Definition of keys. Aerial photographic interpretation keys are variously referred to as airphoto interpretation keys, photo interpretation keys, photo reading keys, P. I. keys, interpretation aids, or simply keys. Keys may be defined as devices designed to aid photo readers and photo interpreters in the rapid and accurate identification of objects from the study of their photo images. Their essential function is to draw the attention of the investigator to recognition features of diagnostic value. These recognition features may be elements of photo images, whole photo images or photo image complexes.

Keys are chiefly comprised of annotated aerial photography on which specific photo images or elements of photo images are emphasized. There is a wide variety of forms in which keys may appear, however. They may be on single prints, mosaics, stereograms or even slides. They may be vertical airphotos, high or low obliques, ground photos or combinations of these. They may appear in infrared, color, color camouflage, panchromatic or other types of emulsions. They may have annotations, titles or legends. They may be accompanied by diagrams, sketches or drawings. In addition, they may be mounted in a card file system, bound in a manual, published in a periodical -- or, as is too often the case, they may merely exist in the memory of an individual interpreter. The latter are called memory keys or mental keys.

Most interpreters make extensive use of memory keys in the same way that one makes use of his vocabulary of memorized words or the multiplication tables. Unlike the words or the multiplication tables, however, most memory keys are not recorded in any reference work. This situation has created two undesirable conditions. First of all, it is difficult for the interpreter to check his memory keys to see if they are all accurate. Thus if the key has resulted from an originally incorrect interpretation, the interpreter will continue to make the same error. Secondly, memory keys do not provide a suitable means for the experienced interpreter to transmit the information that he has learned through years of professional training, specialization and field examination.

Categories of keys. All keys may be classified as belonging to two or more of the following five categories, which, therefore, are not mutually exclusive. The first two of these are based upon the manner in which the keys convey their information while the remaining three are concerned with the kind of information the keys purvey. The latter terms are frequently used to describe the manner into which collections of keys are grouped as well as the individual keys themselves.

Direct keys are photo images which are recognizable in themselves for what they are, e.g., petroleum storage tank, plowed field.

Associative keys are photo images recognizable in themselves and from which, by the process of deduction, information can be provided about the associative factors, such as climate, which may not be shown in direct image form on aerial photography, e.g., the identification of a certain vegetation complex provides additional associative information about the climate, soil, ground water level and trafficability, none of which may be directly visible on the airphoto. Associative keys are the most important keys and at the same time the most difficult keys to master. They are based upon the axiom that in nature nothing occurs by itself. Identification of plant associations, geologic structures and landforms may provide clues to the determination of climate, soils, hydrologic conditions, presence of certain types of rock or mineral deposits, trafficability and many other factors.

Subject keys are photo images concerned with the various aspects of a single subject field, e.g., vegetation, aluminum manufacture, regardless of geographic location.

Regional keys are photo images concerned with all subjects within a given geographic or other type region as contrasted with photo images of similar objects for other regions or the regions with which we are familiar.

Analogous keys are photo image keys prepared for one given geographical or other specified type region which may by extension, be used to solve problems by means of photo interpretation in a similar, but inaccessible region, e.g., certain portions of Canada have soil and plant regimes which are similar to certain known parts of Soviet Europe and Asia where scientific travel may be restricted.[25]

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[25]Although analogous keys as such have not appeared previously in the scientific literature, the principle has been used by most competent photo interpreters for some time. Spurr (1948, p. 176) states: "Knowledge gained from a study of photographs for which detailed information has been compiled, can be applied to the interpretation of similar photographs in the same region." With equal veracity Spurr could have added: "or similar regions."

In reality, a single key might be classified as belonging to all five of these categories. For example, the image of a larch or tamarack tree is a direct key which may easily be identified at some seasons from other conifers because of its deciduous character, thus becoming recognizable in itself. The tamarack image also belongs to the associative key category because it reveals by association the presence of acid soils, a high ground-water table, poor drainage and, in the Arctic, the probability of an extremely thin active layer above the permanently frozen ground. The tamarack is a subject key since it is a part of the subject field of vegetation; it may act as a regional key in that it is a product of the Canadian sub-Arctic forest region. The photo image of the tamarack also has an analogous quality since this tree occurs extensively throughout the Russian taiga, which is not accessible to western scientific travellers.

It is well to point out that most of the individual collections of keys consist of direct and associative keys concerning a subject or region or sometimes a subject within a region, e.g., Nebraskan sand dunes, tundra vegetation of Alaska. Subject as well as regional keys may be valuable as analogous keys. A collection of keys relative to the coke, iron and steel industrial complex in the United States would be useful for interpreting airphotos of similar installations in the Ruhr or in Japan.

The dichotomous or bifurcating key, a device designed to simplify accurate reading from photo interpretation keys by photo readers without professional backgrounds in the subject fields concerned, is appearing more frequently in the literature of today. These terms refer to a system of diagnostic recognition keys arranged in branching formation on a chart or in tabular form. The photo reader is called upon to make a series of individual but simple decisions relative to the appearance of the photo image he wishes to identify. This series of decisions leads him to the correct interpretation of a complex photo image without the necessity of having an appropriate professional background or of using the scientific terminology. Such keys can be derived only by expert interpreters and have thus far been limited to subject keys or keys of a specific subject within a given region.

As an example, a photo reader using a dichotomous key might first be called upon to determine whether or not the airphoto in question showed winter or summer phase vegetation. Having determined that the area concerned was photographed during the summer phase, the reader might be called upon to determine whether the particular image of natural vegetation before him consists of short grass, tall brush or trees. If trees proves to be the answer, the interpreter may further be asked to determine whether the trees are situated in a low marshy area, on a stream bank, in hilly terrain, etc. In the series of questions the current question is always determined by the previous answer. Eventually all types of vegetation but one are eliminated from consideration and the reader is referred to a detailed description of this one type of vegetation and its soil, landform, hydrologic and climatic associations.

Colwell (1945, 1946), an ecologist and forester, established a dichotomous key for determining ground conditions in the tropical Pacific areas through the identification of vegetation. Belcher (1951), a pedologist and highway engineer, established an equally fine method of determining ground conditions from a bifurcating analysis of landforms in temperate areas. Similar branching keys have been developed by other researchers working on contract to the Department of Defense.

Variations in keys. One of the most difficult problems faced by the photo interpreter attempting to establish a series of keys is the tremendous number of variations possible in the appearance of the photo images of a single type of object. In a few instances these variations are so numerous that keys for certain objects must be incomplete, extremely complex or relatively worthless. Normally, however, these difficulties may be overcome through the judicious selection of photo images for use as keys.

The actual determination of keys is a complex and difficult process. Unlike maps which tend to have standard symbols for the detail selected for map presentation, aerial photographs do not have standard keys for photo image detail. This is further complicated by the fact that the detail on an aerial photograph is not selected detail as that appearing on a map, but rather the airphoto is a tremendously reduced reproduction of the actual appearance of a specific portion of the earth's surface at a given time. On aerial photographs there are no blank spaces between the keys. In addition, the keys are normally proportionate in size to the objects they represent.

An individual key does not merely represent an individual object or association complex, but rather, an individual object or association complex (1) at a given scale, (2) on a given type of film (panchromatic, infra-red, color, etc.), (3) at a given season of the year, (4) at a specific camera angle (vertical, oblique, ground), (5) with a given relationship between the source, strength and position of the light and the camera lens, (6) under a specific atmospheric condition, (7) at a given time in the age or development cycle in the subject, (8) according to the natural and cultural patterns of a given region, (9) as processed (developed and printed) according to a specific standard, and (10) with other variables such as the type of sensitized paper, the purity of the water used, or the quality and focal length of the lens. If any of these conditions are varied, the tone, texture, shape, size, shadows, parallax, pattern or position which forms the recognition characteristics of the photo image may change and thus change the appearance of the key itself.

These variations serve to compound an already complex situation, since they cause many similar objects to be characterized by dissimilar photo images and, conversely, many totally unrelated objects to project quite similar images. Examples of this include such incorrect analyses as the photo image of a small paper factory in China being interpreted as a cemetery, native sugar mills on Okinawa as animal-powered pumps (Hack, 1948, p. 495), and animal-powered water pumps in North Africa as occupied gun emplacements.[26] While all of these mistakes were natural for photo readers without access to the proper keys, regional photo interpreters, versed in the local cultural landscape, would not be likely to make such errors.

The large number of variations possible is a major problem in the production and publication of keys. In the process of determining and presenting keys, emphasis is placed upon the recognition characteristics which are least variable. All of the usual phases or varieties of the object which casts the photo image must be well illustrated. It is not unusual to find that a large number of keys must be presented for an individual object or association complex. For this reason, publications of keys are usually restricted to one region, one subject or even one subject within one region, in order to provide adequate treatment of the keys

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[26] The paper factory was mistaken for a cemetery because of the similarity between the white dots of paper drying in the sun and western tombstones. Primitive Okinawan sugar mills, animal-powered water pumps and anti-aircraft emplacements are all circular structures, the direct images of which resemble one another at certain photo scales.

concerned within the space limits of one publication.

In the problem of identifying keys on aerial photography, not the least significant factor is the human one. Regardless of the care in the definition of a key, objects do not look the same to all people, nor do various individuals have the same ability to describe what they see under the stereoscope. Where careful measurement can be made, however, it is possible to reduce the element of human error considerably. Wide background knowledge, careful supervision during an adequately lengthy period of training, availability of photo reference key library, the constant use of photographic interpretation techniques, and frequent field trips with airphotos in hand, all tend to minimize the variability in the human factor.

Uses of keys. Basically, keys are devices to enable photo analysts to read or interpret aerial photography, which is not an end in itself, but an efficient means of solving certain problems. Keys are necessary to the neophyte interpreter or the nonspecialist who wishes to read aerial photography with greater speed and more accuracy. Collections of keys may also be employed as:

1. Library reference materials concerning subjects or regions of research interests.
2. Sources of training aids for producing trained readers or interpreters in a minimum of time.
3. Permanent records of photographic interpretation research and experience as opposed to memory keys.
4. Reliable bases for examining, confirming, improving and enlarging upon existing keys and collections of keys, as well as improving upon the techniques of collection, presentation, distribution, and utilization of the keys.

Compilation of keys. It becomes mandatory for the photo interpreter to consider the procedures necessary for effective keys to be produced. The best keys are produced by field research. When the interpreter is able to visit the area or the subject type installations, he may organize his work in preparing keys as follows:[27]

1. Preparation of a concise statement of the problem.
2. Preparation of an outline for a report on the compilation of keys necessary to solve the problem.
3. Airphoto search.
4. Documentary and cartographic search.
5. Review of collected airphotos, maps and documents.
6. Scale determination, orientation, plotting, indexing and filing of airphotos.
7. Pre-field-work stereo examination of airphotos.
8. Revision of outline for report on keys.
9. Preparation of list of problems to be solved by field reconnaissance.
10. Field reconnaissance (with stereoscope, airphotos and the list of problems in hand).
11. Post-field-work stereo examination of airphotos.
12. Final revision of outline for the report on keys.
13. Coordination and presentation of findings in the form of a collection of keys relative to the subject or area concerned.

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[27] Stone (1948, p. 466; 1951, p. 756) has considered nine steps necessary for the production of authoritative photo interpretation keys. The fourteen steps here shown are based upon the personal experiences of the writer, the stimulation created by Dr. Stone's articles, the paper by Frost and Woods (1948, p. 2) and other professional communications.

14. Presentation of scientific findings based upon keys.

When the interpreter devising the keys is unable to visit the area or installations concerned, steps 9, 10, 11 and 12 must of necessity be omitted and the reliability of the keys is diminished accordingly.

Individual photo images increase in value as keys in proportion to the amount of supporting information pertinent to the photographic illustration which accompanies each photo key. Much of this supporting information is concerned with the variable conditions listed above.

Effective collections of keys devote considerable space to stereo examples of each key under each of the more common varying conditions, and so enjoy the benefits of comparative photography. Attention is drawn to the features which vary the least in appearance and in meaning, for these are the most reliable recognition features. In many instances, the most reliable indicators are not the most conspicuous ones. Care must be taken to point to the diagnostic features rather than those which are most evident on cursory examination.

All authorities agree that authenticity of keys is derived primarily from field experience, examination of airphotos while in the field, observation flights and detailed knowledge about the area or subject concerned. Collections of keys are, in fact, collections of the compiler's experiences. Some students, such as Pfeifer (1946, MS p. 14) and Wieslander and Wilson (1944, p. 717), express their firm conviction that the meanings of images on airphotos are inferred or interpreted only through the training and field experience of individuals, and that this experience and background knowledge constitute the real keys to photo interpretation. While this is not disputed, it must be pointed out that interpretation by training and experience without graphic keys suffers from the basic defects attributed to memory keys earlier in this section.

The era of systematic and regional research, based upon the photo image and the photo key, is now at hand. It is difficult to say exactly when the first airphoto interpretation keys were compiled or published. Military photo interpretation procedures are sometimes said to date back to the balloon photography of the Civil War and Franco-Prussian War. Lee (1922, p. 4) showed that the term key and the concept of analogous keys were in the minds of alert interpreters as early as 1922, when he wrote:

> A necessary preliminary is an acquaintance with the ground photographed or with similar regions and features. Without such a key, the aerial photograph is not always self interpreted and is often unintelligible.

The development of photo interpretation keys may be expressed in capsule form: the invention of the camera and the development of heavier-than-air craft led to an increase in available air photography, later followed by an increase in photo interpreters, and still later by articles or volumes concerned with rudimentary keys. During the late 1930's and 1940's, modern keys appeared in numbers and now master keys, such as the branching key systems of Colwell (1945, 1946) and Belcher (1951), have been published.

PHOTOGEOGRAPHY

It is proposed that the procedure of applying photo interpretation to effect the solution of geographical problems be called photogeography. This term is expressive, concise and with ample precedent in the well-known and commonly used term photogeology.[28] The terms photobotany and

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[28] A cursory glance through three numbers of Photogrammetric Engineering (vol. 13, no. 4; vol. 15, no. 4; and vol. 16, no. 5) reveals no less than 14 articles or references to articles in which the term photogeology is expressed in the title. Authors include Brundall, DeBlieux, Dejardins, Dirmeyer, Melton, Miller, Rea, Smith, Tator, Wasem and Wengerd. Putnam (1947) credits Rea with the first description of the method.

photopedology have not yet reached the wide acceptance accorded the term photogeology, but it appears that the use of these words is also increasing. Those who specialize in the practice of photogeography may be termed photogeographers in accordance with the pattern established by the photogeologists.

Photogeography may be defined as the process of obtaining information of a geographical nature by means of the interpretation of photographs. Such interpretations are based upon the joint employment of geographical training and experience along with airphoto and surface photo interpretation techniques. Sound geographical practice demands that, whenever feasible, photogeography be practiced with and not in place of field examination, library research and other standard geographic research techniques.

MacFadden (1949, p. 108) calls the attention of geographers to the inadequacy of the reconnaissance and inventory tools used in geographic field research. This inadequacy has resulted in excessive demands upon the researcher's time for preparation of his work in a scientific and scholarly manner. The final result is either a research product restricted in scope or deficient in intrinsic character. MacFadden suggests the use of an ordinary 35-mm. camera and a light aircraft of the type available for rental at a reasonable cost ($6 to $12 per hour) at almost any small airport as tools for geographic reconnaissance and inventory. These tools have been available for more than two decades, but few geographers other than occasional pioneering spirits (Light, 1944; Rich, 1941, 1942, 1947) have taken advantage of them.

There are several distinct advantages to the joint use of the 35-mm. camera and the light aircraft as a reconnaissance procedure. Where commercial photography is wanting, the geographer, himself, can often provide a satisfactory substitute; where it is present, he can inexpensively supplement it with detailed obliques of the significant subjects pertinent to his problem. In addition, the geographer, as an amateur aerial photographer, may secure complete photo coverage controlled to his own specifications for such factors as scale, angle, orientation of view, atmospheric clarity, emulsion, seasonal or comparative photography and airphoto image detail in complete conformity with surface conditions at the time of field investigation. Thus, many of the characteristics of commercial or government aerial photography are also present in private reconnaissance photography.

Geographic airphoto interpretation, whether performed with the geographer's own photography or with airphotos from government or commercial sources, permits superior production of geographic knowledge in a variety of ways. For example, it allow the geographer to explore in some detail areas or landscapes hitherto unknown or presently inaccessible to man, such as the Antarctic. It permits reconnaissance of any photographed area or region, large or small, in which the geographer intends to perform field work. Effective airphoto exploration and reconnaissance further permit the geographer to establish a superior plan of research procedures tailored to his specific area, which in turn results in the production of geographic knowledge superior in quantity and quality to that which would otherwise be obtainable. It is also less costly in terms of money and in the most valuable of all research factors, time.

Some landscape patterns, unnoticed for centuries from the ground view, are easily discerned from airphotos. In particular, certain ancient roads, walls and earthworks, long since grown over, buried or plowed under, show with remarkable clarity in arid regions and sometimes even in humid regions (Crawford, 1938; Poidebard, 1932). Patterns, other than historical settlement patterns, not readily recognized from the ground include dense vegetation patterns, major landform patterns, soil patterns and the spatial relationships of all objects whose photo images appear in the airphotos.

Another important aspect of the airphoto in geography is that it offers a detailed and permanent record of the landscape at a given time on a given date. This feature makes possible the escape from a frequent difficulty of geographic field work: the errors or misinterpretations resulting from the collection of data from different parts of an area during different days, weeks, months, seasons or, in some instances, even different years. Where required, however, comparative photography which shows the different aspects of the same landscape at different seasons or in different years is often available. In years to come, historical geography will profit handsomely from these basic records, for the geographers of future times will have available some of the same raw material (airphotos) that are available to the geographers of today. Our present concepts of historical geography, sequent occupance and dynamic landscape would, no doubt, be considerably different if aerial photographs were now available illustrating the landscape as it has appeared through the centuries.

Russell, Foster and McMurray (1943, p. 315) describe this photographic record as a potential encyclopedia of geographic, geologic, sociologic and other types of information which they caution, will not become available for geographers until systematic methods are developed to translate the various elements of the photo image into a vocabulary which speaks in terms of previous experience. Smith (1944, p. 742) states that the record provided by airphotos is more accurate and more complete than that afforded by any save the most elaborate maps. This is a conservative estimate.

Vertical airphotos are of inestimable value to the geographer for use as a map base in the collection and compilation of geographic data in the field. Photos may be annotated by marking with colored china marking pencils or translucent inks either directly on the print or on a cellulose acetate or tracing paper overlay. Field mapping by annotation of an airphoto or overlay is readily performed by the traverse method in which the geographer visits at least one of the objects which cause each type of photo image appearing on the airphotos of his region. The photography must be brought up to date by the field traverse since numerous changes may have occurred in the landscape or its utilization since the date of the aerial photography.

Stereographic viewing of the airphotos in the field is easily accomplished by photogeographers with the aid of a pocket stereoscope. For field convenience, nearly all field investigators with eyes of equal strength may learn to view stereoscopically without the use of an instrument of any kind. The only requirement is the ability to control the convergence and the focus of the eyes so that they converge at infinity while focussed for nearby objects. The resulting stereo model gives the impression of relief which is not obtainable either from the ground or from an aircraft flying more than 2,000 feet above the terrain.[29]

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[29]From the ground, only the relief facing the observer and not the relief in defilade can be observed. From an aircraft, the interocular base is too small to obtain any accurate sensation of relief when flying at altitudes of more than 2,000 feet above the terrain.

The photogeographer is able to visualize whole "county size" parcels of landscape by using mosaics. He may study, in the third dimension rendered by the stereoscope, areas of several square miles in a single view. These factors give the photogeographer a broad view unobtainable by any other means including the viewing of maps which contain only selected detail represented by conventional signs and symbols. Relationships which are important factors in the "synthetic science" of geography are thus more readily and more accurately determined. It cannot be said of the photogeographer that he is unable to see the forest for the trees, although unless he carefully plies his technique the reverse could occur.

James (1934, pp. 84-85) states that:

> In other sciences the broad relationships are the most obvious ones; but in geography it is the overwhelming detail which is, actually, obvious. Like a microbe crawling over the face of a newspaper photograph, we may focus our attention on the details of the printed dots; but until we generalize those dots, the larger design of the photograph lies beyond our range of vision. The more closely we study the shape and arrangement of the dots the less we see of the larger pattern. Until we bring the larger relationships within range of our vision by making use of the map, the significance of what we see is lost. But is not the geographer's primary objective the recognition of these larger patterns -- even of the major lineaments of the face of the earth? May not the detailed study of the dots be made significant if the large patterns of distribution are recognized, and if the relationship of the detail to the more general is demonstrated?[30]

As a source of geographic information, the airphoto lies midway between the map which shows broad distributions and the field examination which reveals great detail. The photogeographer is able to see many relationships not at once evident to the field worker, but distributions over large areas are still beyond his ken. Moreover, airphotos reveal whole

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[30]Crawford (1938) effectively demonstrated the same concept by taking "aerial" and "ground" photographs of a patterned rug.

landscapes to the photogeographer, whereas the data presented by maps are more selective. There are advantages and limitations to minute field inspection, photogeography and map study and there is a place of each in any thorough geographic study.

The utilization of aerial photography in geography does not eliminate the requirement for maps illustrating the broad relationships and large patterns of distribution as expressed by James; instead, airphotos add a more effective medium to the science by which certain of these relationships and patterns can be recognized and another dimension by which they can be portrayed or correlated with other phenomena. Airphotos and maps are not reciprocal; they are complementary.

The views cited in the previous paragraphs indicate that the photogeographer is placed in a position where he may acquire a "feeling" or understanding of the area not available to his brother geographer who does not require airphotos or who has not learned the basic techniques necessary for their interpretation.

Very few works concerning photogeographical methodology appear in the scientific literature. Stone (1951, p. 754) states:

> Air-photo-interpretation is relatively new in geography. Evidences of this youthfulness are the scarcity of articles by geographers on the technique, the recency of development and the relatively low number of formal courses on the interpretational uses of air photos, and the paucity of known geographical research involving developments in the technique.

Other than the article from which this quotation was extracted, there appears to be only one other concerning photogeographical methodology worthy of consideration here. In an article describing applications of aerial photographs to geographic inventory, Russell, Foster and McMurray (1943, MS) attack the problem from the viewpoint of determining specifically what kinds of information airphotos provide or do not provide the photogeographer:

> Many items or elements of the landscape must be inventoried by the geographer. In 1915, Professors Wellington D. Jones and Carl O. Sauer published An Outline for Field Work in Geography which listed 21 broad items which required detailed investigation. Aerial photographs or controlled mosaics have been used to acquire the quantitative and qualitative information on certain of these topics. Numerous items of information are of course unobtainable from the photographs, but only in the case of animal life is the photograph without value, and even here, some indication as to a few certain species may be discerned.

This statement is followed by a detailed analysis of Jones' and Sauer's outline indicating the type of information required by the geographer and the portions of this information which are obtainable in whole or in part by photogeographical analysis, as well as the portions which at that time were not obtainable by this method.[31] During the ten years since the article was written, improvements in photo interpretation have advanced to the point where at least a dozen of the items which the authors specified as not interpretable from airphotos are now susceptible of analysis. For example, salinity was classified as an element of drainage about which no information was obtainable from aerial photographs. The investigations of Dr. O'Neill, a photobotanist at the Catholic University of America, have since disclosed certain reeds and water grasses identifiable on airphotos which not only disclose the presence of salt water but indicate the approximate degree of salinity as well.[32] Advances of this sort are

[31] Although the statement cited and the detailed analysis which followed it appeared in the manuscript copy of the paper by Russell, Foster and McMurray, neither appeared in the published version of the article. Personal communication from Dr. Russell (26 January, 1952) indicates the reason for this omission was the lack of space.

[32] Personal communication from Dr. O'Neill.

resulting from the slow but constant progress of the investigations of the photogeographers, photobotanists, photogeologists and others. Now it remains for the geographer to secure photo interpretation keys for such items as are not within his personal experience (as, for example, the plant association indicator of saline water), or even better, he may secure the collaboration of his colleagues experienced in the related earth sciences.

In this connection, Troll (1949, p. 123) indicates the differences between geography and area research in which geographers must participate on a cooperative basis with members of other disciplines. He credits Hans Bobek as most fittingly describing the position of geography in relation to area research by emphasizing:

> . . . . the modern methods of geography such as functional observation of landscapes, the evolutionary, historical method of research of natural and cultural landscapes, geographical mapping of economic landscapes, and *synthetic air-photo analysis*.[33]

While photo interpretation is being used as one of a number of basic techniques for the collection of data in many fields of knowledge, particularly in the earth sciences and in engineering, in all probability it is the geographers who stand to gain the most by fully exploiting aerial photography. Geography is a science which deals with areas and with the analysis and synthesis of the factors of which areas are composed. In a manner of speaking, the aerial photo or mosaic is, in itself, a rather intensive geographical report on the photographed area. But it is written in a foreign language, a picture language, which, like any other language, must be mastered before it can be readily interpreted. Once the geographer possesses the necessary command of the language, in terms of regional and

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[33]Translation by Dr. Eric Fischer. Italics are supplied by this author.

subject field experience and regional and subject airphoto keys, a substantial portion of the information required for his geographic research is available to him, spatially arranged and in convenient graphic form.

Reconnaissance photogeography. Exploratory photogeography and the making of preliminary geographic investigations or area surveys by analysis of aerial photography constitute reconnaissance photogeography. A number of students have made general or elementary statements testifying to the value of reconnaissance photogeography, although none of them seem to have developed the subject in detail. In fact, the state of the reconnaissance photogeographical technique is well illustrated by the elementary character of the quotations that follow. Bagley (1941, p. viii) states:

> Aerial surveys are indispensable in explorations. No present day expedition is satisfactorily equipped without an aerial camera, an airplane suitable for photography and a short wave radio set.

Effective, detailed geographic or photogeographic studies must await ground surveys which in turn depend upon accessibility. Whitmore (1941, p. 77) points out that accessibility may be determined from reconnaissance photogeography:

> . . . . from preliminary aerial photographs of unexplored country, the expert may be able to determine . . . . the possible locations of routes of travel by both land and water, and the possible locations of emergency landing fields for airplanes.

Time is a critical factor in reconnaissance photogeography. McKinley (1932, p. 479) discusses this point in relation to his aerial photographic explorations in Antarctica:

> Upon completion of the developing of the first season's work, I had time during the winter to study the results. I then realized how much the airplane does to increase one's conception of the vastness of this ice covered land. Hundreds of square miles of territory, with long rolling expanses of white, could be seen at a glance. The inequalities of surface, which show pressure beneath, and the outcroppings of

> rock, which definitely mark the presence of land, all showed plainly. The work of gigantic forces, which twist and break the barrier into deep and awful chasms, became apparent, as it never can be to the lonely traveler, as he stands in awe on the brink of a great precipice, unable to see the many miles of similar upheavals and openings on either side.
>
> To me in an airplane, all the magnificent vista is exposed at once in all its intricate relationships. The aërial camera registers such a view in an instant, and it may then be carefully studied at leisure. Moreover, it records much more faithfully than the eye and retains much more surely than the human memory all the marvelous manifestations of Nature which can be understood only when studied in their entirety.

McKinley (1932, p. 480) compares Prestrude's sledge journey and Scott's ship journey with his aerial camera exploration of the Rockefeller Mountains:

> . . . . his [Prestrude's] trip occupied almost five weeks; ours less than three hours. Prestrude must have travelled within a few miles of the point from which the Rockefeller Mountains were discovered by Commander Byrd in his plane, yet the former did not see them. More of King Edward VII Land was seen from our elevated platform in a few minutes than either Scott from his ship or Prestrude from the surface saw during their entire journeys.
>
> The flight over the Rockefeller Mountains demonstrated definitely the value of the aërial camera in exploration. Not only did it show the trend of the range and the relationship between the peaks, but the photographs later revealed much more than our observation and memory had been able to record. There proved to be many more peaks in the range than we had remembered counting with the naked eye. Although the eye can record with fair accuracy, the memory becomes confused when the range of view is increased, as in the air, and the scene is changing at the rate of 100 miles an hour.

McKinley also points out that the visible world to an Antarctic sledge party can hardly exceed 75 square miles with the horizon but five miles distant, whereas the air crew flying at 10,000 feet may have a view of 50,000 square miles with the horizon 130 miles away.

Eardley (1942, p. 1) explains that inaccessible areas are not considered insuperable hardships in airphoto reconnaissance:

> An aerial survey may be made in a much shorter time than a ground survey, and areas that are inaccessible or difficult to map from the ground impose no special problem to the aerial surveyor if landing fields are not too distant.

The primary purpose of reconnaissance photogeography is to provide geographic information of a general nature, accessibility and locational data, and broad patterns of distribution. The same airphotos, however, are available for analysis to provide a more detailed interpretation of areas selected from the reconnaissance for further study or later ground survey. Russell, Foster and McMurray (1943, p. 11 MS) clearly distinguish between reconnaissance and detailed photogeography:

> Geographic field work may be undertaken on at least two planes of detail, one a reconnaissance survey to establish broad types of distributions, and the second a micro-study intended to set up the minute geographic relationships which make up the broader patterns. Aerial photographs are of value chiefly in the first, broad type of field investigation, although many of the detailed problems can be recognized and solved through an interpretation of photographs.

In some instances reconnaissance photogeography may be the only available source for detailed information. Hack (1948, p. 439) states:

> Aerial photographs are the most valuable source material when detailed information is needed, when the area under consideration cannot be visited, and when geologic maps and other more precise data are lacking.

There is a distinct difference, then, between the two principal uses of reconnaissance aerial photography. In unexplored or unmapped areas, reconnaissance airphotos are produced primarily for the purpose of providing generalized maps, charts or map substitutes or for reconnaissance studies of a photogeographic nature. The reconnaissance photography, however, may then be used like any other aerial photography to perform various kinds of detailed airphoto analyses. It is important to note that these detailed interpretations depend upon the training and past experience of the interpreter; the available pertinent literature, maps or other data; and his field work in the area, if any; all as they exist at the time of interpretation, rather than at the time the photography was flown.

The Antarctic photographs used to illustrate the photo interpretation keys of Chapter V of this work are produced from reconnaissance photography, but Chapter V must be considered as a detailed study devoted to the preparation of regional and analogous keys of continental glacier landscapes, rather than a generalized photogeographical reconnaissance of Antarctica.

The applications of the photo reconnaissance, photo interpretation and photogeographic methods in the Antarctic is presented at the end of the next chapter, which is concerned with the area.

CHAPTER III

THE AREA

The exploration of Antarctica, like that of Africa and the Americas in former times, is being performed spasmodically with frequent omission or duplication of scientific objectives and without a consistent over-all policy. Like other continents in other times, Antarctica is distant from the nations which are contributing the most to its exploration, but unlike the others, Antarctica is separated from all of its neighboring land masses by 600 to 2100 miles of frequently stormy seas. Furthermore, it is many thousands of miles from the only countries which have both the desire to explore the region and the financial ability to carry out such a program. Moreover, Antarctica is girdled by formidable masses of floating ice which are impenetrable to most ships and ready to crush other vessels at any unforeseen turn of the wind or sudden drop in temperature. Finally, there is little incentive in terms of immediate monetary return for exploring inside this belt of pack ice.

The lack of accessibility and the short and infrequent periods of time available for field research in the Antarctic have imposed serious limitations to the geographic investigation of this continental area. There is an acute danger of spreading the research efforts too thinly and ineffectually over the five and one-half million square miles of ice surface that comprise the Antarctic. This danger can be greatly reduced by the utilization of aerial photo reconnaissance and the airphoto interpretation methods described in the previous chapter. The analysis of Antarctic aerial photography enables the photogeographer to furnish two of the elements essential to sound planning of geographic research in the Antarctic. These essential elements are (1) selection of the areas most worthy of study and (2) determining the best means of access to these areas.

The detailed history of Antarctic exploration and the known geography of Antarctica are recorded elsewhere in the scientific literature concerning the South Polar Region,[1] but a concise review of the discovery and exploration and a brief description of the Antarctic, chiefly in map form, is included here to provide the reader with sufficient information with which to evaluate the keys presented in Chapter V. Chapters III and IV also include pertinent remarks, maps and plates relative to the accessibility of the Antarctic, trafficability over the various kinds of Antarctic surfaces, photo reconnaissance and photo interpretation operations in the Antarctic, the existing aerial photographic coverage of Antarctica and the application of the photogeographic method to this area.

DISCOVERY AND EXPLORATION IN ANTARCTICA[2]

Early hypotheses. In the early days of recorded history the vast majority of the earth's land surface, though populated to some degree, was unknown to the advanced Oriental or Mediterranean civilizations. Indeed,

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[1]See Bibliography of Antarctic Bibliographies, appended hereto.

[2]The sources for statements of uncontested historical fact concerning specific events are not referenced individually. Among the best historical references in the English language or which have been translated into English and the primary sources consulted in the preparation of this summary are Fricker (1900), Mill (1905), Nordenskjöld and Mecking (1928), Hayes (1928), Joerg (1930) and [English] (1943). Detailed chronological listings of expeditions appear in U.S. Board on Geographical Names Special Publication 86 (1947), British Admiralty (1948) and [Roscoe] (1951). The last-cited publication refers to more than 5000 works on the Antarctic by more than 2000 authors.

although the pre-Christian Greeks had discovered the spherical shape of the earth and had estimated its size, and although sailors of that era are reported to have nearly circumnavigated Africa, the cartographic dogma established by Ptolemy led his successors, even to the time of Schöner, Mercator and Ortelius in the sixteenth century, to include on their maps and globes a vast hypothetical continent called Terra Australis Incognita. This lengendary continent appeared in different forms on the various maps and globes of the era but generally occupied all of the area south of the Antarctic Circle and half of the adjacent temperate zone and, in some areas, projected far north of the Tropic of Capricorn (Fricker, 1900, maps p. 21 and p. 25). Tierra del Fuego, Australia and sometimes even New Guinea were included as northern portions of this land mass.

Early voyages. The voyages of Drake (1578), Quiros (1605), Torres (1606), Huyt (1627), Tasman (1642), Bouvet (1738), Cook (1768), Kerguelen (1772) and the American and British sealers (1780-1830) successively reduced the possibility of the existence of a Terra Australis Incognita to an area much more nearly that of the Antarctic Continent and its surrounding pack ice as it is known today. More significant voyages were those of Cook (1772-1775), Bellingshausen (1819-1821), Biscoe (1831-1832) and Ross (1839-1843), each of whom circumnavigated the continent, further reducing its possible size. The voyages of d'Urville (1837-1840), Ross (1839-1843) and Wilkes (1838-1842) definitely indicated, however, that a land mass of continental porportions actually did exist.

Scientific exploration. The first recorded landing on the mainland of the Antarctic Continent, exclusive of possible landings of the sealers on the northern portions of the Palmer Peninsula, took place in 1895 (Kristensen). The first shipboard wintering of an explorer was that of de Gerlache (1898-1899) and the first wintering on the continent was made by Borchgrevink (1899-1900). Aside from these, a number of expeditions concerned with and equipped for scientific exploration were sent into the Antarctic during the period between the turn of the century and the First World War. These include the expeditions of von Drygalski, Bruce, Charcot (2 expeditions), Shackleton (3), Amundsen, Filchner and Mawson. More recent expeditions of importance have been those of Mawson, Wilkins (2), Byrd (3), Ellsworth (4), Rymill, Ritscher, U. S. Navy (2) and the continuous explorations of the Falkland Islands Dependencies Survey and the Discovery Committee.

Air exploration. Flying in the Antarctic was introduced by both Wilkins and Byrd during the exploring season of 1928-1929. Aerial photography, however, had preceded the utilization of heavier-than-air craft, the first airphotos having been made from captive balloons by the expeditions of von Drygalski (1901-1903) and Scott (1901-1904), both of which were prior to the first flight of Orville Wright at Kitty Hawk. From the first recorded landing, photography has been considered of paramount importance in Antarctic exploration; since 1929 aerial photography has been regularly employed.

Motivation. At least six stimuli, acting either individually or in concert, have supplied the motivation for Antarctic exploration. In approximate chronological order they are: (1) the desire of the early explorers to open new territories for trade and the building of colonial empires, which led to the earliest explorations of Terra Australis Incognita, (2) the slaughter and near extinction of fur seals for their pelts and oil and the sea elephant for its oil, (3) the race for the discovery of the South Pole, (4) the rise of pelagic whaling, (5) the desire for political sovereignty induced in part by national pride and in part by an economic desire for whaling rights and (6) the desire to perform scientific research. The desires for adventure, fame and glory have also been significant stimuli.

Duplication and omission. With but few exceptions, the accounts of the various Antarctic expeditions show them to have duplicated projects undertaken by other expeditions and to have omitted research projects not covered by other expeditions. From the accounts of these expeditions, it appears that a large proportion of groups which explored this region accumulated a considerable amount of their experience by making many of the mistakes that were previously made by their precursors. Upon completion of field research and subsequent return to civilization, all too many expeditions have been disbanded, their specialized equipment sold or transferred to other use and their experienced personnel absorbed into other pursuits. In many cases only a fraction of the scientific observations or data acquired has been published or otherwise made available to the public. For example, the U.S. Naval Task Force 68 "Operation Highjump" Expedition of 1946-1947, consisted of nearly 5,000 men and 13 ships. Aside from two popular accounts of dubious scientific value, several popular and scientific articles in periodicals and a few classified military documents, the scientific results have never been published. On the other hand, the German National Antarctic Expedition of 1901-1903 with a scientific staff of four, including the leader, von Drygalski, and a total complement of 32, published voluminous scientific accounts of the explorations during the several decades after the expedition's field work had been completed.

Airphotos as permanent records of exploration. This is an aspect in which aerial photography can be of considerable aid to the geographer and the explorer. In the case at hand each airphoto is a record of a given portion of the Antarctic at the time the negative was exposed. When accompanied by the pilot's log and the navigator's chart, each roll of film provides the basic raw material which may be used at any subsequent time for compilation, recomputation or preparation of scientific data and maps. Time may adversely affect the memory of man by dimming his recollections and fusing his impressions of separate observations, but the airphoto which records more detail than the human mind is able to absorb, does not suffer from the effects of time, provided that the film is properly preserved.

Maps. Two maps entitled Discovery and Exploration in Antarctica and Discovery and Exploration in Antarctica: Palmer Peninsula are appended to this study as Maps 1 and 2. No changes have been made in these maps since the season of 1946-1947. The most important of the changes which have occurred since that date are the redefinition of the east coast of the base of Palmer Peninsula and the precise location and configuration of the coast south and southwest of the Weddell Sea, both as determined by the airphoto reconnaissance parties of the Ronne Antarctic Research Expedition.

The delineation of the areas explored by the airphoto reconnaissance of the U.S. Naval Task Force 68 Expedition was furnished to the map compiler by this writer from the official reports submitted to him by the individual Navy and Marine Corps pilots, navigators and aerial photographers and from his preliminary review of the expedition's 65,000 aerial photographs.

No detailed treatment of the history of Antarctic discovery and exploration is presented here in view of the relative completeness of Maps 1 and 2 and in view of the previously expressed purpose of this study.

BRIEF GENERAL DESCRIPTION OF THE ANTARCTIC[3]

Name. The accepted name for the South Polar Continent is Antarctica. In this study the term, the Antarctic, a commonly used contraction for the Antarctic Regions, refers to the South Polar Regions in which the continent of Antarctica is centered. The limits of this area are discussed below.[4]

Position and size. Antarctica is the only polar continent. Centered near the South Pole, the continent would be nearly circular in shape were it not for the northward extending Palmer Peninsula and the two deep reëntrants formed by the Ross and Wedell Seas. The continent is unique in its isolation, being approximately 600 geographical miles from South America, 1,400 from New Zealand, 1,700 from Australia and 2,100 from Africa. The land masses of the earth, other than Antarctica, are so arranged that one can walk from any part of one continent to any part of any of the others, except for Australia which is separated from Asia by numerous short stretches of tropical seas between the islands of Australasia.[5] Even here, however, the longest stretch of open water is only 40 miles.

The Antarctic land mass, including the adjacent islands and the firmly attached shelf ice, approximates five and one-half million square miles in area, almost all of which lies within the Antarctic Circle. Only the

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[3]References cited in the previous footnote also serve as authority for this informational section.

[4]Neither Antarctica nor the Antarctic are defined among the hundreds of place name decisions relative to this region in the U.S. Board on Geographical Names Special Publication 86, although the former term is used in the title of this publication.

[5]The continents within the new world and those within the old world are joined by terrestrial connections. Asia and North America are joined by the winter sea ice of the Bering Strait.

Palmer Peninsula and a half dozen capes in East Antarctica project equatorward of this circle. The coastline of approximately 14,000 miles has been delineated with the exception of a few tiny gaps, although refinements in delineation may be expected for some years to come.

Kosack (1950, pp. 202-206) has published the most recent study on areal measurements in the Antarctic. Among others, he quotes the following estimated areas and has shown their limits on a map:

Region	Square Miles	Square Km.
Antarctic Continent	5,058,356	13,101,154
Continent and islands	5,087,534	13,176,727
Continent, islands and shelf ice	5,446,959	14,107,637
Outer limit of icebergs	29,482,596	76,360,000
Oceanic polar front	20,046,312	51,920,000
Atmospheric polar front	9,050,184	23,440,000
Average limit of pack ice (Nov. 1)	14,177,592	36,720,000
Isotherm of 10 C. (warmest month)	26,193,024	67,840,000

Although insufficient measurements have been made to provide proof positive, Antarctica is quite generally accepted as the world's highest continent. Its ice-capped surface level is estimated as averaging 6,000 feet above sea level or twice the average elevation of Asia, the next in order.[6]

[6] The estimate for the average elevation of Antarctica includes its cover of glacier ice. Some glaciologists and geologists consider glacier ice as a form of rock and as such to constitute a portion of the lithosphere rather than the hydrosphere. Estimates of the height of the continent excluding its cover of glacier ice are entirely unwarranted at this time because of the almost absolute lack of data concerning the thickness of the ice. Moreover, any such figure would have to be corrected for isostatic and elastic earth crustal adjustments and eustatic changes in sea level which would result from the melting and unloading of the Antarctic ice cap in order to be of proper significance.

Limits. Many criteria have been suggested for the delineation of the Antarctic Region; among the more significant of these are the following:[7]

1. Antarctic Circle.
2. Tree line.
3. Equatorward limit of icebergs.
4. Equatorward limit of pack ice.
5. Ten degree centigrade isotherm of warmest month.
6. Zero degree centigrade mean annual isotherm where the isotherm for the warmest month is below ten degrees centigrade.
7. Isoline at which the temperature of the warmest month equals 9.5 degrees centigrade minus 1/30 the temperature of the coldest month.
8. Isoline at which the temperature of the warmest month is nine degrees centigrade minus 1/10 the temperature of the coldest month.
9. Antarctic Convergence.

The Antarctic Circle bears no direct relationship to the natural regions. The tree line, so expressive in the Arctic, is not suitable to the ocean expanses of the southern hemisphere. The equatorward limit of icebergs varies considerably from year to year depending upon such factors as the size and content of these ice masses, the temperature of the ocean

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[7]Criteria numbers 1 through 4 have been suggested by many sources over many years and the original authority is uncertain; 5. A. Supan, German geographer and climatologist; 6. O. Nordenskjöld, Swedish geographer and polar explorer; 7. M. Vahl, Danish plant geographer; 8. O. Nordenskjöld; and 9. British Admiralty (1948, p. 1) from the oceanographical research carried out by the many Discovery Expeditions and the Meteor Expedition (1925-1927) of A. Merz and F. Spiess. The Antarctic Circle and the equatorward limits of icebergs and pack ice are indicated on Map 4. Insufficient data are available to map criteria numbers 5, 6, 7 and 8. The tree line does not exist in the southern hemisphere. Criterion number 9, the Antarctic Convergence, is mapped by Deacon (1937) and also appears in Sverdrup's text (1942, Fig. 158). It has been added to the various limits which appear on Map 4.

waters in which they float, the direction and force of the ocean currents and the number and size of icebergs calved and released from the sea ice. Icebergs frequently wander into the sub-Antarctic areas and occasionally drift into the temperate regions. The limits of pack ice are perhaps more suitable as a boundary, but the edge of the pack ice varies its location from month to month; moreover, these locations are not well known.

The isotherms and the formulae for determining the limits of the Antarctic which are based upon isotherms are dependent upon large quantities of data for which the observations have yet to be made. The derivation of these formulae represent the earnest attempts of polar scientists to produce a factor which can be used as a boundary criterion similarly to the tree line of the Arctic, but the formulae result from theoretical reasoning, whereas the tree line is a natural boundary.

The best criterion established thus far seems to be the Antarctic Convergence, defined as the line where the cold, northward-flowing Antarctic waters sink beneath the relatively warmer waters of the sub-Antarctic. The line is actually a zone approximately 20 to 30 miles in width which extends across the Atlantic, Pacific and Indian Oceans between the 48th and 61st parallels of south latitude. The precise location at any given place and time is made evident by the sudden change in surface temperature which averages five to ten degrees Fahrenheit. Although this zone is a mobile one, it usually does not stray more than half a degree of latitude from its mean position. This line, like the tree line of the north, is a natural boundary, rather than one derived from reasoning. It not only separates two hydrological regions, but also separates areas of distinctive marine life associations and of different climates.

Divisions. Antarctica is commonly divided into halves, east and west of the Greenwich Prime Meridian, and known therefore as East Antarctica and West Antarctica. Another common method of dividing Antarctica is the separation of the polar region into quadrants, each of which is usually named for the adjacent ocean or nearest continental land mass. Quadrants are usually divided by the 0°, 90° and 180° meridians, but the division lines may be oriented in a different manner. Those who agree on lines of demarcation, however, do not always agree on quadrant names.[8]

Divisions based upon meridians as boundaries served a purpose when the region was mostly unknown, but meridians are no longer suitable since they seldom lie along natural boundaries or coincide with explored areas. As Antarctic exploration advanced, the concept of boundaries by halves, quadrants or meridional sectors has largely been replaced by a system which involves the designation of a series of lands which are further subdivided into coasts. The lands and coasts are based upon exploration and, in some instances, upon natural boundaries.[9]

Political divisions are generally pie-shaped sectors bounded by meridians. They overlap, are based upon unrecognized claims and frequently do not coincide with the lands and coasts. It is probable that aerial reconnaissance will provide sufficient information within the next generation

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[8] Among the most commonly used quadrant names are American, African, Australian and Pacific (Demucé, 1906, p. 6, and others). Cansbich and also Mecking (1928, p. 206) suggest Atlantic, Indian, Australian and Pacific. On Map 1, appended to this study, U. S. Government geographers have longitudinally transposed the quadrants 20° in order to render a greater number of major physiographic features, such as the Ross Shelf Ice, and political divisions, such as the Norwegian claim, within a single quadrant.

[9] The divisions into lands and coasts are well illustrated on Map 3, H.O. 2562, Antarctica, Second Edition, 1947. The names on this map are in accordance with the decisions of the U.S. Board on Geographical Names in cases where decisions have been rendered by the board.

to permit division of the continent into suitable natural regions. What effect this will have upon the present political divisions remains to be seen.

Maps. A series of maps is appended to this study.[10] Maps 1 and 2 relative to discovery and exploration in the Antarctic and Map 3, the Hydrographic Office chart of Antarctica, have been cited previously. Map 4 indicates the relative accessibility of the various coasts of Antarctica and Map 5 consists of a map of the Arctic superimposed on Map 4 for comparison with the better known northern areas.

Map 6 shows the present status of airphoto coverage in the Antarctic. Index maps to the current hydrographical chart coverage of Antarctica, Maps 7 and 8, are accompanied by Appendix I, a detailed listing of the maps and charts plotted on the indices as well as an account of many maps which for scale or other pertinent reason were not so plotted. Maps 9 through 15 are maps of the Ingrid Christensen Coast. Listings of older maps and charts, now mainly of historical interest, have been compiled by Denucé (1913) and [Roscoe](1951, Section 20).

Climate. Antarctica has a continental climate with cold summers and severe winters. Geographers and climatologists using variations of the Köppen System all classify Antarctica as occurring almost entirely within EF (glacial climate). Small coastal portions of Antarctica, most of which are located on the Palmer Peninsula, have ET (tundra climate). Further refinement can now be made within the EF category, for sufficient data have been secured to indicate that there are significant regional

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[10] With the exception of Maps 3, 9, 10 and 11, all maps appended to this study were either produced by, produced at the direction of, compiled by or compiled in part by the author.

variations within the area classified as EF in Antarctica.[11] Present data also indicate that latitude for latitude the Antarctic is colder than the Arctic.

A permanent area of high atmospheric pressure with anticyclonic wind circulation exists over Antarctica. The high pressure is caused in part by the rotation of the earth, the planetary wind system and the intense cooling of the surface layers of the atmosphere over the icecap. Strong polar southeasterly winds flow centrifugally outward from the high, continental glacier plateau, down the sloping ice sheet and out over the ocean. The direction of these winds is sometimes so constant that airphotos may be oriented by aligning the snowdrifts and sastrugi with the known prevailing wind direction. The lowest known pressures normally occur near the 65th parallel of south latitude where the western winds are as common as the polar southeasterlies. North of 65°S. the atmospheric pressure increases and westerly winds prevail.

Ocean currents are aligned similarly to the arrangement of the winds, with easterly currents hugging the shores of Antarctica and broad westerly currents circumnavigating the continent to the north of the easterly shore current.

Blizzards are known to be intense, frequent, of long duration and to occur in all seasons. According to Hayes (1928, pp. 214-218) Mawson experienced monthly averages of wind speed of 49, 51.5 and 60.7 miles per hour

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[11]These regional variations are not reflected by differences in regional vegetation as is the case with the areas in the Köppen System and most other regional climatic classifications, since except for few species of mosses and lichens the severity of the climate precludes the presence of any vegetation. Nevertheless, the differences are significant in terms of formation of glacier ice, the resulting ice forms and the ability of man to survive in the area.

for three consecutive months at his base camp in 1913. While on a 91-day sledge trip Mawson had 61 days of snowfall or drift, and 33 days with winds of Beaufort Force 8, 9, 10, 11 or 12 (gale through hurricane force).

Precipitation occurs mainly in the form of snow, with some hoarfrost and in some areas a little rain. Strong winds transport the surface snow and loose firn, causing an appearance of more precipitation than actually occurs.[12] Seasmoke is common over open water during low temperatures.

Antarctica is enclosed by the mean annual isotherm of 32°F., which means it must have a climate that is colder than even that of Greenland in the north. The known winter temperatures of the Antarctic seldom exceed -75°F. and are moderate considering the lowness of the annual mean temperature, which is accounted for by the low maximum temperatures of the Antarctic summer. The almost constant winds lower the sensible temperatures considerably. Wind chill is a significant characteristic of the region.

Surface features. The morphology of specific types of land and ice surface features in the Antarctic is treated in greater detail in Chapter V of this work.[13] In general, the rocks and rock structures of Antarctica are similar to those of the other continents. Where the land is ice-free, the surface morphology is based upon igneous, sedimentary and metamorphic rocks of all ages from the pre-Cambrian to the late Tertiary, as well as

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[12]See Keys 256-258, Chapter V.

[13]Chapters V and VI contain many stereographic illustrations of typical Antarctic surface features. Descriptions of specific coastal features, by area, may be found in the U.S.H.O. No. 138, Sailing Directions for Antarctica, 1943, and the British Admiralty's Antarctic Pilot, 1948.

volcanic rock formations of later dates. Exposed fossiliferous sedimentaries and coal seams indicate that Antarctica had a much warmer climate during Paleozoic and Mesozoic times.

Antarctica is almost completely covered by an icecap of varying thickness, the average depth of which has been estimated at two thousand feet, but which may be much greater. Exposed land occurs in the form of bare mountain peaks, dry valleys, "oases,"[14] sea cliffs and surglacial moraines. Rock and "soil" polygons, similar to some kinds of those in the Arctic do exist, but the areas in which they can be formed are quite rare.

Some of the present day surface features of significance include the South Polar Plateau, an icecap ranging from six thousand to eleven thousand feet in altitude and which extends into the area still unknown to man; the shelf ice formations, unique features of the Antarctic, occurring in the Ross and Weddell Seas and attached to the coasts at numerous other points; and the ever-present coastal cliffs. The latter may consist of either ice-free or ice-capped rock, but most of them are composed of sheer, vertical walls of firn or glacier ice rising from 10 to more than 200 feet above the sea wherever glaciers or shelf ice meet the ocean.

Reconnaissance and detailed investigations of many parts of the continent indicate that not only is the current trend one of glacial recession, but also that former glaciation was considerably more extensive than at present. Glacial striae, perched moraines and erratics demonstrate that the glacier ice previously rose to altitudes of from one to three thousand feet higher than its present level. In spite of the recent glacial

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[14]Areas of exposed land essentially at glacier level and surrounded by glacial ice are frequently, though incorrectly, termed "oases." No acceptable term has been offered for this type of area.

recession, the Antarctic continental glacier is still in a higher state of development than glaciers anywhere else on the earth, including that of Greenland. The presence of coal seams and fossiliferous sediments formed in the late Mesozoic indicates the present continental glacier cannot be older than late Tertiary.

Flora. Except for rare instances of snow colored by red or green algae and except for ponds, the colors of which are likewise affected, no vegetation is visible on airphotos of Antarctica. More than 300 species of lichens and 70 species of mosses are known to exist in the Antarctic. Mostly, they growin small patches and in rock crevices or under loose, translucent stones where they are protected from the wind. Nothing comparable to the Arctic tundra exists anywhere on the continent, although one species of grass and one flowering plant have been discovered in local areas on the northward-extending Palmer Peninsula. Some bacteria exist in bird and seal excrement. Fungi have been found on pebbles. Vegetation in the water, however, presents a different story. Where shallow, the sea bottom is frequently "lush" with vegetation. Kelp grows to a length of 100 feet. Diatoms, the basic food upon which all life in the Antarctic is dependent, are so numerous in the upper layers of the ocean that they often color the sea ice yellow.

Fauna. Seals and whales are the only mammals in Antarctica. These large animals are frequently visible on airphotos. Individual seals may be observed on medium scale photography; when gathered in colonies on the ice, seals may be observed at almost any airphoto scale. Whales are now hunted by aerial reconnaissance (Grierson, 1949).

Birds include several varieties each of the penguins, albatrosses, petrels, shags, sheathbills and skuas. The penguins, like the seals, may be visible on aerial photography, especially when their black backs contrast with the white ice or when their white fronts contrast with the dark rock of their rookeries. They are not usually visible on airphotos when in the water, however.

Penguin, albatross and cormorant rookeries are identifiable on airphotos, but those of the petrels are not. Skua breeding places, skuaries, are not identifiable on aerial photography, but they exist in or adjacent to virtually every penguin rookery, except those of the emperor penguin, which breeds during the cold winter night on the fast sea ice.

The great majority of the Antarctic fishes belong to the Nototheniiformes group. They are numerous in species, varied in appearance, generally under three feet in size, bottom swimmers, carnivorous and edible.

Terrestrial invertebrates are few in numbers and species. They are usually found under rocks at penguin rookeries and other favored places and include such forms as mites, rotifers, protozoa, and a wingless mosquito, Marine invertebrates, however, are numerous in numbers and species. One of them, the Euphausia superba, feeds upon diatoms and in turn serves as a food supply for the whales, seals, penguins and the larger fish.

Arctic vs. Antarctic. One of the best ways to briefly describe the Antarctic is to compare and contrast random facts relative to this continent and the better known Arctic. A few such random facts are:

Arctic	Antarctic
Ocean surrounded by continents.	Continent surrounded by oceans.
Winds, currents broken by arrangement of land masses.	Winds, currents circumpolar and unbroken by land masses.
Glacier icebergs.	Tabular and glacier icebergs.
Glaciers in limited area.	Glaciers everywhere, shelf ice.

Arctic	Antarctic
Beaches, shallow water.	Beaches rare, vertical ice cliffs, deep water offshore.
Much paleocrystic sea ice.	Little paleocrystic sea ice.
Puddled sea ice common, hard.	Puddled sea ice less common and frequently rotten.
Variety of soils.	Mantle rock rare, no soils.
Tundra.	No tundra, some mosses and lichens, grasses and flowers very rare, no sphagnum.
Center: ice-covered ocean with marine life present.	Center: ice-covered plateau, no food supply, no life.
Land mammals: musk ox, reindeer, caribou, fox, hare, etc.	No land mammals.
Amphibious mammals: seals, walrus, polar bears.	Amphibious mammals: seals.
Great Auk (extinct).	Penguin (extant).
Flying insects, other insects plentiful.	No flying insects, other insects rare.
Primitive man.	No primitive man.
One million population north of 60° N.	No population south of 60° S., except whalers and explorers.

ACCESSIBILITY

Ships. For at least eight months of the year (April through November) Antarctica cannot be reached by ship. Many portions of the continent are not accessible in midsummer (December and January). During the most favorable month for accessibility (February) from one-third to two-thirds of the continental coast cannot be reached by normal surface vessels. During late summer (March) some coastal areas are open, but this is a most dangerous time for ship operations in the Antarctic, since refreezing sometimes occurs without warning. Ships inside the pack during this month stand the chance of being beset and frozen-in for the winter or even of being nipped or crushed.

Fully one-third of the continental coastline has never been approached by ship at any time. Included in this area is the only unclaimed coast and hinterland in all Antarctica, from 90° W. to 150° W. (Maps 1 and 4).[15]

The principal cause of this inaccessibility is pack ice of the consolidated pack variety. This is the most severe form of pack ice, containing much pressure ice and no significant open-water spaces. It is not navigable by any type of surface ship.

Close pack, composed of floes which are mostly in contact, is navigable by specially constructed vessels, such as ocean icebreakers, but cannot be traversed by ordinary ships. Open pack consists of floes in infrequent contact and with many leads and polinyas, making ice navigation relatively simple.

Certain coastal areas favored by winds and currents become essentially or entirely free of pack ice for limited periods during the southern summer. A frequently used passage to the continent, resulting from the effects of favorable winds and currents on the pack ice, lies along the 180° meridian leading into the Ross Sea. There are no records of ships having failed to gain access to this, the southernmost sea in the world, during the summer season (Map 4). This area stands in contrast to unclaimed area mentioned above which lies in the middle of a large

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[15] It appears that the nations which have claimed the more accessible or more valuable portions of the Antarctic have set this 60-degree sector aside to be claimed by the United States. In fact it is shown as a United States claim on many maps, e.g., Gould (1940, Fig. 2), although the government of the United States has never announced a claim to any part of the Antarctic.

coastal area known to have a normal state of inaccessibility. No ship has ever reached the coast in the long stretch between Edward VII Peninsula and Alexander I Island, a coastline of nearly 90 degrees longitude (Map 4).

Between the pack ice and the fast ice which fringes the coastline, a lead of open water is found which sometimes permits a certain amount of lateral passability for surface vessels along the coast. A passage to this continental lead must be found before it can be utilized, however. Once access has been gained to such a lead other problems must be faced before the actual coastline can be reached over the narrow fringe of fast ice. These include the tendency of the fast ice to break away and drift out to join the pack ice without warning and the presence of cracks in the fast ice formed as a result of shear, tension or torsion.

The most difficult problem of all is encountered when the pack ice and the fringing fast ice have been passed and the ship or ice party comes face to face with a portion of Antarctica's cliffed coastline. While a few parts of the coastline have a gently sloping rock or ice surface and while beaches occur in rare instances, the principal type of shoreline is either a steep rock cliff or, as is more often the case, a vertical ice cliff formed by the floating snouts of glaciers, shelf ice barriers or the seaward face of piedmont ice afloat. An exploring party facing one of these cliffs might have to travel along the coast for more than a hundred miles before finding a place where a landing could be made with reasonable safety.

The optimum conditions for ship landings in areas of shelf ice occur where the barrier has been split by a tension crevasse, where the seaward advance of the shelf ice has been impeded by a submerged rock formation, thus causing the formation of a bay in the shelf ice, such as the Bay of Whales, or where the shelf ice adjoins an island or part of the continent. Shelter for the ship and natural ramps leading from the sea ice to the surface of the shelf ice occur more frequently at these places. Other good landing areas include fiords and portions of the continental coastline where the continental glacier slopes gently to the sea.

Reconnaissance aerial photography of a large portion of the coastline of Antarctica has been completed (Map 6). Photo interpretation provides the most rapid, most comprehensive and most reliable method of choosing proposed landing sites and landing site alternates and evaluating them in terms of site, situation and approach.

Maps. The relative accessibility of Antarctica by use of conventional surface ships is indicated on Map 4, which also delineates the maximum extent of icebergs, the extreme limit of the Antarctic pack ice, the probable minimum limit of the pack ice and the 32° F. isotherm of the warmest month. The small scale of this map, 1:60,000,000 should be noted. While the map is largely self-explanatory, the reader's attention is invited to the fact that the three accessibility symbols merely indicate the degree of accessibility in approaching the coast. No indication is given on this map of the difficulties in landing once the coast is reached. Map 5 is similar to Map 4 except that it is overprinted with a map of the Arctic as seen orthographically as if looking through a transparent globe. General comparisons may be drawn between the accessibility of the Antarctic and the more familiar Arctic.[16]

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[16]Maps 4 and 5 were compiled by Dr. Arthur Hall from information provided by Dr. Siple, the writer and others at the request of Mr. S. W. Boggs of the Department of State.

From the foregoing it appears that conventional surface ships can reach the Antarctic coast only during certain seasons and only then at a limited number of favorable locations. Under these circumstances there is an increasing probability that airborne exploration techniques will develop rapidly.

Aircraft. Accessibility by aircraft is an entirely different problem from accessibility by ship. Except in the case of helicopters, the mother ships of which must now approach within 50 miles of the continent to make their use feasible, aircraft may be launched from outside the area of pack ice or even from one of the other continents in the southern hemisphere.[17] Broad areas of unnavigable pack ice, wide belts of unpredictable fast ice, pressure ridges, shelf ice barriers and rocky forelands are of no consequence to the aircraft pilot. His problem is to find a site on level, undisturbed ice suitable for the landings and take-offs of the type of aircraft concerned.

The determination by photo interpreters of ice landing areas for aircraft is more difficult and more complex than determining ship approaches. Photo keys for conditions of ice moisture and ice stability have not yet been developed. The chief value of photo interpretation in this case is that by photo analysis of the ice morphology it is possible to eliminate a large percentage of prospective sites from consideration and to choose from among the remainder the sites which are most suitable for actual test.

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[17] The U.S. Navy Task Force 68, 1946-1947, launched flying boats from seaplane tenders and combination ski-wheel aircraft from an aircraft carrier, the ships remaining outside the pack ice. The Deutche Antarktische Expedition, 1938-1939 launched flying boats from outside the pack ice. The U.S. Navy Task Force 39, 1947-1948, employed helicopters which were launched from the flight deck of an icebreaker and seaplanes which were launched in leads within the pack ice.

Each type of aircraft has its own requirements for a landing surface. In case of a helicopter on floats, any level surface of undisturbed ice, firn, snow, rock or water which is free of obstructions to the rotor blades will suffice. In contrast, the heavy, wheeled, multi-engined airplane requires a prepared runway of mat, compacted firn or else a natural, level, crevasse and crack-free hard ice surface covered with a thin layer of snow or firn, such as might be found on a frozen meltwater lake or on an ice floe.

Experience acquired during recent field work in the Antarctic has shown that light aircraft, weighing up to 8,000 pounds and mounted on skis, require only level, undisturbed glacier or sea ice for landing areas. Antarctica provides more natural landing areas of this type than may be found in the rest of the world. Very little research is known to have been performed relative to the ability of heavy aircraft to land on ice. Experience at Little America, however, proved that aircraft weighing 33,000 pounds gross, which is now considered medium weight, had little difficulty in landing and taking off on level shelf ice surfaces.[18] More information must be obtained relative to the minimum requirements for stability and compactibility of snow, firn and ice necessary for take-offs and landings, including the initial landing shock, of the various types of aircraft which might be employed in polar flying.

In general, the best places for landing aircraft are the smooth, uncrevassed areas of shelf ice or the polar plateau. Smooth, thick, fast, sea ice in sheltered locations is also acceptable. Areas of ice movement

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[18] In reality, the pound pressure per square foot of ski is of more importance than the gross weight of the aircraft in determining its requirements for landing on ice surfaces since the weight per unit of contact surface determines whether or not the snow, firn or ice will support the ski-equipped aircraft.

must be considered poor sites. All known areas of exposed rock in the Antarctic are too rough for any aircraft except helicopters.

TRAFFICABILITY

Not only is the Antarctic a difficult place to approach, it is also a difficult place in which to move about, either by foot or by vehicle. Trafficability[19] in Antarctica is a product of three factors: physiographic features, surface conditions and weather as these factors relate to the vehicles available to effect the type of locomotion desired. Since the ways in which the major physiographic features affect trafficability are evident, and since vehicles originally designed or redesigned for use in polar regions have been modified or service in polar weather conditions, the important consideration which remains is the relationship of the individual vehicle to the surface conditions present in the Antarctic.

Trafficability table. To provide for comparative analyses, the writer has prepared a tabular outline of surface trafficability in the Antarctic (Plate 1). Because of its brevity and the tremendous number of variations possible, this table does not take into consideration such vitally important factors as the length and purpose of the journey, the range of the vehicle, the food and fuel required and the weather forecasts. For these reasons the table should not be used as a sole judge for evaluating the serviceability of a specific vehicle-surface combination.

In studying the table it is important to realize that great variations may occur within a single type of surface. Firn, for example, may be rough as sandpaper or smooth and polished, loose or firm, flat or in sastrugi,

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[19]The term trafficability as used here refers to the passability of various regions or the ability of vehicles or people to move about within a cited area.

ANTARCTIC SURFACE TRAFFICABILITY TABLE

I SURFACE CHARACTERISTICS (All types of level surfaces)

II SEA ICE (Proper surface assumed)

	SNOW, soft and deep	FIRN, granular and firm	ICE, bare and hard	ICE, thin snow cover	SASTRUGI, average size	CREVASSE, narrow--2'	CREVASSED AREA, complex	DISTURBED ICE, complex	ICE CLIFFS, barrier, glacier	BED ROCK, without overburden	MORAINE, all types	VOLCANIC DEBRIS, all types	MELTWATER, shallow	WATER, ocean	6' Thick: 1-5/10 cover	6' Thick: 6-7/10 cover	6' Thick: 8-9/10 cover	6' Thick: 10/10 cover	Solid Cover: BLACK ICE, thin	Solid Cover: BRASH, thin	Solid Cover: TWO FEET THICK	Solid Cover: SIX FEET THICK	Solid Cover: CRACK, narrow--2'	Solid Cover: PRESSURE RIDGE
Foot Transport:																								
1. Shoes, mukluks, etc...	U	S	1	S	S	S	U	U	U	G	S	S	2	*	*	*	U	S	U	U	20	S	S	S
2. Snowshoes.............	G	S	U	S	S	U	U	U	U	*	*	*	U	*	*	*	U	S	U	U	20	S	U	U
3. Skis..................	S	G	U	G	S	3	U	U	U	*	*	*	U	*	*	*	U	G	U	U	20	G	3	U
4. Man-hauled sled.......	U	G	S	G	S	S	U	U	U	*	*	*	U	*	*	*	U	G	U	U	20	G	S	S
5. Dog-hauled sled.......	U	G	U	G	S	S	U	U	U	*	*	*	U	*	*	*	U	G	U	U	20	G	S	S
Motor Vehicle Transport:																								
6. Wheeled vehicles......	U	U	4	S	U	U	U	U	U	S	U	U	U	*	*	*	U	19	U	U	20	S	U	U
7. Tractors..............	U	S	4	G	S	5	U	U	U	S	6	6	U	*	*	*	U	19	U	U	20	G	5	7
8. Amphibious tractors...	U	G	4	G	S	5	U	U	U	S	6	6	G	S	G	8	8	G	U	S	S	G	5	7
9. Weasels...............	9	G	4	G	S	5	U	U	U	S	6	6	G	10	S	8	8	G	U	U	S	G	5	7
Aircraft Transport:																								
10. Airplane, wheels.....	U	U	U	S	U	U	U	U	11	12	U	U	U	*	13	13	13	S	U	U	14	S	U	U
11. Airplane, skis.......	9	G	U	G	S	U	U	U	11	*	*	*	U	*	13	13	13	G	U	U	14	G	U	U
12. Airplane, floats.....	*	*	*	*	*	*	*	*	11	*	*	*	*	S	15	15	15	U	U	U	U	U	U	U
13. Airplane, flying boat	*	*	*	*	*	*	*	*	11	*	*	*	*	G	15	15	15	U	U	U	U	U	U	U
14. Helicopter, wheels...	16	S	S	G	S	U	U	U	11	G	S	S	U	*	13	S	S	G	U	U	S	G	U	U
15. Helicopter, floats...	S	G	S	G	S	U	U	S	11	G	S	S	S	S	G	G	G	G	U	U	S	G	U	U
Water Transport:																								
16. Ship, icebreaker.....	*	*	*	*	*	*	*	*	*	*	*	*	*	G	G	G	S	17	G	G	G	17	*	S
17. Ship, wooden.........	*	*	*	*	*	*	*	*	*	*	*	*	*	G	S	8	8	U	S	S	U	U	*	U
18. Ship, steel..........	*	*	*	*	*	*	*	*	*	*	*	*	*	G	S	8	U	U	S	S	U	U	*	U
19. Boat, small..........	*	*	*	*	*	*	*	*	*	*	*	*	*	S	S	8	U	U	U	U	U	U	*	U
20. Raft, rubber.........	*	*	*	*	*	*	*	*	*	*	*	*	18	S	S	8	U	U	U	U	U	U	*	U

III LEGEND

G -GOOD
S -SATISFACTORY
U -UNSATISFACTORY or DANGEROUS
* -NOT APPLICABLE

1. Shoes with crampons are satisfactory.
2. Boots are suitable for shallow water only.
3. Experienced skiers may cross openings up to nearly one-half the length of their skis.
4. Vehicle can operate but cannot pull a load.
5. Vehicle may use planks or depend upon momentum. Cracks two feet wide are dangerous.
6. Unsatisfactory because lugs and treads break.
7. May require aid of shovels or explosives.
8. Depends upon distribution of the floes.
9. Varies inversely with softness of snow.
10. Unsatisfactory in heavy waves or swells.
11. Only aircraft are able to cross the barrier or glacier ice cliffs without using a bay, island or natural ramp.
12. Bed rock is seldom sufficiently smooth.
13. Depends upon size of individual floes.
14. Depends upon the weight of the aircraft; satisfactory for light planes, may be dangerous for heavy varieties. Wheels usually require greater ice thickness than skis.
15. Depends upon size of open water areas.
16. Satisfactory with tarp spread for landing.
17. Modern steel icebreakers usually can get through. Many variables, including the age of the ice, snowcover, temperature, salt content and the type of icebreaker determine whether ramming or heeling are necessary.
18. The rubber raft is an excellent vehicle for traversing meltwater of almost any depth.
19. Varies inversely with thickness of snow.
20. These are satisfactory methods of travel, but the ice may break up and go out.

IV NOTE This table was prepared by the author after consultation with Dr. Paul Siple and Major Vernon Boyd, U.S.M.C., experts on the subject of Antarctic trafficability. There are so many variables involved that not all the ratings shown here were agreed upon unanimously. This table should not be used as the sole basis for evaluating the serviceability of a specific vehicle--surface combination, since it cannot take into account such vitally important factors as the length and purpose of the travel, the range of the vehicle, the food and fuel required and the weather forcasts. The slope and orientation of surface features were not considered in the preparation of this table. In general, the trafficability varies inversely with the degree of slope and the complexity of feature orientation. In rating foot transport it should be remembered that skis and snowshoes can be removed to overcome certain obstacles. In rating aircraft only landing areas were taken into account. JHR on level or rolling ice terrain or on land or sea ice. Obviously such variations have a decided effect upon trafficability and yet firn has a character of its own sufficiently strong to maintain its identity as a particular type of surface.

The table classifies the various modes of transport into foot, motor, aircraft and ship categories. All vehicles belonging to a single one of these categories possess a number of characteristics in common regarding trafficability, e.g., no method of foot transport is suitable for crossing open water. Each vehicle commonly used in the Antarctic is rated for its ability to pass over each of the major types of surface found in the South Polar Region. Aircraft may pass over all types of surface and so are rated only on their ability to land and take off from the various surfaces.

More Antarctic exploration and research has occurred offshore than on the icecap, e.g., oceanographical research and coastal exploration by ship. In recognition of this fact the trafficability of each vehicle is also considered as it relates to sea ice. Part II of the table is based upon the assumption that the sea ice surface is suitable for the vehicle concerned as indicated by Part I, and accordingly gives the value of each vehicle for transport in relation to the thickness of the sea ice and the percentage of water covered by it. If the sea ice surface conditions are not appropriate for the vehicle concerned, the analyst may eliminate this vehicle without consulting Part II.

From a brief glance at the table one may assume that the best all-around vehicles in each of the four classes are skis, amphibious tractors, helicopters on floats and icebreakers. While this is normally true, generalizations like this one may be dangerous since the purpose of the travel, the length of the journey, the food and fuel requirements, the weather to be encountered and the variety of surface conditions to be met might make some other kind of vehicle or combination of vehicles far more suitable than those mentioned. Any modern well-equipped expedition would be expected to have more than half of these means of movement available.[20]

Firn. Firn surfaces are almost everywhere an aid to transportation. All vehicles designed for icecap mobility operate well on firn. Ski-equipped aircraft experience little difficulty in landing or take-off. Loose firn is sometimes difficult to walk through and accentuates blizzard conditions on windy days, but these factors do not prohibit movement, they merely make it more difficult.

Snow and ice. Soft snow is less passable than firn. Many vehicles can move over it, but usually with difficulty and at a larger proportionate expenditure of energy than for similar movement over firn. Hard glacier or meltwater ice, when not slick, may be used by almost any vehicle. Slick ice, however, makes a very difficult surface upon which to move and when it is situated on a slope, slick ice is a definite hazard. Tractors may operate on bare, slick ice but are unable to pull their own weight over it. Hard ice, slick or otherwise, with a few inches of snow or firn cover, however, makes one of the very best surfaces for all vehicles other than those in the ship category. Snow, firn and ice are all white in color but may be distinguished from each other on airphotos, especially if two or more of them appear on the same photograph.[21] The

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[20]The writer used all these vehicles while in the Antarctic, except for the wooden ship.

[21]See Chapter V.

problem is largely one of comparing texture and tone scales.

Sastrugi. One of the most common surface conditions in Antarctica is the presence of myriads of long, low, linear, usually ridgelike dunes of snow or firn called sastrugi.[22] The linear forms are generally aligned parallel to the direction of the prevailing wind. They are usually not over two feet in height and 50 feet in length, although much greater lengths occur in some areas. Sastrugi are not generally considered of importance as obstructions to ice vehicles or to aircraft which land parallel to them; however, movement is impeded by their presence.

Ice cliffs. Vertical cliffs of ice occur at the floating ends of glaciers, at the barrier ends of shelf ice and at the sides and snouts of wall-sided glaciers. Since these cliffs form most of the shoreline of Antarctica, they are of considerable significance in Antarctic trafficability analysis. Except for aircraft, no vehicles are able to pass over these barriers. Without aircraft, passage over the barrier is found only where the cliffs have been split or where they adjoin land. Mention has already been made of the use of natural drift ramps, where available. Ramps may be built by the use of explosives and bulldozers, if the use warrants the expense and danger involved.

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[22]The term sastrugi is perhaps more properly spelled as zastrugi. The word is of Russian origin and was borrowed for English usage from the German literature. In the German transliteration of the term from the Cyrillic into the Roman alphabets, the initial letter "s" is used since this is correct German for the "z" sound in the original Russian word. When the word began appearing in the English language publications, the "s" was not replaced by a "z" as would have been necessary to retain the sound of the word as pronounced in Russian and in German. The form sastrugi is now so firmly established in scientific English usage that perhaps more would be lost in terms of energy and confusion than gained in etymological precision by reverting to the proper spelling at this time.

Pressure ridges. The forces of wind, tide, currents, swell, temperature change or combinations of these may exert sufficient lateral pressure on sea ice to cause it to buckle, crack and crumble at the edges and to pile up blocks of ice, sometimes to a height of 20 feet or more above sea level. Pressure ridges of this sort are frequently miles in length and may be traced with ease on airphotos. When less than 30 feet in length, these ridges are called hummocks, and pose no trafficability problem. The longer pressure ridges act as minor barriers to most kinds of transport, including icebreakers, since a pressure ridge 12 feet high might mean a total thickness of sea ice at that point of more than 24 feet. Pressure ridges are nearly always passable, however, is sufficient effort is expended.

Disturbed ice. Areas of highly disturbed ice, seracs or areas of criss-crossed crevasses[22] are exceedingly dangerous and generally impassable to all forms of traffic, except air.

Meltwater. Streams, lakes, ponds and puddles formed on glacier or shelf ice surfaces from the melting of surface snow as a result of direct heating by the sun or from the presence of heat radiated from exposed rock or rock dust create a barrier to all types of transport except the amphibious tractors, rubber rafts and aircraft. Meltwater streams and ponds may be crossed on foot or even by dog sled when the depth does not exceed a few inches. Meltwater sometimes fills crevasses. Meltwater puddles on sea ice may be so numerous that travel through such areas by any means other than icebreaker or aircraft is to be avoided at all costs. Sometimes the meltwater surfaces freeze over with a crustal layer of ice too thin

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[23]The Icelandic term skauk was introduced into the English glaciological literature by Taylor (1922, p. 87) to be used in place of the more awkward English phrase, crevasse field.

to support the weight of a man, even on skis. This type of ice is particularly poor for dog sled travel since it cuts the paws of the dogs and shortly renders them unfit for travel.

Exposed land. Bedrock, talus, glacial moraine and volcanic debris are the principal forms assumed by exposed land in Antarctica. Most bedrock areas are covered with moraine or erratics and are in steep, irregular slope. Exfoliation is common where the bedrock structure lends itself to this form of weathering. Volcanic debris, talus and loose moraine all differ in origin, but because of their unconsolidated character all react much the same insofar as passability is concerned. Generally speaking, vehicles designed for ice transport as well as wheeled vehicles are useless here. Tracked vehicles may operate but they are difficult to manage and the lugs are easily broken on the sharp rocks. Helicopters on floats provide the best means of transportation in this type of landscape, but they must be landed with extreme care to prevent the rotor from angling over and striking the rocks.

Soils and vegetation. Neither soils nor vegetation occur with sufficient frequency in Antarctica to merit consideration of their effect on trafficability.

Pack ice. The ocean icebreaker will operate in most types of pack ice until a nine-tenths or ten-tenths cover of sea ice of sufficient thickness is reached. It is the preferred vehicle for traffic through Antarctic seas, but it does not contain large holds for storage purposes (except for a few of the Russian icebreakers which are designed for cargo carrying). Although not evident in the table, wooden ships are far less vulnerable to sea ice than the steel-skinned unless the latter have been specifically designed to operate in sea ice. Wooden hulls are more flexible than steel plates and rigid frames.

The large ten-man rubber raft is a most convenient vehicle for ship-to-shore exploration. It is easily portable, carries more than a ton of weight, is of very shallow draft and is landed with greater ease under conditions of moderate swell than a whaleboat or wooden boat. Although no such instances are known to the present writer, the raft apparently would make a suitable vehicle for crossing extensive areas of meltwater.

Fast ice. Sea ice which remains fast in its position of growth along the coast is known as fast ice. It may be of a few feet or tens of miles in width. In some areas it becomes much thicker than ordinary sea ice. Fast ice, because of its levelness and lack of crevasses, is sometimes preferred to the adjacent land ice for coastwise traffic. Vehicles employed on icecaps are generally suitable for use on fast ice. Dangers arise from thin spots or cracks in the ice and from the habit of the fast ice to break up and drift out to join the pack ice without warning. Some explorers have gone out to sea with it.

Coastal lead. In many instances a belt of open water separates the pack ice from the continent and its fringe of fast ice. As the Antarctic summer progresses, more and more of the fast ice breaks up and drifts out to join the pack, thus moving this belt of open water closer and closer to the continent. In many areas these leads of open water actually abut the continent or its ice cliffs. This is true even along large stretches of the 90 degrees of coastline in West Antarctica which have never been approached by ship. Ships and small craft may operate effectively in this area but first must find access to it and then stand in the danger of pack ice drifting in to close about them, or of a sudden freeze.

Valley glaciers. Along mountainous coasts the valley glaciers provide the best highways to the polar plateau. Their surfaces, consisting of moving glacier ice, are far from ideal, but are certainly to be preferred for purposes of travelling to the surfaces of the mountains which they separate. Even aircraft take advantage of these glacial valleys to climb slowly and evenly to the plateau level, thus saving considerable amounts of fuel.

Polar plateau. The known portions of the polar plateau provide an extremely large, relatively level, firn- and snow-covered surface good for operating almost any type of ice craft or aircraft, even though the snow and firn here do not have the stability or compactness of the shelf ice or coastal glacier surfaces.

Significance of Antarctic accessibility and trafficability. The limitations of movement to, within and from Antarctica make airphoto analysis of relatively greater value here than in areas of greater accessibility where scientific field investigations can be accomplished conveniently and without unusual difficulties or expense. Aside from its normal advantages, aerial photo reconnaissance and photo interpretation of Antarctica can provide sufficient information for compiling or correcting aeronautical charts or similar small-scale maps, for delimiting the boundaries of physiographic regions, for the selection of "type areas" characteristic of the region and determining the accessibility of these "type areas," for selection of the most valuable areas in which to conduct field work and for indicating the best means of access to these areas, including the selection of landing points for ships and landing areas for aircraft.

The value of a photogeographer's work in this area is the product of his native capabilities times such factors as his training in geography, his experience in continental glaciology, his familiarity with Antarctica, the quality of available aerial photography, his knowledge of photogeographic methods and his ability to apply them to the area.

CHAPTER IV

APPLICATION OF THE METHOD TO THE AREA

There are no significant differences in the photo reconnaissance and photo interpretation methods used for Antarctica and those used for the more temperate regions. There are, however, important limitations imposed by conditions of the natural environment upon the standard procedures for photo reconnaissance. These limitations cause both a quantitative and a qualitative loss in the aerial photography available for interpretation, which in turn limits the information obtainable from the interpreter's analysis of the resultant photography.

LIMITATIONS OF PHOTO RECONNAISSANCE AND PHOTO INTERPRETATION IN ANTARCTICA

The factors which most severely limit photo reconnaissance and photo interpretation in Antarctica consist chiefly of the difficulties involved in Antarctic flying.

Bases. There are no established air bases in Antarctica. Explorers have succeeded in establishing landing areas for light aircraft with little difficulty, but the fueling and maintenance of these planes are a more difficult matter. Light aircraft are limited in radius. Medium aircraft have a greater range but represent more difficult basing problems. Heavy, multi-engine aircraft with ranges of 5,000 to more than 10,000 miles could be more suitably based on another continent and flown to Antarctica. There are, however, no such bases anywhere south of 55° S. or less than 2,100 geographical miles from the South Pole, and only South America has a base as close as this. There is an area of more than 30,000,000 square miles, more than ten times the size of the United States, centered about the South Pole in which there are no suitable bases for these airplanes.

The aircraft now in use on aircraft carriers and seaplane tenders, which can operate just outside the pack ice, do not have sufficient range, when loaded with the fuel, camera equipment and survival gear, to photograph the far interior of Antarctica. The bases used on the continent thus far have not been capable of supporting aircraft with sufficient range to photograph more than a limited area, usually less than 1,000 miles from the base. No alternative bases exist in case of emergency. These are the factors that have largely determined the limits of the areas photographed to date.

Logistic support. Every item used by the south polar explorer must be carried to his base since nothing is available in Antarctica except ice and rock and in most places there is no rock. Some food is available in terms of penguin and seal meat sufficient for small groups at certain coastal locations. Supplying Antarctic bases by icebreaker-escorted cargo ships through pack ice or by air cargo plane over the pack ice is both difficult and expensive.

Navigation. Loran, shoran and radio range systems have not been established in Antarctica. The sun is not visible during the long winter night and the stars are unavailable for celestial navigation during the long summer day. High overcasts frequently hide the sun or stars in the seasons in which they do appear. Good maps are not extant. Adequate maps are available for only a few portions of the coastal area. Landforms or iceforms suitable as landmarks are generally either uncharted or incorrectly charted, especially those which are in the continental interior. Few pilots have been suitably trained in the problems peculiar to polar navigation. Here the meridians converge rapidly, the sun may not set and the magnetic compass is rarely dependable. There are no railroad tracks for the lost pilot to follow. In short, it is difficult for the pilot to get to where he wants to go, to know when he is there and to know where he has been, if and when he can manage to return to his base.

Weather and climate. The period of September through February has thus far provided the best flying weather in the Antarctic. Even during this season, periods of flying weather are limited to a few hours or a few days at a time, the latter being infrequent. There may be longer periods of suitable flying weather away from the marine influence at the coast, but bases in the interior would be difficult to man and supply. Seaplanes and flying boats stand in danger of being overloaded from the accumulation of too much ice from frozen spray when taking off at air temperatures below freezing.

Although the temperature of the layers of the atmosphere adjacent to the icecap may rise above the freezing level, temperatures as low as minus 40° F. may be encountered in normal summer photographic flights. Under such conditions, the aircraft cabin must be heated or the aerial photographer will not be able to perform such simple, but necessary, tasks as the reloading of the camera film magazines.

High winds affect photo reconnaissance in two ways. Winds at the aircraft base lift the loose firn off the ice surface to form a blizzard, thus preventing the photo airplane from taking off. High surface winds in the area to be photographed also lift the loose firn from a few inches to a few feet into the air, effectively blurring the detail of the terrain.

Of greatest importance is the absence of meteorological stations on the Antarctic Continent to aid the base forecaster in his daily prognostications and the absence of complete and systematic weather records to enable him to make a general prognosis.[1]

Light conditions. Three kinds of frequently occurring light conditions plague the aerial photographer: (1) the long winter night, (2) the sun low on the horizon, and (3) the high overcast. Best known of these is the long winter night, during which a portion of Antarctica is plunged into 24-hour darkness while the remainder has but several hours of twilight each day. At the present time night reconnaissance photography for large areas is neither practical nor desirable in the Antarctic, although flares, flash bombs and electronic lighting units are available for this purpose.

During the Antarctic spring, the amount of light gradually increases and photo reconnaissance may be performed at any time which is appropriate for the latitude and the other factors governing the amount of light in the area to be photographed. Plates 2 and 3 have been prepared by the author so that the flight planner may graphically determine the duration of sunlight and twilight at the aircraft base and in the area to be photographed.

During a large portion of the periods of adequate flying weather, the sun is either at or just a few degrees above the horizon. Since in trimetrogon photography the three cameras are so oriented that they cover the earth's surface from horizon to horizon and for 20 degrees above the true horizon, the sun sometimes shines directly into the camera lens.

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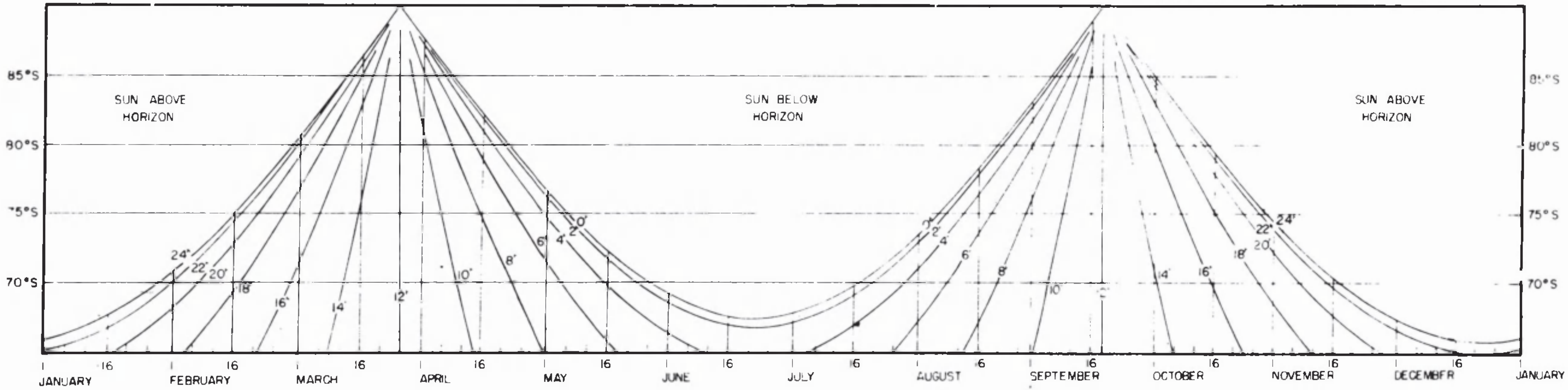
[1]There are normally a few weather stations operating on the outlying islands, such as the South Orkney Islands, the South Shetland Islands, Heard Island and Macquarie Island, but no permanent weather stations operate on the continent itself.

DURATION OF SUNLIGHT IN THE ANTARCTIC



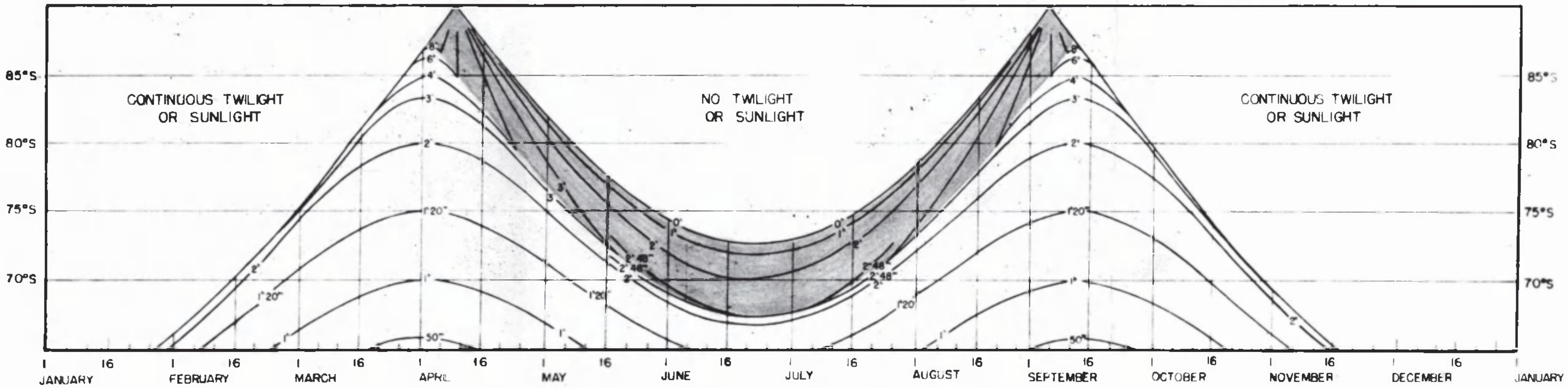
Sunrise and sunset are considered to occur when the upper edge of the disk of the sun appears to be exactly on the horizon. The isolines of this graph indicate the number of hours from sunrise to sunset, in effect the number of hours of daylight. Continuous daylight occurs in the area marked SUN ABOVE HORIZON, while continuous darkness, including twilight, occurs in the area marked SUN BELOW HORIZON.

In the portions of the graph which are difficult to read accurately, the phenomenon itself is generally uncertain. Even in the most accurate parts of the graph, time may not be determined with a certainty of less than five minutes. The accuracy is greatest during March and September and decreases rapidly for other seasons of the year and toward the pole. Near the curves marked 2 hours and 22 hours the uncertainty may exceed an hour and near the curves marked 0 hours and 24 hours the sun may fail to rise or set. These large uncertainties are the inevitable consequences of the physical circumstances which create the phenomenon and are not due to any inadequacy in the graph per se. In addition it must be remembered that any elevation of the observer above the earth's surface, the occurrence of any unusual atmospheric refraction or the presence of irregularities on the horizon will cause a difference in the actual period of sunlight. The effect of increases in elevation of less than two thousand feet is negligible, however.

This plate was produced from information provided in a number of graphs and accompanying texts concerning a similar problem in the higher northern latitudes which may be found in Tables of twilight, sunrise and sunset, a supplement to the American ephemeris (1946), U. S. Naval Observatory, Washington, D.C. For plans demanding strict accuracy, the formulae of this publication should be converted and used for the southern hemisphere, allowing for corrections in time, place and condition.

JHR

DURATION OF CIVIL TWILIGHT IN THE ANTARCTIC



Civil twilight occurs during the somewhat indefinite periods before sunrise and after sunset during which the natural illumination usually remains sufficiently intense for the performance of ordinary outdoor operations. While civil twilight is now rigidly based upon the interval of time when the sun is less than six degrees below the horizon, the amount of illumination during this period varies greatly according to weather conditions, especially cloudiness and haze.

The graph shows the interval which precedes sunrise or that which follows sunset. In the areas marked CONTINUOUS TWILIGHT OR SUNLIGHT the sun's upper limb is never more than six degrees below the horizon, while in the area marked NO TWILIGHT OR SUNLIGHT continuous darkness reigns. Adjacent to the area marked NO TWILIGHT OR SUNLIGHT lies a region in which the sun is continuously below the horizon, but near enough to the horizon for a portion of each calendar day to cause twilight to occur. Since there is no actual sunrise within this region, however, the "pre-sunrise" twilight is followed immediately by the "post-sunset" twilight and so the values read from this shaded portion of the graph must be doubled to indicate the total period of continuous twilight. In the portions of the graph which are difficult to read accurately, the phenomenon itself is generally uncertain. Even in the most accurate parts, time may not be determined with a certainty of less than five minutes. The accuracy is greatest during April and September, and decreases rapidly for other seasons of the year and toward the pole. In addition it must be remembered that any elevation of the observer above the earth's surface, the occurrence of any unusual atmospheric refraction or the presence of any irregularities on the horizon will cause a difference in the actual period of twilight. The effect of elevations of less than two thousand feet is negligible, however.

This plate was produced from information provided in a number of graphs and accompanying texts concerning a similar problem in the higher northern latitudes which may be found in Tables of twilight, sunrise and sunset, a supplement to the American ephemeris (1946), U. S. Naval Observatory, Washington, D.C. For plans demanding strict accuracy, the formulae of this publication should be converted and used for the southern hemisphere, allowing for corrections of time, place and condition. JM

Filters have been developed to eliminate some of the resultant difficulties but there is still a noticeable lack of detail in this kind of photography. Oblique and surface photos taken directly away from the sun are also somewhat difficult of interpretation since the shadows which help reveal the detail are hidden behind the features which cast them.

High overcast cloud formations or haze often blot out the Antarctic sun. The sunlight penetrating the overcast becomes extremely diffused, radiating in all directions. Some of this light is reflected back to the underside of the overcast where a portion of it is again reflected at varying angles to the ice surface. This process continues, building up large amounts of diffused light in the atmosphere, which illuminates all sides of the individual objects which comprise the landscape. As a result, it is sometimes necessary to decrease the lens opening or increase the shutter speed of the camera to avoid overexposure.

Overexposure, however, is the least of the photographer's difficulties at this time. When such conditions occur over ice terrain with no open water or exposed land within view, the diffused light obliterates the horizon and eliminates all shadows.[2] Airphotos taken at such times are entirely useless. They cannot be matched stereographically for three-dimensional viewing. Detail, if it exists at all, is extremely poor in definition. Under such conditions there is also the very real danger of the photo reconnaissance aircraft flying into the polar icecap, for in the absence of a horizon the pilot is unable to distinguish between the overcast above and the ice below until it is too late to avoid a crash.[3]

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[2]See Chapter V for illustrations of this "white day" phenomenon.

[3]In 1946-1947 and again in 1947-1948 aircraft were lost in the Antarctic in just this manner.

Topography. A further limitation of photo reconnaissance results from the high elevation of the Antarctic Continent. Relatively few aircraft are able to fly at a sufficient altitude above the 11,000-foot elevation of the polar plateau to make feasible its complete photo coverage at reconnaissance scales. The weight of the oxygen equipment and the additional fuel required to fly at these high altitudes reduces the range of the aircraft. Some of the uncharted mountains covered with snow or ice on one or more sides constitute a danger during twilight, darkness or high overcasts.

Photographic processing. Lack of adequate photo processing equipment for rolls of aerial film ten inches wide and more than 200 feet in length may necessitate developing the film after the expedition has left the field. This eliminates the opportunity for reflying photo cover of areas where the original photography proved to be unsuitable. Camera failures sometimes go unnoticed when the film can not be processed.

The problem of securing a sufficient amount of fresh water for negative and print washing is acute when the fuel is low or when there are no personnel available to melt the snow. McKinley (1932) reported on the long hours required to melt the 200 gallons of water necessary to process one of his 75-foot-long rolls of film. The film in modern cameras is wider and three times the length of McKinley's film, and the trimetrogon cameras are mounted in batteries of three, again multiplying the amount of water, chemicals and other supplies required.

Many difficulties are imposed unwittingly upon the photo interpreter by the photo laboratory technician who is unskilled in the development and printing of photography of ice terrain. In this instance the film is often overdeveloped in an attempt to bring out an image when all there is to be brought out consists of a few shades of very dark gray and black (very light gray and white on the prints). In this way the detail is lost before the airphotos reach the analyst.

Processing standards of airphotos of ice-covered terrain must be set high, otherwise water marks, static electricity marks, scratches and specks of dust may easily be mistaken for objects which have a logical place on the ice surface such as cracks, crevasses, meltwater, tents, scattered surficial moraine or animal life. Lens reflections should be minimized and positive prints of the ice terrain should be printed at a near white, not muddy gray.

Required supplementary data. Maps and ground information which aid the interpreter in other regions are generally not available for the Antarctic. This limitation may be somewhat offset by employing a "gremlin" camera suited to the particular requirements of the problem. The "gremlin" is a recording camera activated by the same intervalometer as the reconnaissance cameras and set to photograph the gages of a chronometer, thermometer, radio altimeter, pressure altimeter, inclinometer, data card and the faces of other instruments as appropriate, which, when analyzed with the reconnaissance photography, the pilot's log and the navigator's track chart, will enable the photo interpreter to determine such factors as the scale, location and orientation of the airphotos. "Gremlin" recording cameras can supply most of the information needed for mapping photography, but do not provide definite ground control points, which are necessary for precise mapping. To obtain this control data,the presence of surveying parties on the ice is required.

Special photography. Special photographic techniques are now being used to overcome some of the limitations to photo reconnaissance and photo interpretation in the Antarctic. Color photography, off to a slow start because of the difficulty of processing it in the field and the lack of knowledge concerning the local color temperature, is now a practical technique for revealing features in the landscape not evident in black and white airphotos. When properly exposed and developed, color airphotos of Antarctica make some elements of photo interpretation less difficult and more accurate. Differences in the surface textures of snow, firn and ice, the presence of meltwater and its depth, snowbridges, crevasses and the works of man are examples of photo images depicted more clearly by color. The use of color airphotos or color motion pictures taken from the reconnaissance aircraft as a supplement to the regular black and white aerial photographs is a distinct benefit to the photo analyst, particularly if he has not flown over the areas concerned.

Continuous strip stereo photography may prove useful for recording and examining linear features such as shelf ice barriers and valley glaciers. It will also be useful in determining depths of meltwater. Infrared emulsions may reveal characteristics of the Antarctic landscape not visible in panchromatic film.

The helicopter has been used with great success in obtaining low altitude obliques of features whose images might be of questionable interpretability on high altitude, small-scale obliques. The helicopter has not yet been perfected for long-range work nor for local reconnaissance with a vertical camera mount. Studies are now under way concerning the evaluation of radarscope photography of ice terrain.

<u>Photographic specifications</u>. Antarctic reconnaissance aerial photography requires scales, coverage and other specifications similar to those that would be needed in other parts of the world for comparable interpretation problems.

AERIAL PHOTOGRAPHIC COVERAGE OF ANTARCTICA

Airphoto analysis of Antarctic landscapes was not possible 25 years ago. Although by that time photography was a century old and practical aircraft were no longer a dream, no airplane photography of Antarctica existed.[4] But once this method of reconnaissance was applied and the results evaluated, its development came rapidly, though quite irregularly.

More than 110,000 aerial photographs have been taken of Antarctica. Half of these were made by a single expedition during the latter part of one summer season,[5] while the remaining half is a product of 25 years of effort on the part of more than 16 expeditions.

Development. Sir Hubert Wilkins made the first Antarctic flight and took the first Antarctic aerial photos during a flight over the Palmer Peninsula in the 1928-1929 season.[6] Later in the same southern summer, Colonel (then Captain) Ashley C. McKinley (1932), a professional military aerial photographer with Rear Admiral Byrd's first Antarctic expedition, began the scientific airphoto reconnaissance of Antarctica. This included airphotos of portions of the coast and interior of Marie Byrd Land, the Ross Shelf Ice and in the following summer the South Pole itself. Wilkins

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[4]An exceedingly limited amount of experimental captive balloon aerial photographs had been made in local areas which had already been subject to intensive surface examination. Von Drygalski's balloon photography, taken during the German Antarctic Expedition, 1901-1903, is still on file in the Archiv für Polarforschung, Kiel (Richter, 1951), and the balloon photography of Shackleton taken on the British National Antarctic Expedition, 1901-1904, was published in 1908 [Wilson].

[5]U.S. Naval Task Force 68, "Operation Highjump," 1946-1947 made more than 65,000 aerial photographic exposures for reconnaissance purposes. Kodachrome aerial motion pictures were also taken.

[6]Where not otherwise noted, authority for statements concerning aerial photographic coverage of Antarctica may be found under the corresponding reference in the source column of the legend on Map 6.

also continued his aerial photography during the 1929-1930 summer season and added aerial motion picture photography. During this same season the British-Australian-New Zealand Antarctic Research Expedition under the leadership of Sir Douglas Mawson performed aerial photo reconnaissance in East Antarctica, while at the same time and but a short distance to his west, Consul Lars Christensen's third expedition under the command of Captain Riiser-Larsen was similarly occupied. Thus, within a year of the time of the first airplane and airphoto reconnaissance flight in Antarctica, four major expeditions were engaged in procuring aerial reconnaissance photography.

Byrd continued the aerial survey of Marie Byrd Land and the Ross Shelf Ice on his second expedition, 1933-1935. John Rymill, leader of the British Grahamland Expedition, 1934-1937 continued the airphoto survey of the Palmer Peninsula, concentrating on the central section of its west coast. Lincoln Ellsworth, on his historic flight across Antarctica from the Weddell to the Ross Seas in the summer of 1935-1936, took 66 airphotos of landmarks in this previously unexplored area with a 35-mm. camera.

In the following summer, Consul Lars Christensen, accompanying his sixth expedition, directed the efforts of Viggo Widerøe as pilot and Nils Romnaes as aerial photographer in the making of oblique aerial reconnaissance photography for much of the coast of Queen Maud Land. Maps have been made from this photography.[7]

The Deutsche Antarktische Expedition, 1938-1939, under Alfred Ritscher (1942), began the first large-scale aerial photographic attack on a portion of the Antarctic interior. With typical German thoroughness, Ritscher's

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[7]See Map 7, sheets C-1 through C-12 (blue). Maps 9, 10 and 11 are reduced photostats of three of these map sheets.

flying boats took more than 12,000 oblique airphotos which resulted in three published maps of some 350,000 square kilometers of previously unexplored land.[8] Again photo survey and photogrammetric instruments were used in exposing the photography and in preparing the maps, but the maps still could not be said to be precise because of a lack of ground control points. O. von Gruber explained the photogrammetric survey processes used and R. von Klebelsberg presented an analysis of the New Schwabenland morphology in Der Deutsche Antarktische Expedition, 1938-1939 (Ritscher, 1942).

The U.S. Antarctic Service Expedition, 1939-1941, with bases under the field command of Dr. Paul A. Siple and Commander Richard B. Black, considerably expanded the photo coverage of Marie Byrd Land and the Ross Shelf Ice as well as making an airphoto survey of Charcot and Alexander I Islands and of the southwest and southeast coasts of the Palmer Peninsula. Aerial color photography was used experimentally for the first time in the Antarctic. The technique of flying photo circles was practiced, giving effective panoramic views from air stations located over geographic positions which contained some elements of ground control. Unfortunately, no maps were published directly as a result of the aerial photography of this expedition[9] but 13,575 airphoto negatives, now filed in the National Archives, were added to the 18 rolls of aerial film made on the two earlier Byrd expeditions and previously filed there.

From 1941 through 1946, the countries of the Northern Hemisphere were
[8]See

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[8]See Appendix I for reference to these German maps which are not plotted among the charts on Index Map 7. These maps accompany Ritscher's (1942) account of the expedition.

[9]Manuscript maps prepared by Siple, Butler and others have not been published.

too busily engaged in World War II to consider Antarctic exploration. An Argentine expedition in 1943 took a few oblique airphotos in the vicinity of Port Lockroy, however.

In the 1946-1947 season, the U.S. Naval Task Force 68, operating under the First Antarctic Developments Project, planned and executed an intensive photo reconnaissance survey of the coasts of Antarctica. Previously, only oblique photography had been used, but the aircraft of Task Force 68 were provided with trimetrogon installations which permitted horizon-to-horizon cover and vertical photography of the path of flight. "Gremlin" cameras were installed to provide additional data for mapping controls. Sixty-five thousand aerial negatives were exposed by the expedition's 12 long-range aircraft, operating from two Task Groups based on seaplane tenders at sea and a third Task Group based on the shelf ice at Little America. Most of the coast between 15°E. and 170°E. and between 95°W. and 130°W. was photographed by single, double or even triple trimetrogon flights parallel to the general shoreline, with occasional sorties into the interior averaging 200 miles in depth. Photo reconnaissance was also carried out over parts of the polar plateau, including the South Pole and the plateau areas east, west and south of the Ross Shelf Ice.

In 1947 and 1948, the Royal Australian Air Force photographed Macquarie and Heard Islands.

The 1947-1948 season saw two American expeditions in the field. The U.S. Naval Task Force 39, operating under the Second Antarctic Developments Project, sent surveyors ashore at selected points to obtain the ground control necessary for the utilization of the previous season's aerial photography for mapping purposes. In addition, vertical airphotos were taken of the Davis Sea coastline, Bunger's "Oasis" and the junction of the Knox and Budd Coasts. Low altitude obliques were made of these areas, as well as McMurdo Sound, Little America, Peter I Island and Neny Fjord from helicopters.

Meanwhile, the Ronne Antarctic Research Expedition was busily engaged in a trimetrogon survey of Alexander I Island and both coasts of the Palmer Peninsula to their southernmost limits. Ronne's principal accomplishment was the discovery of the Weddell Sea Shelf Ice and Edith Ronne Land to its south. With this discovery came the final substantiation of the fact that Antarctica is one continent, not two.

At this writing, the combined British-Norwegian-Swedish Expedition (1950-1952) is actively engaged in exploring the interior of Queen Maud Land by both ground and aerial reconnaissance. It is known that airphotos have been made of the shelf ice coastline of this area and also of the mountains near 73°S. and 13°W. (Sverdrup, 1950; Walford, 1951). Additional airphoto coverage is planned for the 1951-1952 season.

<u>Present status</u>. Map 6, Antarctica: Aerial Photographic Coverage, illustrates the present status of areas surveyed by reconnaissance type aerial photography. A study of this map reveals that the symbols for the flight lines of the various expeditions have varying qualitative values in terms of the amount of terrain actually photographed. In most instances, the symbols actually represent the paths of the aircraft when the aerial cameras were in action rather than the area actually covered by the photography, which would necessitate a much broader symbol in most cases.[10]

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[10]For example, the heavy, continuous line symbol of Task Force 68 trimetrogon photography is broken wherever the cameras were turned off. In a few instances where this information was lacking, as was the case with the German photography, there was no alternative but to plot the entire flight line.

The amount of terrain actually covered in any one photograph depends upon many variable factors, including the type of camera mounted in the aircraft and its position and focal length, as well as the altitude of the airplane above the terrain photographed and the local atmospheric conditions.[11]

The specific areas covered by aerial photography are not indicated on Map 6 because of (1) the lack of all the variable factor information necessary to plot the coverage, (2) the unavailability of a considerable portion of the photographic prints for plotting purposes, and (3) the lack of maps at a sufficiently large scale and with a sufficient amount of topographic detail and accurately plotted landmarks upon which to plot the airphotos other than empirically.[12]

As of 1951, the greater portion of the coastline of the Antarctic Continent was covered by aerial photography, but the interior, except for specific instances, was essentially barren of either exploration or aerial photographic coverage. Four significant parts of the coastline still

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[11]An aircraft flying at an altitude of 10,000 feet above sea level over an ice plateau of 5,000-foot elevation and using a 12-inch focal length aerial camera in a vertical position provides photographic coverage for only three-eighths of a mile on either side of the path of flight, or not as wide as the flight track drawn on the map. On the other hand, the one-side oblique photography of the U.S. Antarctic Service Expedition or the both-side oblique photography of the Deutsche Antarktische Expedition covered vastly wider territories. The trimetrogon photography of the U.S. Naval Task Force 68 and of Ronne's expedition covered from horizon to horizon approximately 132 miles at an elevation of 10,000 feet or more above the terrain, assuming reasonable atmospheric clarity on both sides of the aircraft.

[12]Comparison of Map 6 which records the photo flight lines with Map 1 which shows the boundaries of the "explored" areas is invited. The latter are derived from the former by calculating how far the aircrewmen could see or the camera could photograph from the path of flight based upon the variable factors cited above and the record of visibility in the pilot's log.

remained to be photographed: 5°W. to 42°W., 75°W. to 97°W., 144°E. to 151°E. and the north-south stretch of the well-known coast of Victoria Land from 71°S. to 77°S.

The future. Now that a substantial portion of the Antarctic has been surveyed by reconnaissance photography over a period of less than 25 years, and now that many of the problems involved in securing aerial photography of the Antarctic have been met and dealt with, it would seem an ideal occasion to begin conservation of manpower, conservation of materials, conservation of time and conservation of finance through organizing and planning future aerial reconnaissance on a cooperative basis. Each future mission or group of sorties should fly segments of a guiding or master plan. Well-planned reconnaissance with the aircraft and equipment now available could provide complete, high-level trimetrogon coverage for all of Antarctica and at far less expense than the expenditures incurred for the random purpose aerial photography of Antarctica now extant.

Previous attempts to provide an international control for Antarctica have not been notably successful. The suggestion of the United States that Antarctica be governed under a trusteeship of the United Nations was not acted upon favorably by that body. In August 1948, the government of the United States, noting with concern the maneuvering of British, Argentine and Chilean naval vessels in the South American Antarctic as a result of overlapping claims to that area by these countries, sent notes to the seven countries claiming Antarctic territory, i.e., Argentina, Australia, Chile, France, New Zealand, Norway and the United Kingdom, suggesting the establishment of a limited form of international regime. The proposals were accepted in principal by New Zealand and the United Kingdom, but were opposed by some of the others, particularly Argentina and Chile. Argentina flatly refused any eight-power condominium or United Nations trusteeship, while Chile cited the miserable failure of the Spitzbergen eight-power treaty of 1914.[13]

The problem of joint airphoto reconnaissance expeditions is not insurmountable, however,[14] since any agreement for a cooperative plan to provide aerial photo coverage of the entire Antarctic may specifically state that sovereign rights are in no way affected by the project. The equipment would largely have to be provided by the United States and the United Kingdom, who would also have to share the major portion of the costs, aided by contributions from the others, particularly Australia, New Zealand and Norway, unless the project could be financed through the United Nations.

However devised and executed, any such plan would provide, through aerial photography, photo interpretation and reconnaissance photogrammetry, the initial exploration and evaluation of the whole of Antarctica, as well as airphotos and maps of sufficient scale and detail with which to plan future operations and to perform photogeographic and field research.

Availability. In the United States, selected prints of Antarctic aerial photography are generally available to qualified individuals and institutions for scientific purposes through negotiation with the National Archives (Byrd I and II Expeditions and U.S. Antarctic Service photography),

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[13]The eight powers were Denmark, France, Germany, Netherlands, Norway, Russia, United Kingdom and the United States. Spitzbergen was finally awarded to Norway in 1920.

[14]The British-Norwegian-Swedish Antarctic Expedition of 1950-1952 is adequate proof of this statement.

the Department of the Navy (U.S. Task Forces 68 and 39 photography), the Department of the Air Force (Ronne Antarctic Research Expedition photography), and the American Geographical Society (Ellsworth and Wilkins expeditions photography). While no attempts have been made by the author to procure photographic prints made by foreign expeditions, it is assumed that such photography would be made available for scientific purposes by the British and French governments, both of which have received selected photography from the American government, and also by the Norwegians. The fate of the aerial film made by the personnel and equipment of the Deutsche Lufthansa on the German Antarctic Expedition, 1938-1939, is not known to the author, but if it survived World War II, its presence is undoubtedly known to the staff of the Archiv für Polarforschung in Kiel.

A considerable quantity of still and motion picture surface photography in both color and black and white is available for certain local areas.[15] This photography is invaluable in the orientation of airphoto analysts, especially those who have never been in the area. Of particular interest is the U.S. Navy's collection of approximately 175,000 feet of 16-mm. kodachrome motion picture film, along with 10,000 black and white stills and 2,250 color transparencies, made on its two recent expeditions. Some of the 16-mm. kodachrome footage is aerial motion picture film.

APPLICATION OF THE METHOD TO THE AREA

Ever since the first airphotos of the von Drygalski and Scott expeditions at the turn of the century (Richter, 1951; [Wilson], 1908),

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[15] [Roscoe, John H.] (1951) lists 75 selected official and personal holdings and publications of still and motion picture photography.

aerial photographs of Antarctica have had but three principal uses to the scientist and explorer, who have employed them for field orientation and planning, map making or illustrative purposes.[16] Even these three uses have been rare, considering the amount of photography now available and the dearth of information about Antarctica.

This study offers another use for the aerial photography of the Antarctic, namely that of a tool, a tool designed to enable the photogeographer to examine aerial photography of unfamiliar Antarctic terrain and, by means of previously prepared photo interpretation keys, to perform a geographical analysis or provide an accurate description of the areas concerned.

Putnam (1947, p. 559), who also cites Rea (1941), Joliffe (1945) and Brundall (1947) as being of like mind, indicates the comparative recency of using airphotos in place of ground reconnaissance. Rea, Joliffe and Brundall also point out the limitations of the method. Putnam

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[16]The itinerary and planning of the United States Naval Expedition, 1947-1948, was based upon the photography taken the preceding year. Examples of the cartographic use include Hansen's (1946) set of 12 maps of portions of the Queen Maud Land coast, compiled from the airphotos of Lars Christensen's 1935-1936 expedition, and von Gruber's set of three maps of New Schwabenland (Ritscher, 1942), compiled from the Deutsche Antarktische Expedition, 1938-1939 aerial photography. Other maps include the set of six provisional maps of the Walgreen Coast, Amundsen Sea, compiled from the United States Navy photography by the United States Geological Survey in collaboration with the United States Hydrographic Office and lithographed by the Aeronautical Chart Service. Siple (1945) presents an excellent example of using aerial photography for illustrating an account of the geographical operations from the West Base of the United States Antarctic Service Expedition, while Black (1945), in contrast, performs the same function for the East Base altogether without the use of illustrations. Debenham (1948) used aerial photos of the Ross Shelf Ice taken in 1947, selected for him by the author, to illustrate an article for which he had performed the field work some 35 years earlier. Ritscher (1942) published a separate volume of aerial photos and maps made from airphotos to illustrate his account of the Deutsche Antarktische Expedition, 1938-1939. One-third of his 60 oblique airphoto illustrations are three-dimensional anaglyphs.

emphasizes that, while the rewards in terms of saving time and expense are tremendous, there are many pitfalls for the unwary. All seem to agree that only in unusual circumstances can photo analysis be a complete substitute for field work, but recognize that there are times when field work is either not feasible or not possible. The method is rated as unexcelled for reconnaissance studies of inaccessible areas and for isolating areas worthy of detailed analysis.

Smith (1944, p. 744), in discussing surface features in general, states:

> Detailed studies of limited areas frequently provide a key for the interpretation of regional geomorphic features. In applying the results of the former to the latter, reconnaissance methods are commonly employed, and under favorable conditions critical studies of aerial photographs or mosaics alone may suffice.

The appearance of a particular type of ice surface feature can be divided into photo image elements which are capable of analysis and therefore capable of successful identification. If the polar geographer can learn to identify the photo image elements of such factors as snow, firn and glacier ice, the correct interpretation of glacial morphology will not be a mere chance but will approach an expected reality.

If the reconnaissance aerial photography is to be taken at a future date, the photogeographer can facilitate his interpretation by planning the flights in advance with the pilot, navigator, aerial photographer and photogrammetrist to make certain that complete flight logs, track charts and records of altitude above terrain are maintained. He may also ask for large-scale test photos to be made of typical landscapes during the regular reconnaissance flights by the intermittent use of long focal length cameras in the same aircraft.[17]

The geographer should also plan to obtain some oblique photographs, some color transparencies and some infrared photography for regional color appreciation and for images which do not show up well in panchromatic emulsions. In some instances, different film-filter combinations may be used to photograph identification characteristics not visible to the naked eye. Low altitude obliques, ground photographs and panoramic photography may be planned by the photogeographer if a helicopter is at the disposal of the photo reconnaissance team.

Airphoto interpretation is no substitute for research in the field. It is a fact, however, that approximately 100,000 airphotos have been taken of areas of Antarctica on which man has never set foot, and of many areas which man is not likely to explore personally for many years to come, if ever. Photogeographers can provide geographical analyses of these areas by use of photo interpretation keys developed on the basis of their experiences or the experiences of other geographers and explorers in similar regions elsewhere in the Antarctic.

Chapter V consists of a set of general photo interpretation keys especially developed for Antarctica. In Chapter VI, these keys are

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[17]For example, a six-inch trimetrogon installation at 20,000 feet above terrain will render vertical airphotos at 1/40,000 and oblique airphotos at even smaller scales. A 48-inch camera on the same sortie, however, would provide vertical photographs of selected portions of the same terrain at a scale of 1/5,000, allowing large-scale airphotos from which various types of morphology could be analyzed with more accuracy. Once the recognition features of a particular formation or condition were established from the large-scale photos, such formations and conditions could be plotted from the regular small-scale cover. Photography from the 48-inch focal length camera would not be practical for the entire area, however, since each photo at 1/5,000 would cover only 1/64 of the area covered by a 1/40,000 airphoto taken under the same conditions.

applied, by means of photogeography, to the analysis of the Ingrid Christensen Coast, an area with which the author and all other professional geographers are not familiar. The result is a geographic and morphologic analysis of an Antarctic region in which no geographer or morphologist has ever set foot.

CHAPTER V

SOME KEYS FOR TYPICAL ANTARCTIC SURFACE FEATURES

Introduction. Regional photo interpretation keys are prepared for two classes of users: photo interpreters and photo readers. The photo interpreter category consists of those with special training or skills in one or more of the fields closely associated with the subject concerned: in the case at hand, the polar geographer, the ice morphologist, the glacial geologist and the polar explorer. In the subject concerned, the photo reader category is composed chiefly of individuals in closely allied professions who are not familiar with the processes or ice formations associated with glaciation on a continental scale, and those who may be fully competent in other fields of endeavor, such as cartography, who wish to make use of Antarctic airphotos.

Members of the photo interpreter group need little but the photo image and its scale in order to determine significant associative factors which, themselves, might not be visible on aerial photography. This determination is achieved from previous field experience. This past experience, the spatial orientation apparent on the aerial photograph, the large field of coverage at a single glance and the use of the stereoscope for three-dimensional viewing may enable the well-qualified investigator to detect or identify many items of consequence that he could not have recognized if given the same or even an appreciably longer period of time for surface investigation. For the benefit of the photo readers, however, it is essential that as much exact and pertinent information as possible be furnished in simple terms within the brief space available for captions and annotations. Photo interpretation keys with long, detailed descriptions may defeat their own purpose.

It is important to remember that although collections of keys are clearly informative, they should not be considered as texts, but rather as tools for the operating photo reader or photo interpretation specialist.

Although these keys were produced as tools, several original developments have resulted from the research which was required before diagnostic image elements could be isolated and significant photo interpretation keys could be derived from them. For example, after a study was made of the currently existing schemes for the classification of glaciers proposed by such students of Antarctic ice as Ferrar, Gourdon, Hobbs, Nordenskjöld, Wright and Priestley, it was noted that one of the most significant types of Antarctic glaciers had not been included in any of the classifications. To remedy this situation, the term "channel glacier" is proposed here for the features described in Keys 22 through 30.

In addition, new and significant information is provided concerning shelf ice undulations, the origin of shelf ice, the configuration of sastrugi, the shapes of snowdrifts caused by small obstacles as well as those caused by large obstructions, the development of meltwater lakes, the occurrence of moraines, ice recession, polygonal terrain, the "white day" phenomenon, glacial dissipation by blizzards and human occupance of South Polar iceforms and landforms. Confirmatory evidence to support previously existing theories concerning the origin of many other features of the natural landscape is presented in photographic form.

New terms, such as "floating fissure," "reentrant rift," "ice morass," and "right angle drift" are introduced to describe features newly discovered or not previously classified.

Keys. The photo interpretation keys herein emphasize diagnostic features of typical Antarctic landforms and iceforms. They are subdivided for convenience into the following groups:

Subject Grouping	Keys
Major Ice Formations	1---17
Glaciers	18---34
Ice Tongues	35---46
Shelf Ice	47---70
Icebergs	71---86
Snow, Firn and Ice	87---95
Sastrugi	96--117
Snowdrifts	118--137
Crevasses	138--168
Radiation	169--176
Meltwater	177--192
Moraines	193--218
Mountains	219--228
Coastlines	229--241
Islands	242--244
Antarctic Phenomena	245--267
Flora and Fauna	268--284
Human Occupance	285--343

Although the keys have been organized in subject groups, it must be emphasized that, because of the unity of landscape, excellent examples of many of the subjects may be found in sections primarily concerned with other subjects. For example, snow, firn and ice are especially treated in Keys 87 through 95, yet almost all of the 343 keys illustrate some condition of snow, firn or ice. Similarly, sastrugi, specifically examined in Keys 96 through 117, appear in many other keys.

Each key consists of two parts. These parts are the photo image and the associated written analysis. The photo images are predominantly vertical and oblique airphotos in stereogram and single print form. The individual prints of the stereo pairs and stereo triplets are separated by heavy black lines. This unusual presentation technique has been devised to aid the reader who may be unaccustomed to the use of the stereoscope. Three-dimensional vision is best obtained by placing the stereoscope so that its centerpiece is directly over the heavy black line. If this is done, each lens should fall into position over a photo image of the same object. Upon looking through the instrument, the reader may observe three images of the landscape which will appear to be separated from each other by heavy black lines. The images at the extreme left and right may be confusing, may show superimposition of differing landscapes and will not have depth. The image in the center, however, which is framed on both sides by heavy, black lines, should appear in three-dimensional form. If, instead of three-dimensional vision, the reader sees double imagery within the center, black-bordered frame, he should ascertain the apparent position of any outstanding image with relation to its double. If the duplicate images are above and below one another, the reader should rotate the stereoscope horizontally about a vertical axis passing through its center until the images fuse or reach the same plane. If the duplicate images are side by side, rather than above and below one another, the reader should adjust the stereoscope by pushing the lenses closer together or pulling them farther apart until the images fuse. Almost anyone with reasonable power of sight in both eyes can quickly and easily obtain stereo vision with the aid of a stereoscope. With a little additional practice, many people can train themselves to "see stereo" without the use of any instrument.

The second portion of a key consists of an associated written analysis in the form of captions and annotations relative to photo data, scale and the diagnostic features of the photo image. On these keys, known scales have been indicated by a line representing a length of approximately 1,000 feet on the surface of the earth. Where such lines would obviously be too long, this distance has been reduced to 100 feet. The direction of ice movement, where known and deemed pertinent, is indicated by arrows one-half an inch long with a shaft one-eighth of an inch wide. Arrows of other sizes or shapes which occasionally appear on the keys are generally designed to call the attention of the reader to specific objects in the photo illustration. Annotations and captions have been kept to a minimum, consistent with providing the reader all of the information which he must have in order to employ the key successfully and effectively in the examination of Antarctic aerial photography.

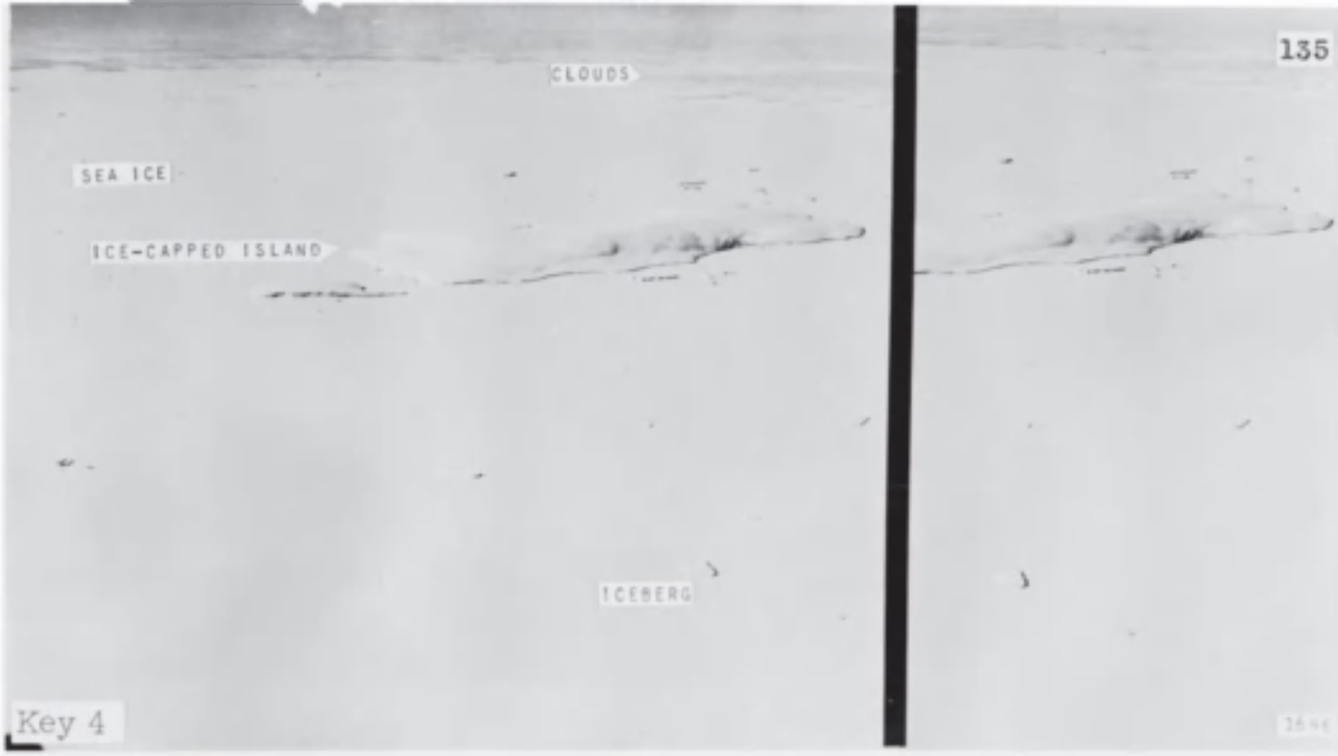
It is virtually impossible to cite the precise locations of most of the airphoto keys which follow, since relatively few accurate geographic positions have actually been established in Antarctica. Estimated locations of the keys can be no more accurate than the navigator's flight track and the aerial photographer's data sheets; however, approximate locations to the nearest degree are given for those airphotos which were not taken at sea. This information has been annotated in the lower right corner of most of the keys. Since the photo reconnaissance flights in the Antarctic have generally been along or near the coast, it has been necessary in most instances only to indicate the longitude in order to designate the area in which any airphoto was taken. In a few instances, as in the case of Victoria Land and the Palmer Peninsula, where the coasts trend north and south, or where the airphotos have been taken at considerable distances inland, the approximate latitude and longitude are both recorded.

CONTINENTAL GLACIER is the term applied to an ice sheet or ice cap which covers a substantial portion of a land mass of continental size, obliterating its surface configurations.

Key 1. The South Polar Ice Plateau occupies the heart of the Antarctic continental glacier. This airphoto, taken over the South Pole, shows the area to be a nearly "featureless" firn plain of 10,000 feet elevation. The firn here is less dense than at sea level. Sastrugi (Keys 96-117) are everywhere. Not visible here are the broad, gentle undulations that occur in the surface of the ice plateau adjacent to some of the outlet glaciers.

Key 2. A littoral sector of the continental glacier at a point where it is unimpeded by major topographical barriers. Families of crevasses, visible where the ice overrides the more rugged terrain, and the recently exposed islands or peninsulas indicate that the glacial floor is not smooth. Ablation, including removal of ice by solar melting, subaqueous melting, wind action, wave action and evaporation, at this location is at least equal to the supply, keeping the continental ice from advancing far beyond the shoreline. The water is deeper off the ice coastline on the right than at the left, probably averaging more than 500 feet. The vertical ice cliffs at this location probably average more than 100' in elevation above sea level. Here, the seaward edge of the glacier advances until it becomes waterborne, breaking off when sufficient leverage has been created for tidal action to create icebergs. Note the typical blending of clouds and glacier which makes the horizon appear quite indistinct.

Key 3. A surface view of the continental glacier at a gentle gradient coast. Here, the grounded ice wall is only 10 feet above sea level. The sea floor at such locations may be profusely covered with marine vegetation. The characteristic upslope inland sometimes rises to elevations of greater than 9,000 feet without a significant break or change in the topography. Scale is indicated by the two men followed by three penguins.



ISLAND ICE is similar to continental glacier ice save for the smaller land mass involved. Island ice usually covers the entire island upon which it rests, blotting out the terrain irregularities. ICE-CAPPED ISLAND is the term for the island thus covered. The phrase ICE ISLAND ICEBERG describes an iceberg which resembles an ice-capped island.

Key 4. This ice-capped island is easily distinguished from an iceberg by its great height, which may be noted in relation to the normal-sized tabular iceberg off the coast near the center of the island. When the island ice recedes, it will leave highland ice (Keys 7, 8 and 9) and perhaps wall-sided glaciers (Key 21) or avalanche ice (Key 15) if the rock perimeter is sufficiently steep. The adjacent seas bear undisturbed fast ice of one season's growth. Clouds and cloud shadows are billowy in the background.

Keys 5 and 6. Presented here are surface photos of a skerry covered by island ice but lacking the floating ramparts of the island in Key 4. The dimensions of this island are approximately 75 by 150 feet. It has an elevation of ten feet with a firn cover of ten feet. Small islands of this type are difficult to recognize on aerial photos unless perimeter rock has been exposed by tidal or wave action or unless comparative airphoto cover is available.

HIGHLAND ICE is defined as a comparatively thin, but continuous, ice sheet, with or without firn or snow cover, overlying any flat or undulating land surface and conforming to a considerable extent to the irregularities of the land upon which it rests (Wright and Priestley, 1922, p. 148).

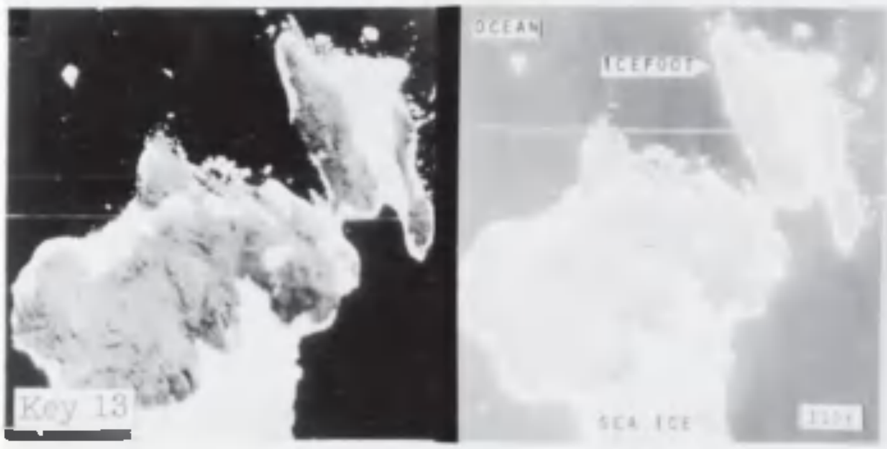
Key 7. Highland ice is most easily recognized in areas of rugged terrain where conformance of the overlying ice sheet, except for occasional cliff faces, is self-evident. Recognition or location of highland ice in flat lands is not feasible by either airphoto or ground analysis unless an electronic device, such as an airborne magnetometer or radio altimeter, is keyed into the photo flight track by means of a gremlin camera or electronic recorder. The patch of level highland ice at the lower right is revealed by the steep ice falls which border it. The mountains in the extreme background have no highland ice cover. The heavily crevassed areas beneath the direction-of-movement arrow are areas of rapid ice drainage from the valleys into the ocean, lower left.

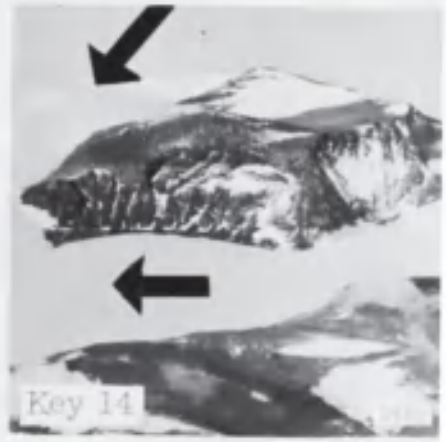
Keys 8 and 9. Here local fields of highland ice supply the tributary and valley glaciers. In the background of Key 8, highland ice occupies the slopes of coastal mountains and the tops of mountains too high for the continental ice to submerge. Key 9 illustrates a small highland ice plateau.

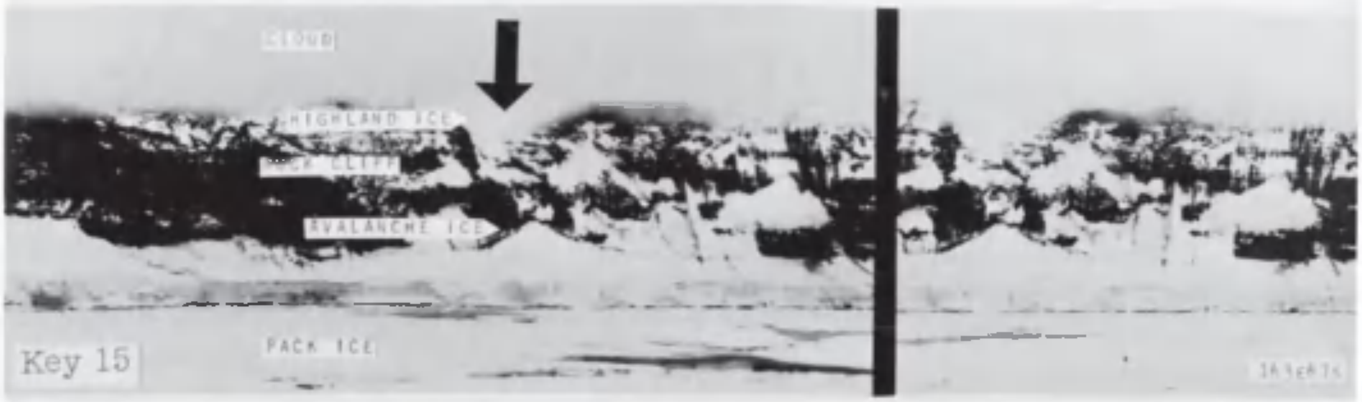
CIRQUE ICE is the body of glacier ice within a cirque, when the cirque depression is not obliterated by continental, island or highland ice which prohibits normal cirque action. While at present many Antarctic cirques are inactive, climatic modification may again permit these cirques to deepen and enlarge their depressions by frost action on the cirque walls, meltwater action at the base of the bergschrund and ice movement pushing out the debris. In the meantime, most Antarctic cirques remain windswept and bare or entirely submerged in glacier ice.

Key 10. Stereo-triplet of cirques which have formed arêtes(sharp ridges), and cols (ridge saddles). Sharp differences in elevation make stereo vision difficult to attain on this stereogram.

Key 11. Incipient cirques and cirques with cirque glaciers in foreground.







SNOWDRIFT ICE must be distinguished from snowdrift. The former consists of relatively permanent drifts which change to firn or glacial ice. The latter is temporary. Both are caused by the accumulation of drift snow in the lee of projections or in depressions. Along the coastline, snowdrift ice is frequently associated with icefoot (the ice inshore from the innermost tidal crack) upon which it may rest.

Key 12. Rocky coastlines, extensive moraines and areas of exposed bed rock are normal sites for snowdrift ice. Here, snowdrift ice may be seen behind the ship (which is 269 feet long), along the coast and inland.

Key 13. Insular snowdrift ice with icefoot along the coastline and sea ice at the bottom of the stereogram.

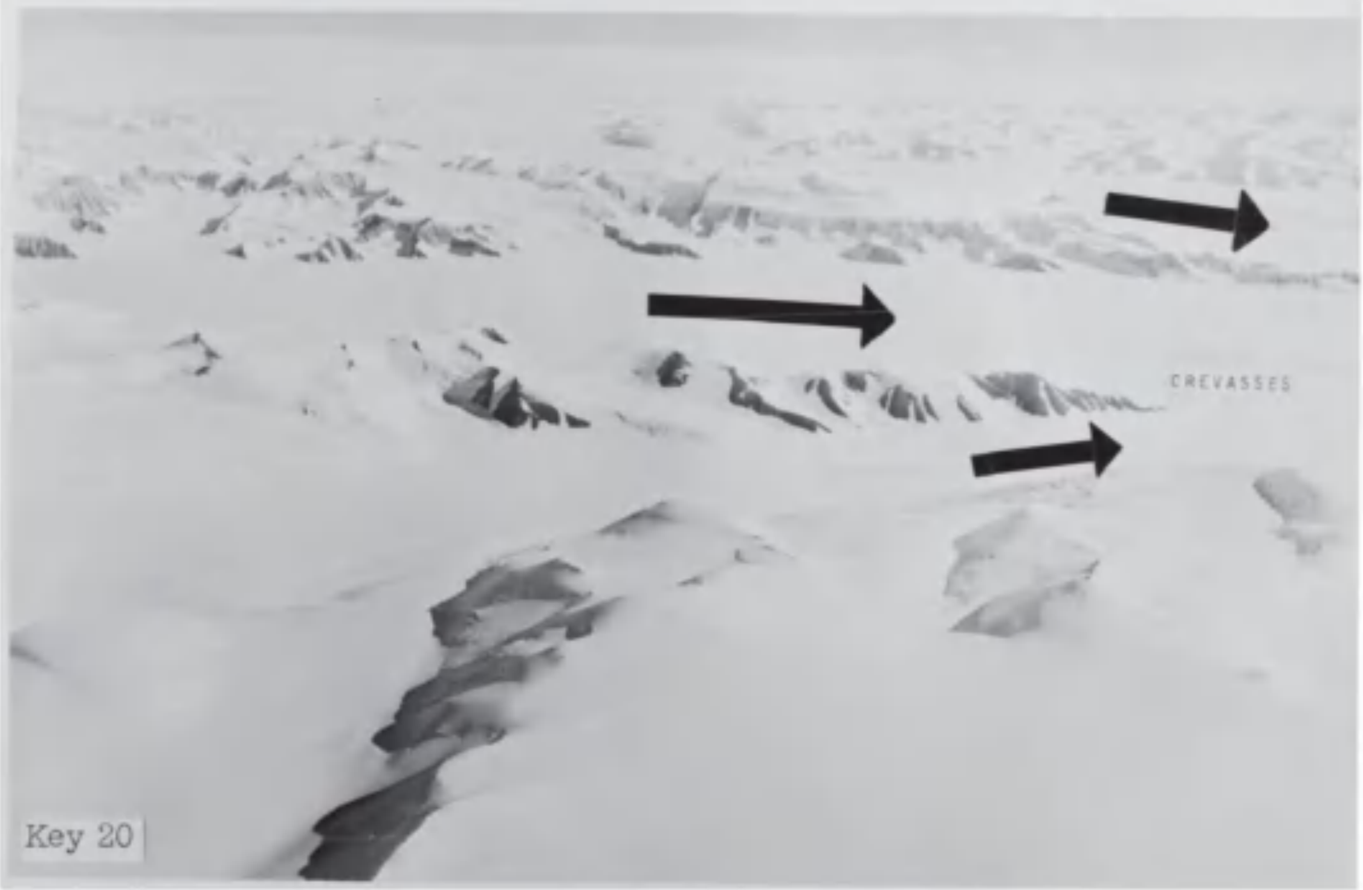
Key 14. Snowdrift ice in cirque basins and depressions.

Key 15. AVALANCHE ICE may frequently be mistaken for snowdrift ice. The small icefoot glacier at the center of the photo is fed by avalanches of glacier ice and its cover of firn and snow from the highland ice above, the edge of which can be seen dipping below the local cloud formations at this point (below arrow).

Keys 16 and 17. Icefoot glaciers derived from snowdrift ice. Late summer phase sea ice in Key 16. Unlike snowdrifts, these glaciers contain glacier ice and firn.

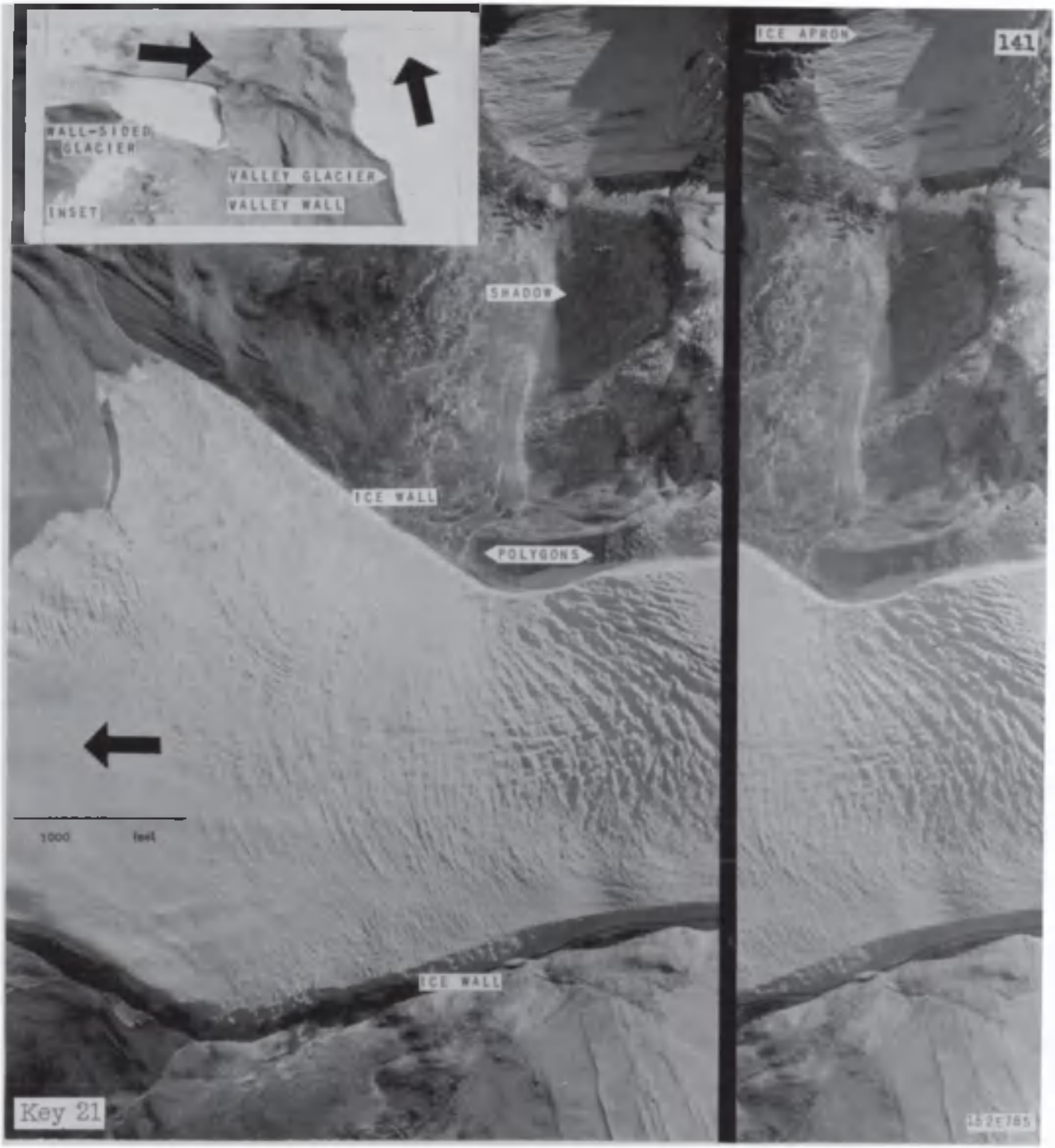
VALLEY GLACIERS are streams of ice, supplied chiefly by cirques, highland ice or continental glaciers which progress to lower elevations while confined by valley walls. CIRQUE GLACIERS emerge like tongues from cirques, discharging locally into valley glaciers or other ice masses.

Key 18. Left, a small valley glacier fed by cirques and drifts. Right, active cirques with cirque glaciers. Note that bergschrundes are not always visible in airphotos. Note meltwater below the cirques.



Key 19. Valley glacier and tributaries. Crevasses and ice falls indicate sudden changes in the elevation of the underlying rock or the direction of ice movement. Valley glaciers create channels by modifying previously existing drainageways.

Key 20. Complex valley glacier system. Topography, glacial junctions and crevasses (all shown here) as well as moraines and meltwater features (not apparent here) aid in interpretation of glacial motion, speed and direction.



WALL-SIDED GLACIERS are local remnants or extrusive extensions of highland ice which advance over adjacent exposed rock surfaces unconfined by valley walls. The characteristic features of these glaciers are: (1) the lack of a distinctive depression for its channel, unless inherited, and (2) their steep, wall-like sides of glacier ice which support the glacier surface well above the surrounding terrain.

Key 21. Locational view (inset) and detailed stereogram illustrating the principal characteristics of wall-sided glaciers as indicated above. An ice apron appears at the foot of a similar glacier (top right). Polygons indicate character of "soil" in some regions of permafrost. Polygons (along upper side of wall-sided glacier) are rare in Antarctica.

Key 22

CHANNEL GLACIERS are streams of ice located within the continental glacier which progress to lower elevations at a more rapid rate than the adjacent continental ice; such glaciers are not limited either by ice walls or valley sides and their surfaces are at essentially the same level of elevation as the neighboring continental ice.

In vast regions of Antarctica, the continental glacier slopes gradually downward from an elevation of 10,000 feet to sea level without any significant break in the ice topography. While essentially all parts of the continental glacier are moving outward from the polar plateau, aerial photo coverage of the Antarctic Littoral definitely proves the ice to be advancing more rapidly in some areas than in others and thus not evenly along the entire continental glacier front. These fast-moving portions act as outlet channels for much of the continental ice, therefore, the name "channel glacier" is proposed as a suitable term for this phenomenon.

Features that readily distinguish channel glaciers from the surrounding glacier ice include pressure ice, ice-covered or ice-free medial moraines along the line of flow and/or intense crevassing with the major crevasses oriented at right angles to the direction of glacial movement. These features are identifiable on oblique aerial photography taken at considerable distances from the glaciers concerned.

Glacial flow is controlled by both the configuration of the underlying topography and the surface level of the ice. Since there is no difference between the surface elevations of the channel glaciers and the adjacent ice, it must be assumed that the rapid flow is a product of the subglacial rock surface structure, the outlines of which are completely concealed by the ice. Moreover, since the presence of such depressions on the surface of the subglacial rock is difficult to establish, short of surface or airborne geophysical means, and since the ice stream appears appears and acts differently than the typical valley glacier, channel glaciers form a seperate category of glaciers.

Key 22. Portions of a channel glacier complex at the point where it intersects the continental coastline. Note the severe tranversal crevassing in the channels. The adjacent ice is subject to tensions which here have resulted in a network of minor crevasses oriented in a different direction and covered with drifting snow or firn. The open sea is at top left but the actual coastline is near the center of the airphoto.

Keys 23 and 24. Oblique views of the channel glacier at Mount Gauss. Although it may be difficult for the inexperienced observer to distinguish, this channel glacier assumes the form of an icefall, descending sharply, perhaps as much as 1000 feet, to the sea. This introduces the subject of scale appreciation of continental glacier ice forms on airphotos. Few individuals who have not performed field work on a continental glacier would estimate this "exposed rock" to be 1150 feet in elevation with glacier ice rising to 400 feet on the continental side and falling to sea level at the ocean. The summit of the "inactive" volcano was found by Drygalski's and Mawson's expeditions to have been glaciated in former times but currently to be supporting mosses, lichens and a petrel rookery.

Channel glaciers are prolific producers of icebergs. Land-formed ice is broken off by tidal action, generally into rectangular blocks which resemble, but are distinguishable from, shelf ice tabular icebergs. The former have a content of glacier ice, rather than firn, resulting in a darker photo-tone and they are also subject to more intense crevassing, which is evident from the air view.

In the airphoto looking seaward (bottom photo), the open water of the ocean is covered with a layer of clouds right up to the coastline, a common Antarctic phenomenon. Note that a discerning eye is necessary to differentiate between cloud, as in the background of this photo, and glacier ice, as in the background of the landward view (top photo).

Keys 25 and 26. A channel glacier in the Denman Glacier area. Medial moraine and meltwater ice from the nearest nunatak disappear into the glacier downstream. Pressure ridges may have resulted from lateral pressure produced at the point where the nunatak restricted the glacier. Linear depressions indicate the glacier to be waterborne in the foreground and middleground of Key 25.

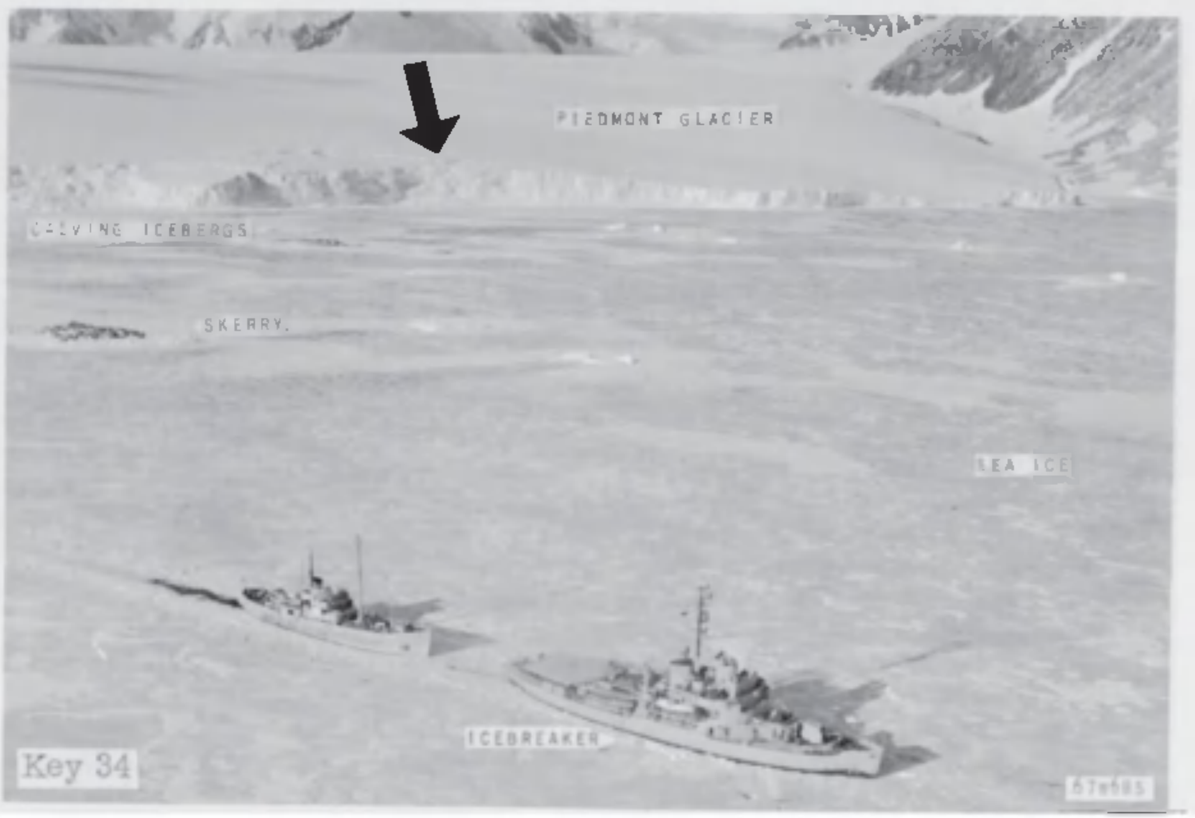
Keys 27 and 28. Same glacier as Keys 25 and 26, looking seaward from the same point in space. Note the longitudinal ridges, the dark tone of which is caused by crevasse shadows, not moraine. Ridges become transverse and lost in depressions filled with light-toned drift snow toward the left of the airphoto. The glacier is waterborne here.

Keys 29 and 30. Another type of channel glacier. Large seracs and crevasses at lower left and in stereogram are covered by snowdrifts downstream but reappear in calving icebergs at glacier snout. Ridges (double arrow), if not crevassed, may be ice-covered moraines caused by nunataks and tributary glaciers upstream. Linear depressions adjacent to ridges may contain meltwater under favorable conditions.

PIEDMONT GLACIERS result from the confluence of expanded-foot glaciers which form ice sheets over level areas at the bases of mountainous terrain.

EXPANDED-FOOT GLACIERS of Hobbs (1911, p. 45) and Wright and Priestley (1922, p. 155) are only of academic interest here, since they rarely occur at the present stage of Antarctic glaciation. Expanded-foot glaciers are valley types with tongues expanded from the release of pressure upon leaving the valleys.

Keys 31 and 32. Piedmont glacier at Neny Fiord. Highland ice on mountains helps supply valley glaciers, the expanded feet of which coalesce on the narrow coastal plain and extend into the fiord in one broad sheet. Cliffed front, typical of seaward glacial faces appears at right; sloping front, typical of glaciers ending on land is at left. Stereogram shows firn-layered cliffs at center and rapid rise of glacier surface. The scale is indicated by the ships (top) and the helicopter (bottom).



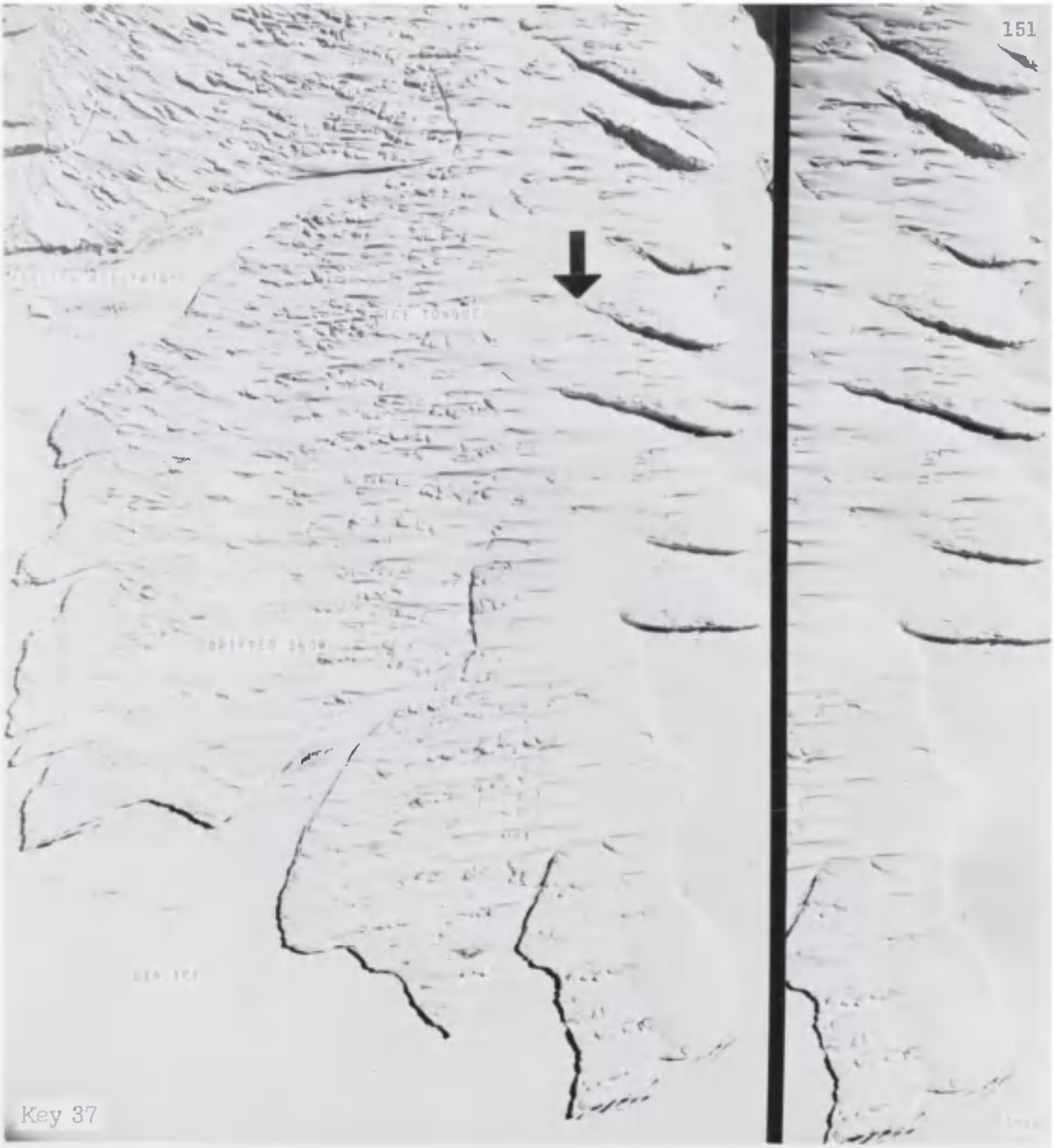
Key 33. The crevasse pattern indicates that this piedmont glacier descends sharply and becomes waterborne near its cliffed edge. Mountains with their supplying valley glaciers are often obscured by clouds. Precipitation in situ also contributes to the formation of piedmont ice.

Key 34. A continuation of the piedmont glacier illustrated on the preceding page. Note calving icebergs, low cliffs and lateral moraine.

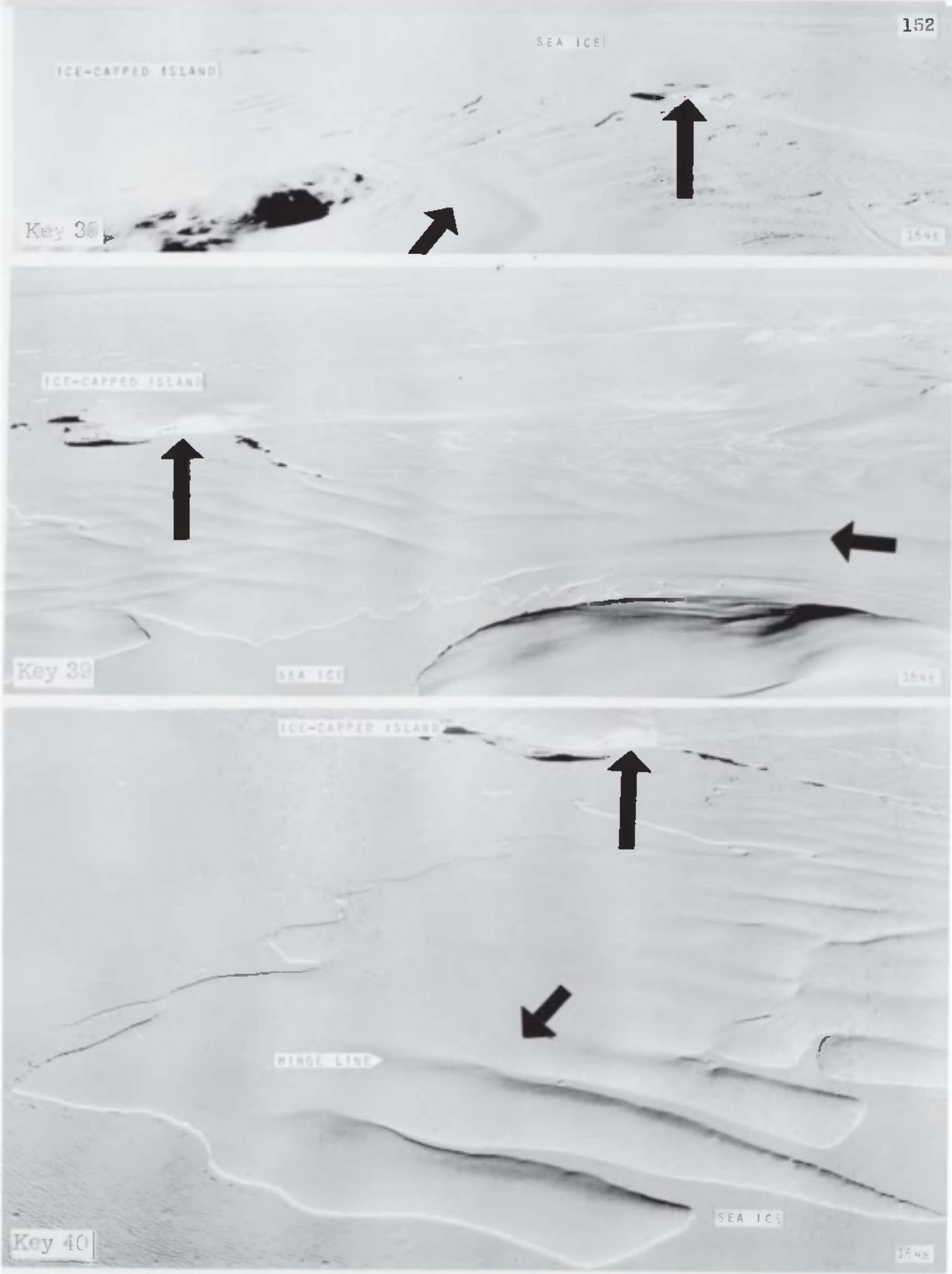
ICE TONGUES are floating extensions of glaciers. The floating ice extends farther out to sea than along the coast, otherwise the term "piedmont ice afloat" is suggested. Since the Antarctic continental ice extends into the sea alomost everywhere along the coast, the term "ice tongue" is reserved for extensions that are tongue-shaped and function like a tongue with the changes in sea level. The latter is determined by whether the glacial extension is of sufficient length to rise and fall with the tide and is advancing sufficiently fast and with the cohesion required to prevent calving at the point where the ice begins to float. Ice tongues are relatively permanent, lasting for centuries, though constantly changing in size and shape.

Key 35. A floating ice tongue with glacial crevasses and hinge lines. It is 12 miles long and ranges from five to three miles in width.

Key 36. A floating ice tongue with drifted-over and cemented glacial crevasses upon which has been superimposed a series of tidal hinge lines. The latter are formed when certain specific crevasses commence to act as the hinge upon which the entire tongue swings with the tide until the floating ice has advanced sufficiently far for the tide to again overcome the tensile strength of the glacier ice and form a new, parallel hinge line in one of the crevasses nearer the point at which the ice becomes waterborne. Hinge lines occur at regular intervals and are readily visible on aerial photographs, especially at the sides of the ice tongues where they frequently split, permitting small reentrants of sea ice. They also occur through the center of the tongues, but they are generally drifted over here, making them difficult to spot on airphotos and almost impossible to locate visually from the surface. Icebergs usually calve at hinge lines rather than at simple crevasses, but not always nor at every hinge line. At the right the hinge lines along the coast are producing icebergs rather than ice tongue. This may be the result of a steeper descent, slower ice movement, bottom configuration or other factors not perfectly understood. Airphoto examination shows a high correlation between rapidly moving ice and floating ice tongues.



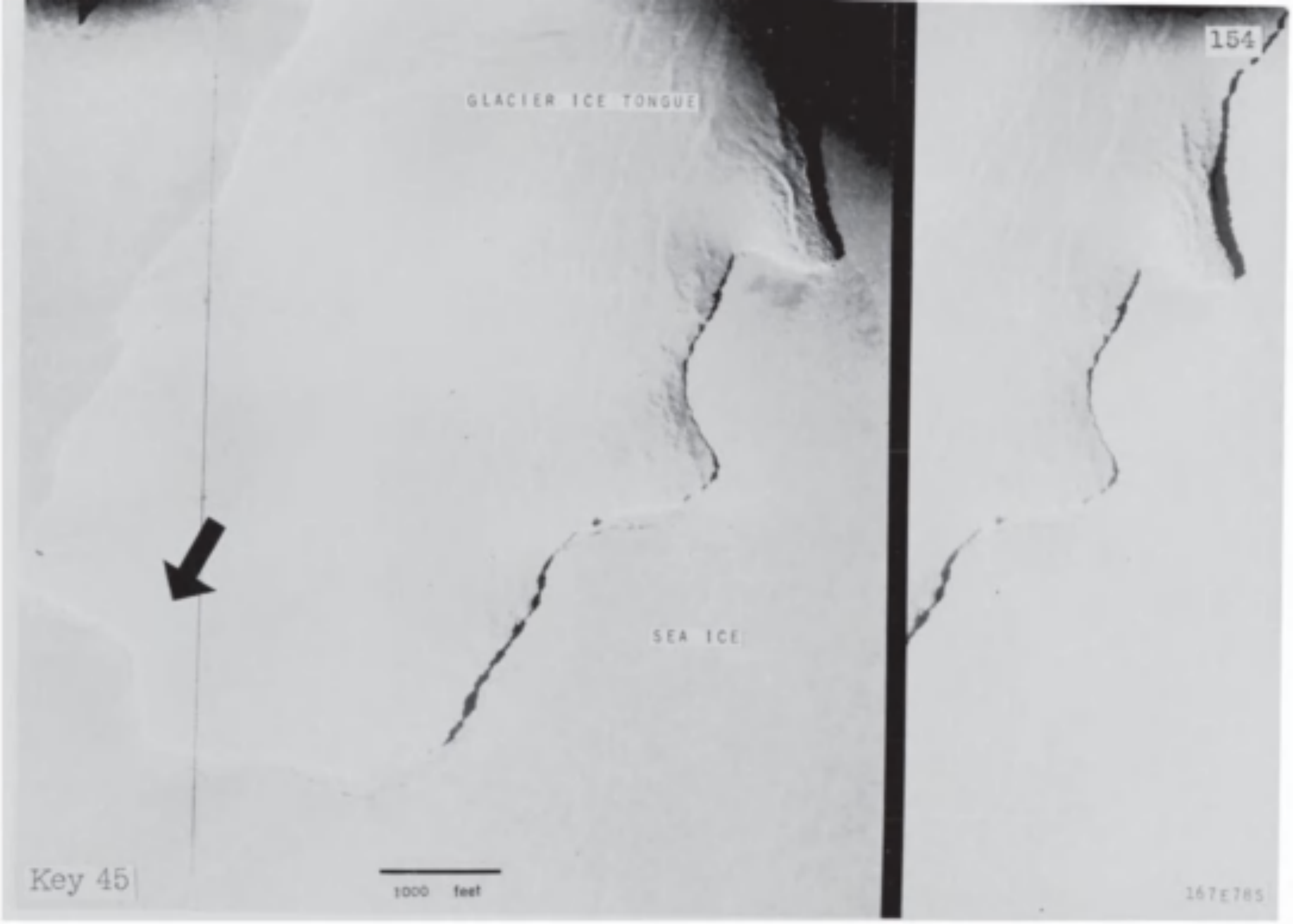
Key 37. A floating ice tongue extending for more than four miles to sea, over three miles of which are visible here. Some ice tongues are so long that they have been explored and named independently of their glacial roots. The apparently strong and constant local winds (from left to right) in this area are evident from the drifted snow which has almost obscured the crevasses and hinge lines. The local ocean current, invisible beneath the sea ice, appears to be in the same direction. This is indicated by the superior development of the reentrants on the left side of the tongue.



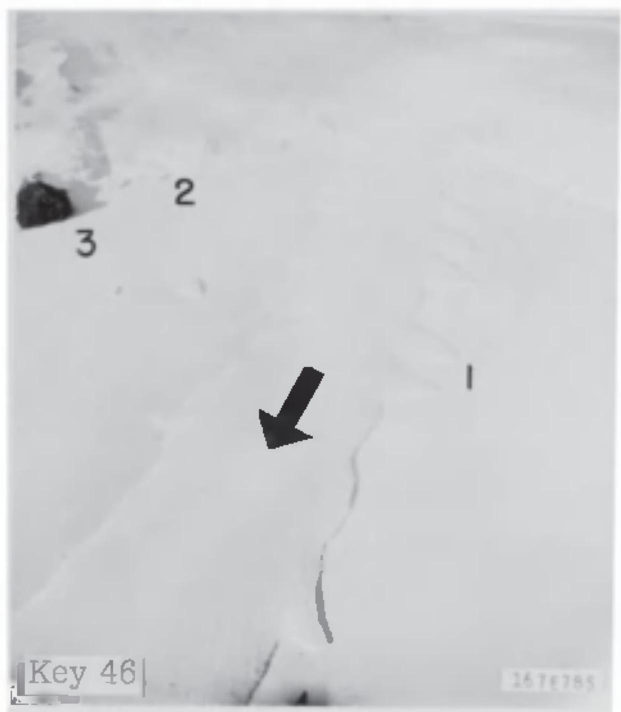
Keys 38, 39 and 40. Three views of a floating ice tongue. Long arrows indicate the same landmark. Note the two ice-covered islands.

Keys 41, 42, 43 and 44. Four examples of floating ice tongues. In Key 43 a huge section of the floating ice tongue, separated from its base in a previous season, will go to sea as a gigantic iceberg when the local fast ice breaks out. This appears to be imminent from the presence of the coastal lead (background) and the shear crack (foreground).

Photo tone value for cliffed ice, except under overcast conditions, will nearly always differ significantly from the surface ice tones, enabling easy recognition of ice cliffs. The last dozen figures illustrate this key, showing bright-toned cliffs reflecting the sun and dark-toned cliffs in shadow.

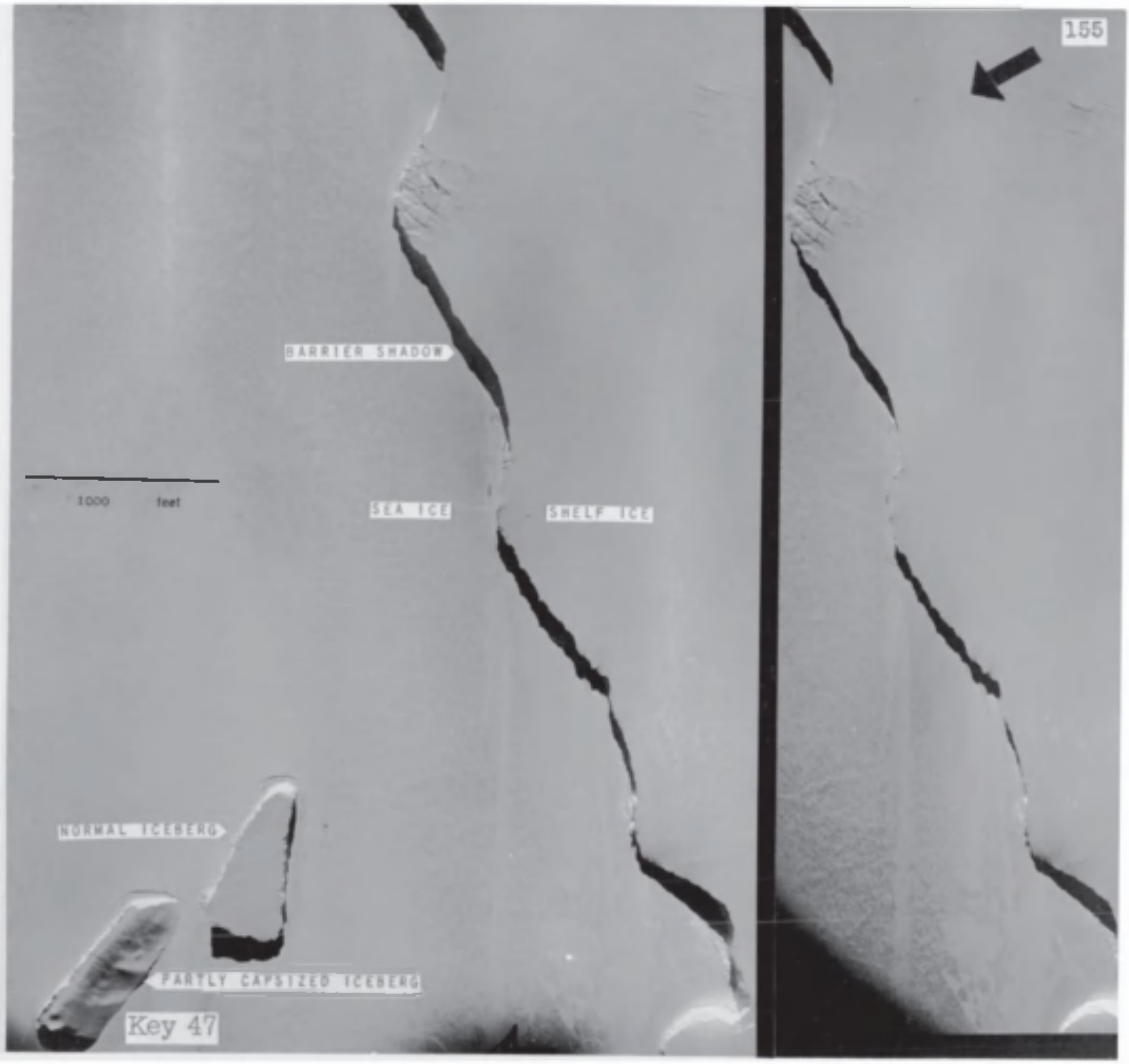


Key 45



Key 46

Keys 45 and 46. Famous Glacier Tongue in McMurdo Sound was studied by members of Scott's and Shackleton's expeditions which were based nearby. It is 40 to 100 feet high, about five miles long, less than a mile wide, has almost parallel sides, advances several feet a day and is afloat. All this can be assessed from airphotos. Size and shape are matters of measurement. Evidence of movement is contained in the appearance of thin spots in the fast ice near its base, pressure ridges in the sea ice between it and outlying islands (not visible on these photos), and the gentle, transverse undulations which represent annual growth according to Wright and Priestley (1922, p. 203) but are more than likely a form of tidal hinge line. The absence of tide cracks in the adjacent fast ice demonstrates that the tongue is afloat. Note the following: (1) spurs and snow ramp, (2) normal ice dissipation from a high gradient shoreline, and (3) exposed portion of a volcanic shoreline. Ice tongues here are much larger and far more common than in the Arctic. Note the difference in surface character between the one-season sea ice and the floating ice tongue.

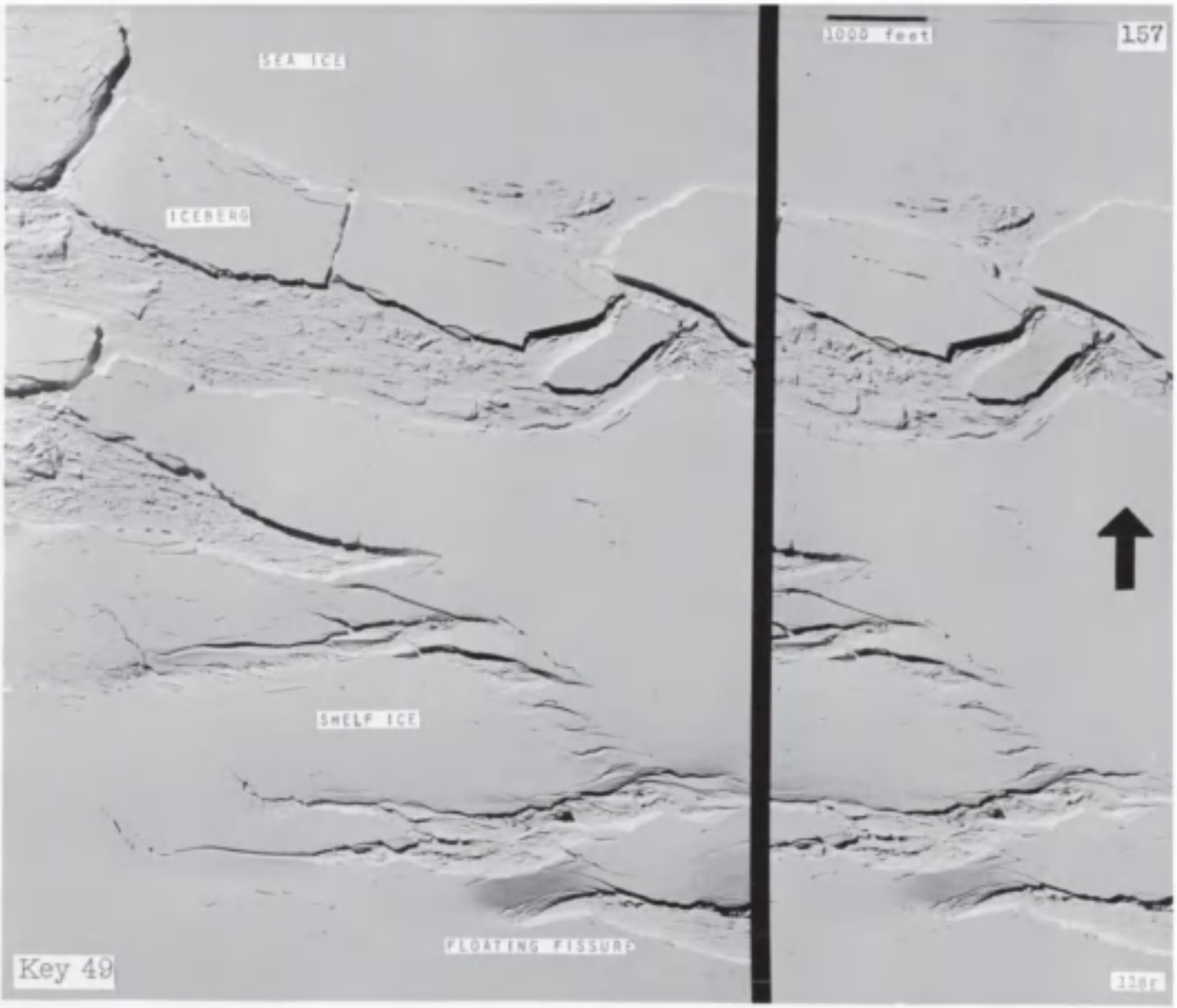


SHELF ICE is a term denoting massive and relatively flat-surfaced ice formations attached to and extending seaward from an ice-covered land mass, and which originated from and are nourished by a constant accumulation of snow and wind-blown firn upon seaward extensions of land ice, beset or grounded icebergs, persistent fast ice, shoals or skerries or suitable combinations of these. Shelf ice is normally partly waterborne with vertical cliffs at the seaward floating edge, called barriers, from which tabular and other types of icebergs calve periodically. The nearly level shelf ice surface is frequently disturbed by such features as submerged islands, glacier pressure waves, hinge line undulations and crevassed areas. Recent research (Poulter, 1950) provides evidence that the compressed firn below sea level may be saturated with sea water. (Continued on following page.)

Key 47. A vertical ice cliff (barrier) divides the sea ice (left) from the shelf ice (right). Minute surface patterns illustrated here are typical for each of these types of ice. Capsized and normal icebergs are beset in the sea ice (lower left). Black tones are shadow, not open water.

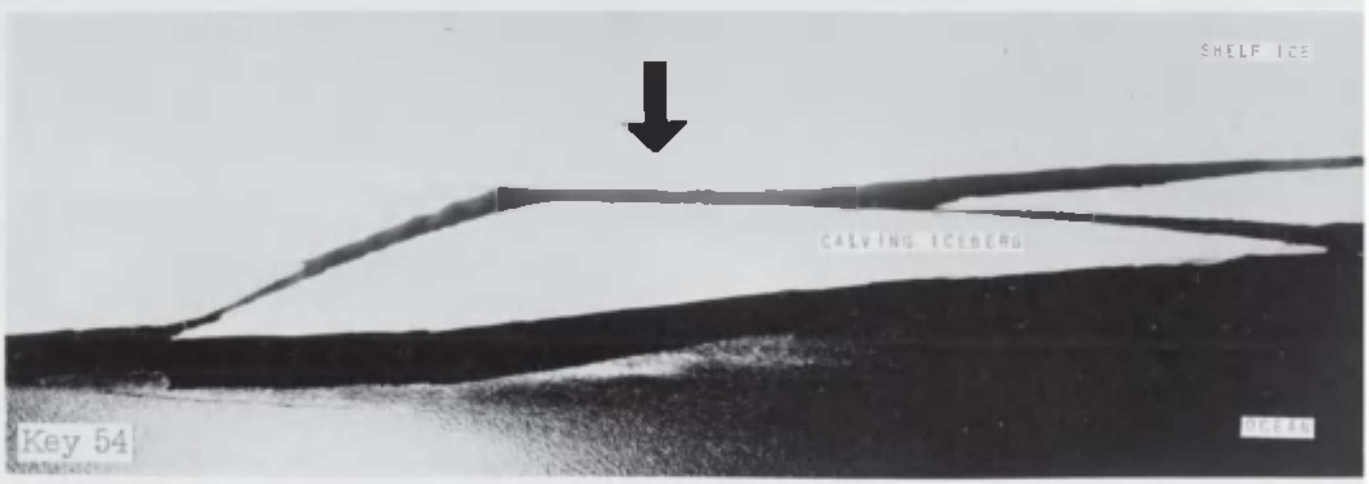
SHELF ICE. Two predominent, visible features of shelf ice are the constant vertical barrier (cliffs) and the tremendous mass of raised, flat, compressed firn ice. This large ice mass is known as either a barrier or a shelf ice. The latter term predominates in American usage, in which the term barrier is generally restricted to the cliffed edge of the shelf. Nordenskjöld (1909, p. 322) proposed shelf ice as a morphological term and Joerg (1930, p. 4) proposed the consistent use of this term in place names. Roberts (1950) and Wordie (1950) present the cases for and against this usage.

Key 48. The Gillies Islands project through the Shackleton Shelf Ice at a point near its junction with the continental glacier. Note the contrast between these gross glacial formations and also the typical zone of shelf ice disturbance in the lee of the islands. Such rifts reflect white in the sunlight (as here), black in the shade and are indistinguishable in overcast weather.

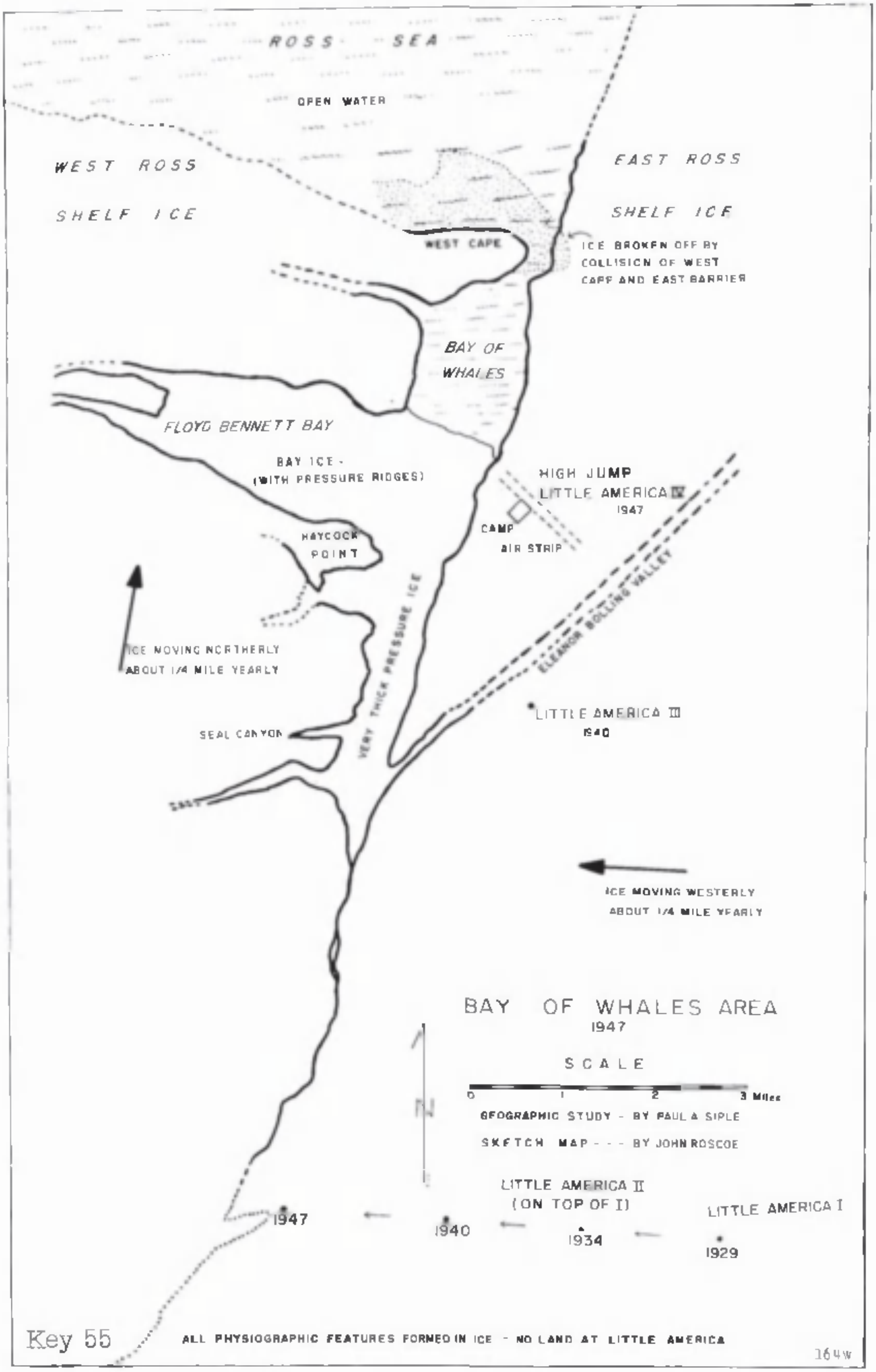


Key 49. FLOATING FISSURES. The wide, crevasse-like structures illustrated above appear to result from both shear and tension. They have vertical sides and flat bottoms which are interrupted by shelf ice seracs and avalanched bits of shelf ice all frozen in a matrix of sea ice and partially drifted over with snow and firn. The cliffed sides extend below sea level and may continue through to the bottom of the shelf ice, although this is not essential to the presence of water and sea ice since the shelf ice is permeable and may be saturated below the water line.

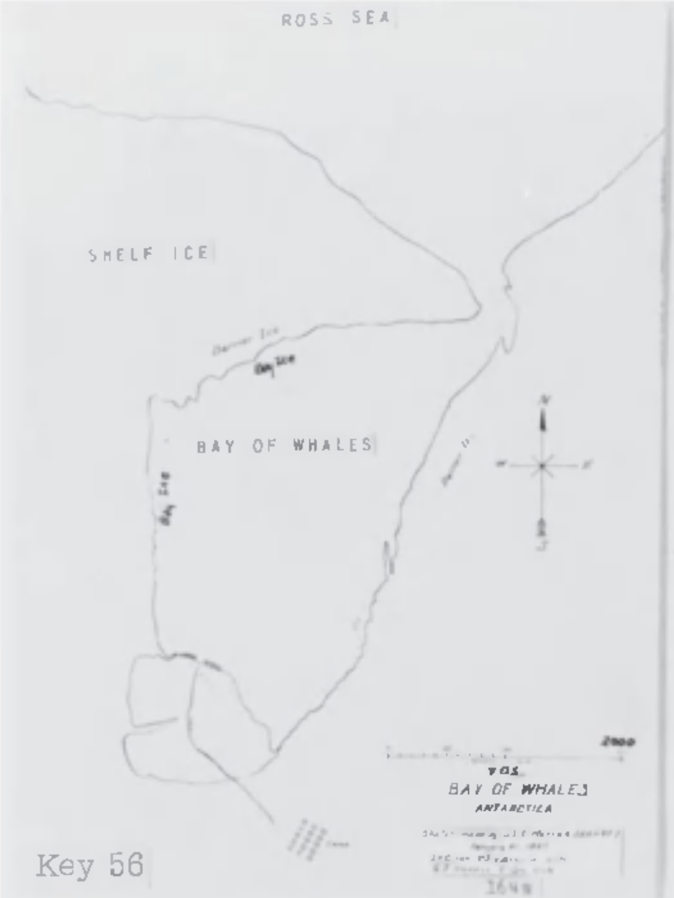
The rifts widen as they advance seaward, eventually contributing to the formation of icebergs as shown here. The term "floating fissure" is suggested for these chasms which are not known to have been observed in other than waterborne ice, nor to have been precisely described or classified in previous scientific literature. These floating fissures bear no relationship to crevasses formed over land masses and are distinctly different from other types of rifts or riftlike features which occur in floating ice, such as hinge lines and hinge line reentrants, tension reentrants and the like. They might fit within the loose definition for barrancas or dongas (see [English], 1943, p. 21) but they have no real resemblence to the features of African morphology to which these terms are generally applied. (See also Keys 151-158.)

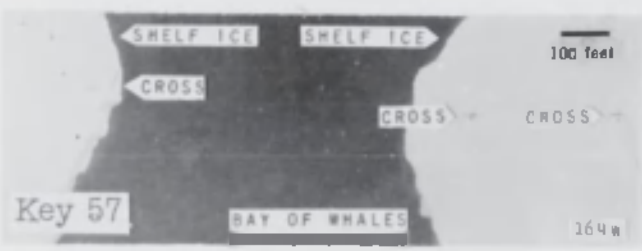


Keys 50 through 54. Five aspects of shelf ice. Key 50 shows a tension reentrant. Fast ice, hinge line depressions and snow ramps permit access to the shelf ice through the barrier at this point. Contact of cold air with open water causes "frost smoke." Key 51 shows traditional shelf ice with a smooth, uncrevassed and level surface. The scalloped, serrated barrier, however, indicates that shelf ice icebergs are not always tabular, rectangular or blocky. Key 52 illustrates the barrier face of crevassed shelf ice showing typical cleavage. Note the wave-cut ice foot just above sea level. Key 53 shows the appearence of crevassed shelf ice from above. Key 54 shows "tabular" icebergs calving from shelf ice. Tidal marks (not shown here) visible on the barrier indicate grounded shelf ice.



Key 55. Geographic sketch of the Bay of Whales prepared by Dr. Siple, member of all four expeditions concerned, is presented for orientation of the illustrations which follow.





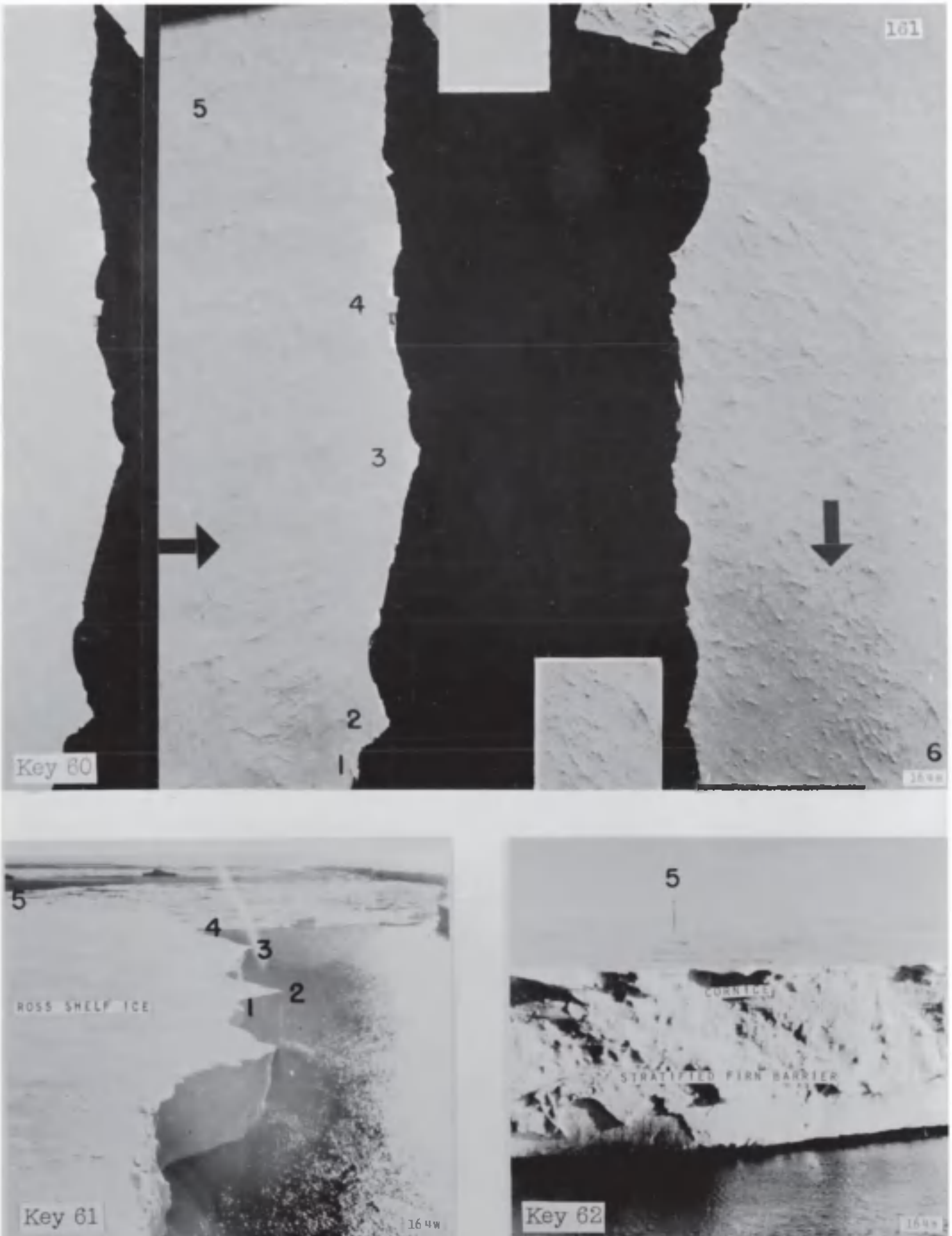
When shelf ice passes over or around obstacles, bays and disturbed ice patterns are formed. (Similar formations occur in glacier ice afloat.) Ice-covered Roosevelt Island, 1,257 feet in elevation, splits the outward-moving Ross Shelf Ice into two segments separated by the Bay of Whales. The differential motion of the two segments, as well as the pressure ice and the crevasses resulting from the impact of the shelf ice on the island, causes the bay to be constantly changing in size, shape, location and general appearance.

Key 56. A rapid sketch map of the Bay of Whales made from surface radar reflections from the barrier walls.

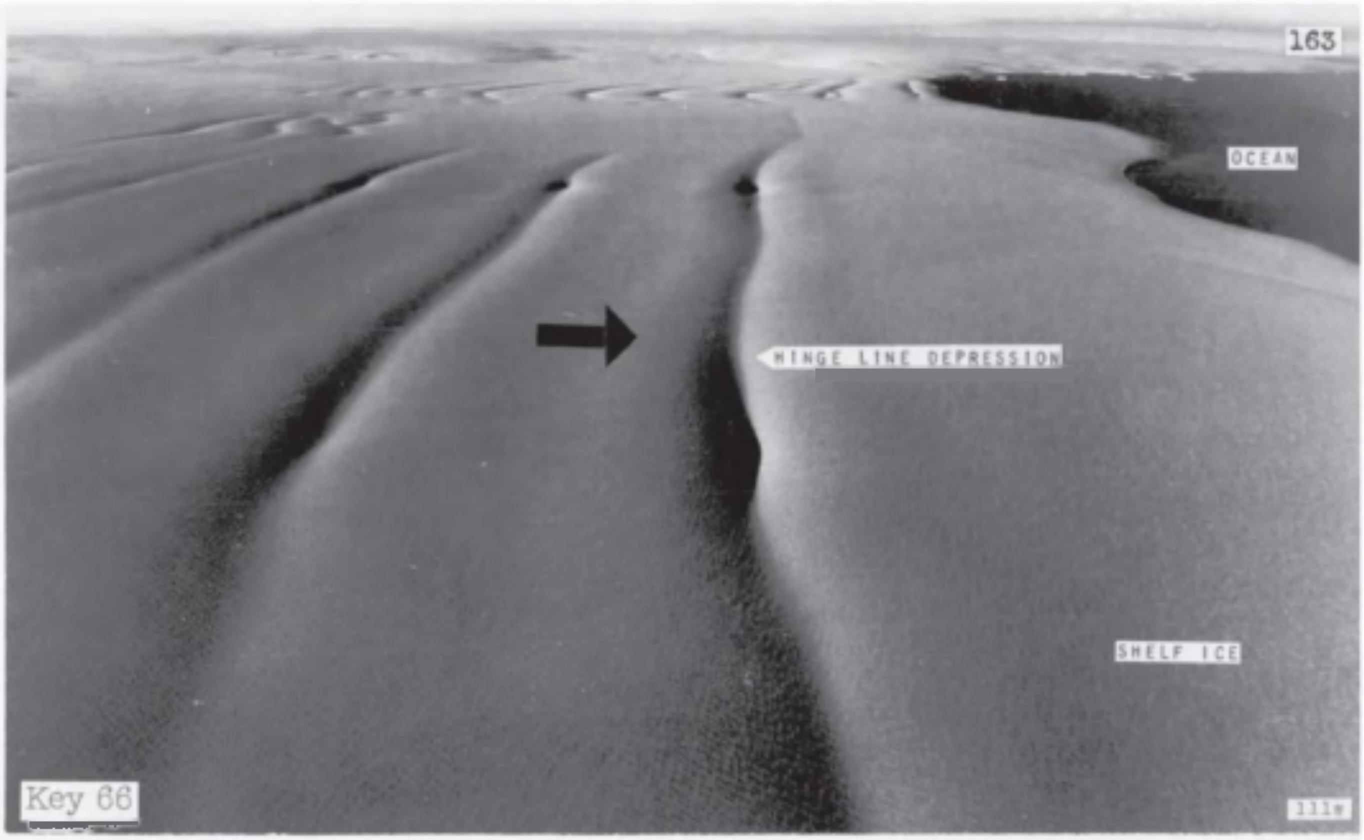
Key 57. Four masts and crosses were aligned across the narrow bay entrance by Dr. Siple in 1947. This photo, taken two weeks later, shows the crosses to be 65 feet out of alignment, indicating a differential ice lobe movement of 4.6 feet per day.

Key 58. One year later the crosses of elevated cloth strips were covered but the masts remained clearly visible. The third and fourth masts were then a quarter of a mile out of camera range.

Key 59. An iceberg navigated the narrow entrance channel and bore down upon the ships moored to the ice. The 10,000-ton ship at right was nearly rammed but got under way before iceberg usurped its berth.



Keys 60, 61 and 62. Annotations 1, 2, 3 and 4 refer to common points on the oblique and vertical views. Numbers 5 and 6 are the masts shown in the preceding figures which were aligned the previous summer. The insets in Key 60 provide a stereo view of the masts and covered crosses.

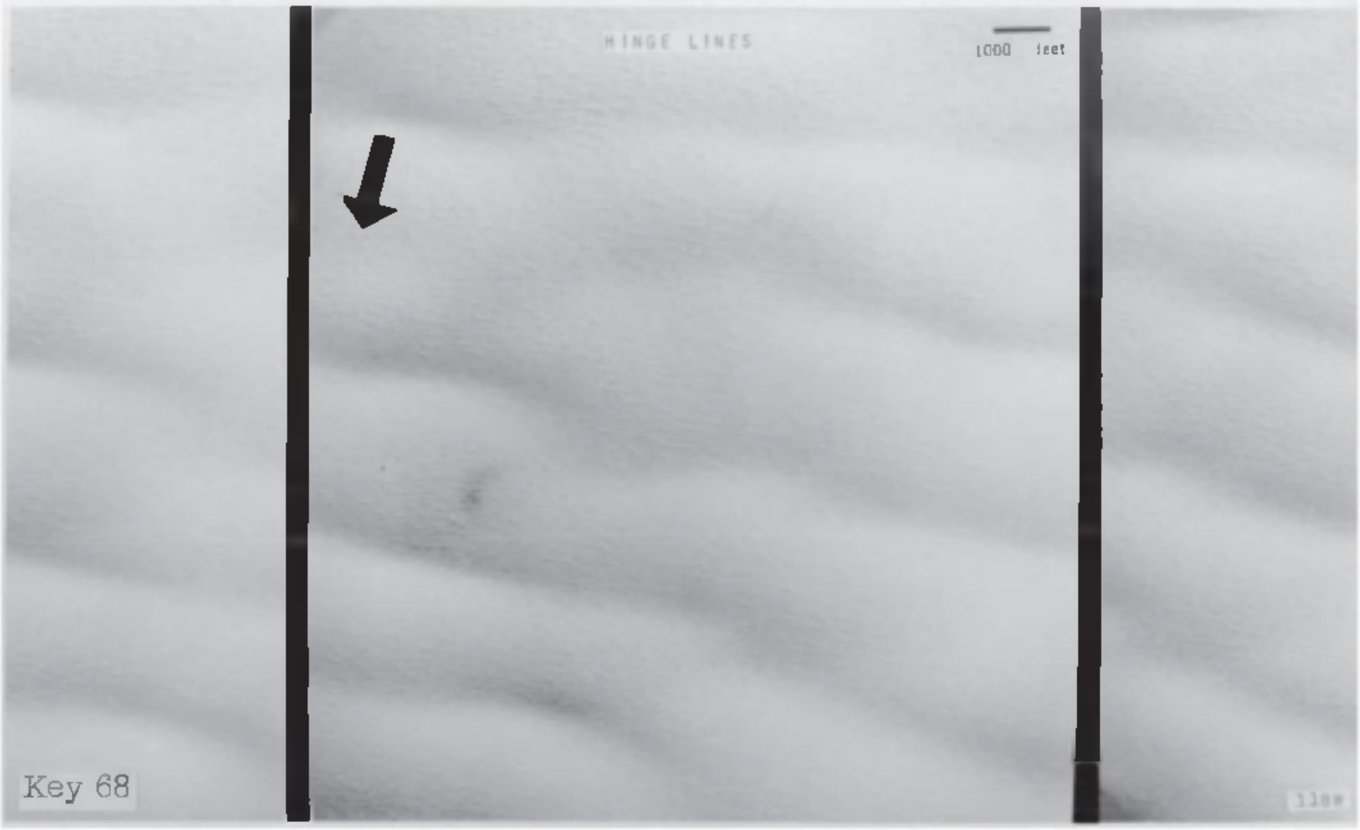


SHELF ICE UNDULATIONS occur in a variety of forms and locations. All parties having crossed the Ross Shelf Ice to the polar ice plateau refer to the PRESSURE WAVES formed in the shelf ice by the impact of the tributary glaciers (not illustrated here). Somewhat similar waves occur on a smaller scale when shelf ice moves through zones of constricted or obstructed flow.

Shelf ice coastal areas also contain undulations. These may originate from various causes including bottom obstructions and the release of pressure, but from the regular alignment and spacing of some, it appears evident that these, at least, are products of tidal movement. As the shelf ice leaves its bed rock and morainal support to become waterborne, hinge line depressions gradually form at the hinge lines (tidal cracks) from which the floating mass swings vertically with the tide until the shelf ice has extended itself sufficiently for the tide to again overcome the tensile strength of the shelf ice and form a new tidal crack parralel and inshore from the old ones. According to Siple (1951, personal communication) the most landward hinge line may be a straight walled canyon with a sea ice floor.

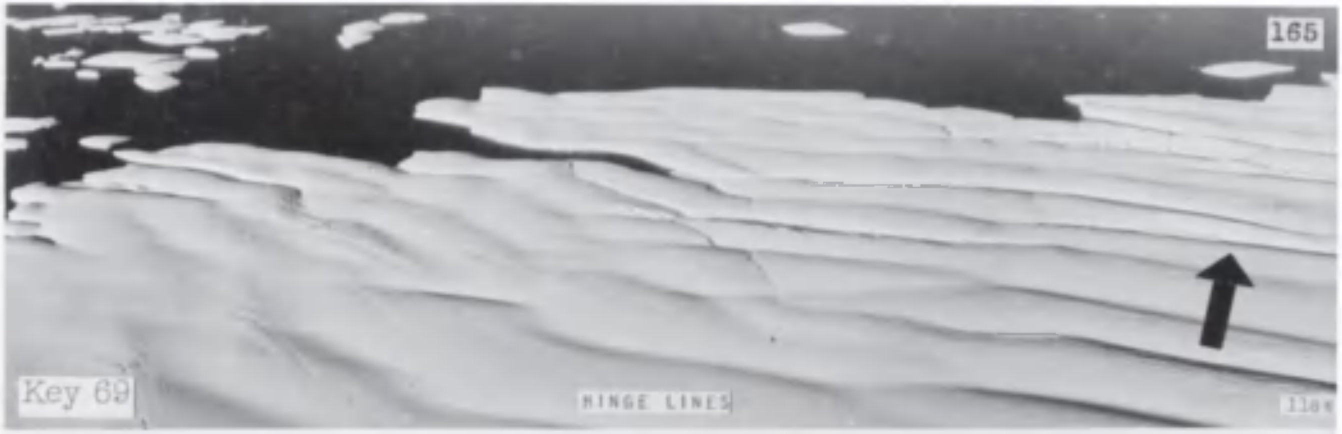
Debenham (1948) believes that the valleylike depressions result from the tidal action of the sea water entering the hinge line crack and leaving a thin film of water which freezes to each of its walls, the accumulated daily thicknesses of which tend to push the original walls of the tidal fissure further apart and create a linear depression in the portion of the fissure above sea level. The resulting trough is partially filled with firn and snow. It must be pointed out, however, that crevasses in land ice do not drift-fill in this manner and that tidal cracks in sea ice sometimes produce ridges rather than depressions.

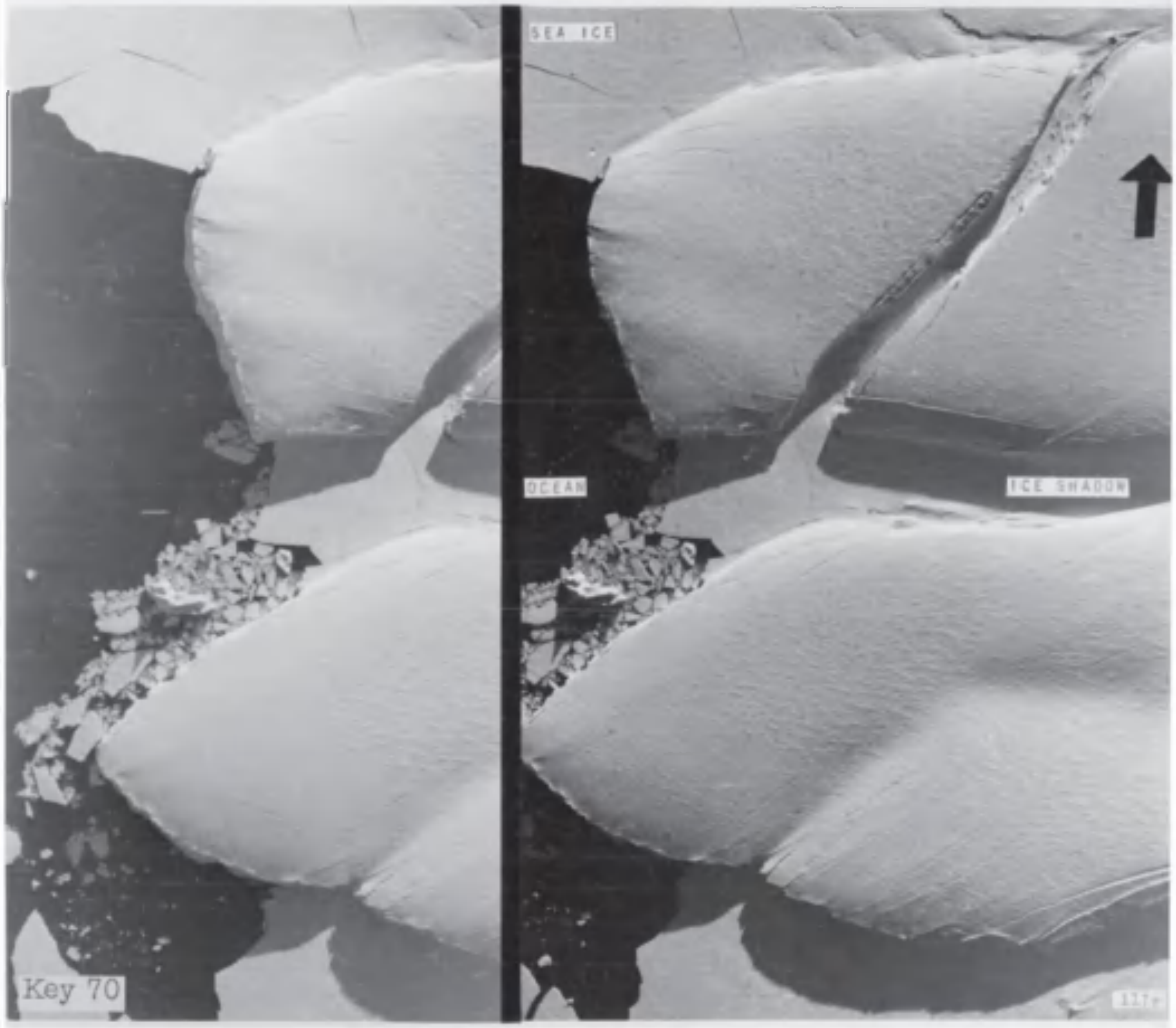
Key 66. The spacing, orientation and symmetry of the relatively sharp linear depressions here indicate a tidal origin. Hinge line depressions may resemble ridges on individual airphotos because of an optical illusion. Here the sun is at left throwing shadows to right.



Key 67. Imperfect orientation and lack of symmetry may indicate a tidal origin associated with more complex subglacial topography. Two basic orientations of depressions are visible, one generally parallel to the horizon and the other extending diagonally from the top left. A scale comparison is visible between the crevasses typical of land ice formations (right) and the hinge line depressions. The presence of active crevasses would indicate that all or a part of the area may be grounded or at least grounded at low tide. It is significant that these undulations occur only in the areas of ice adjacent to the ocean.

Key 68. Sastrugi are absent on the lee sides and in the bottoms of hinge line depressions. These undulations are bothersome to surface travel and they restrict the directions in which aircraft may land or take off, but they are not dangerous except in crevassed areas or near the seaward edge.





Keys 69 and 70. Shelf ice undulations not parallel to the shelf ice barrier form reentrants in the hinge line depressions. The troughs and swells of the various types of pressure waves and hinge line depressions vary from one to 50 feet in relief and from 300 feet to three miles between centers. There is no known correlation between this relief and spacing, although there is less variation in the hinge line undulations than in pressure waves from tributary glaciers and obstructions. Similar undulations occur on glacier ice tongues and piedmont ice afloat.

Key 71

Antarctic icebergs are here classified according to (1) place of origin, as glacier icebergs, shelf icebergs and floebergs; (2) character, such as tabular icebergs, firnbergs, unconformity icebergs and ice island icebergs; and (3) state of dissolution, such as weathered icebergs, bergy-bits, growlers and brash. These are described in greater detail in the following keys.

GLACIER ICEBERGS originate by calving from coastal portions of the continental glacier or its channel, valley, wall-sided, piedmont or icefoot glaciers or from floating ice tongues. They consist of blue- or green-tinted glacier ice which is sometimes covered with lighter-toned snow. Antarctic glacier icebergs are generally much larger than their Arctic counterparts, frequently reaching lengths of two miles and occasionally reaching much longer lengths. Traditionally, glacier icebergs possess irregular shapes, crevassed or seracked surfaces and high density glacier ice, causing a large percentage of the iceberg to remain submerged.

Shelf icebergs and floebergs are treated in the following keys.

TABULAR ICEBERG and ICE ISLAND ICEBERG are descriptive terms applied to certain icebergs because of their shapes. The terms FIRNBERG and UNCOMFORMITY ICEBERG are indicative of the ice content. All icebergs, regardless of their special properties, disintegrate successively into WEATHERED ICEBERGS, BERGY-BITS, GROWLERS and BRASH. Growlers and brash which are remnants of icebergs cannot be distinguished from growlers and brash which are remnants of other ice forms, except by microscopic inspection.

Key 71. Glacier icebergs have traditionally been characterized as of irregular shapes and crevassed surfaces. Airphotos, however, reveal a high incidence of smooth-surface icebergs and blocky icebergs. Here both crevassed and smooth-surface types are being calved from the same glacier. The block type is calved from channel glaciers and floating ice tongues as illustrated in Keys 24 and 36. The term glacier iceberg is therefore limited to place of origin and ice content and has no significance in relation to size, shape or surface condition.

Key 72

Key 73

SHELF ICEBERG is proposed here as a genetic term for all types of icebergs originating in shelf ice. Shelf icebergs tend to vary considerably in character, producing tabular, firn, unconformity, breadloaf (Keys 74 to 77) and ice island icebergs. They are generally much larger than glacier icebergs and floebergs, frequently extending for several miles in length, but they are less dense than these others.

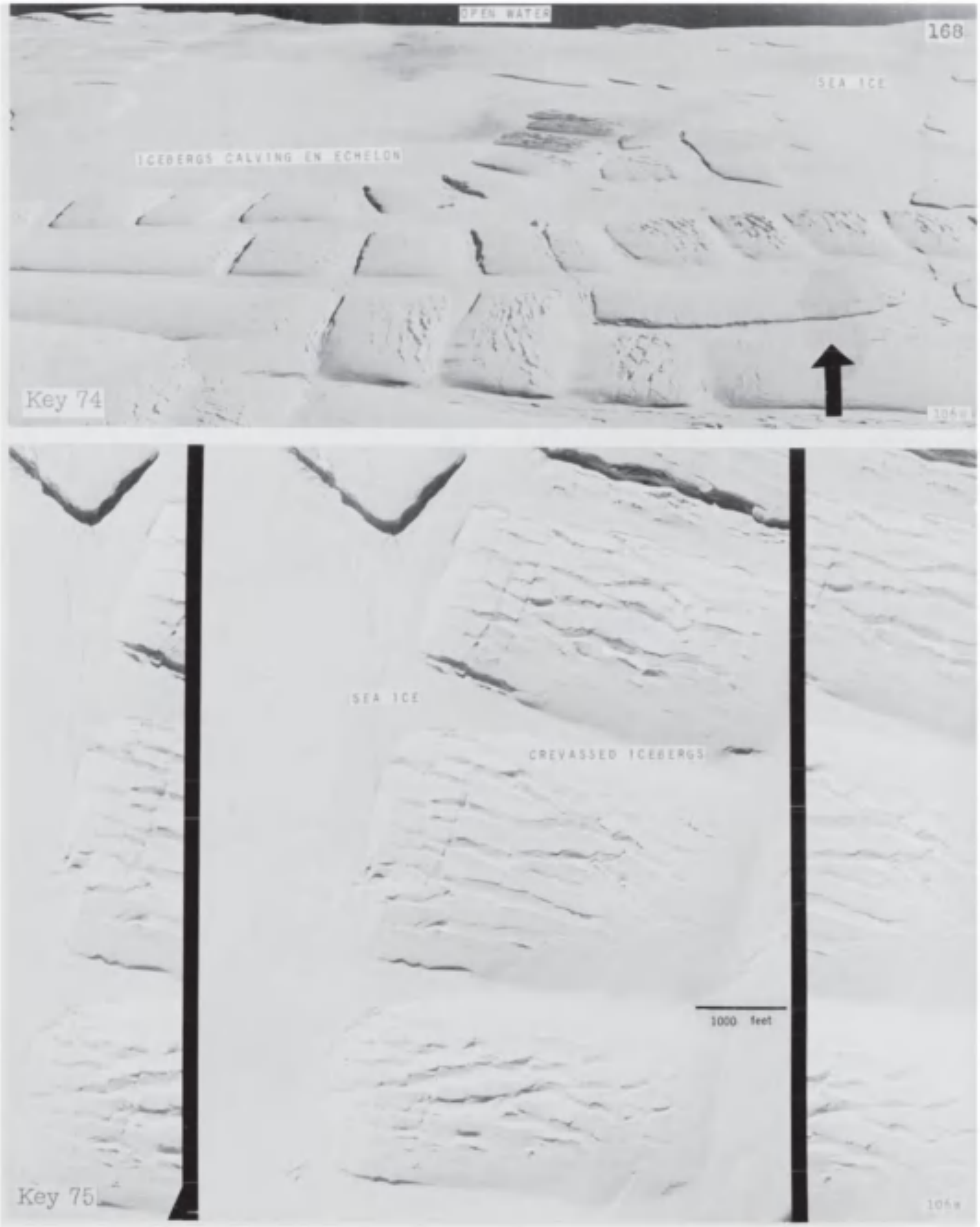
FLOEBERGS, unlike true icebergs, are largely of marine origin. They form from fast ice which has remained in situ for several seasons, accumulating several layers of sea ice underneath and snow and firn above. They also may form from icefoot affected by tidal, storm or pressure action. Floebergs have flat or irregular surfaces, commonly reaching ten feet above the sea surface, although heights of 40 feet do occur. Low floebergs are difficult to distinguish from sea ice; high floebergs resemble icebergs of several varieties.

TABULAR ICEBERGS are normally derived from shelf ice, but may also originate in piedmont ice afloat or glacier ice tongues. They are characterized by vertical sides (40 to 150 feet), flat upper surfaces (smooth or crevassed), blocky appearance, and when formed in shelf ice they may be a dazzling white color and have a large intergranule air content, making as much as one-fifth of the mass float above sea level. There are several authenticated reports of tabular icebergs 25 miles or more in length; [English] (1942, p. 25) reports one of more than 100 miles in both length and width and 130 feet in elevation above sea level.

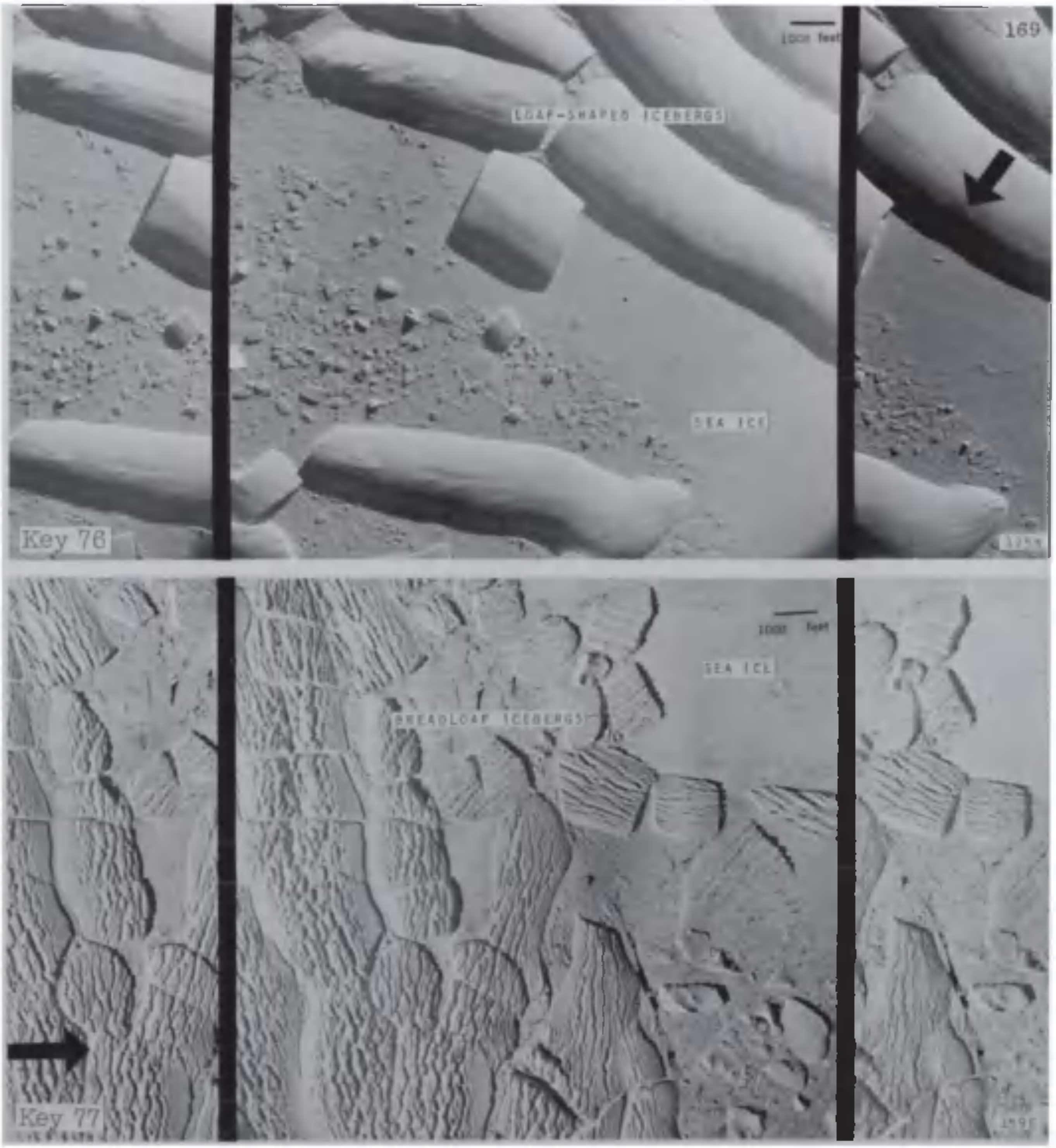
FIRNBERGS (névé icebergs) are rare types of tabular icebergs composed of less dense firn strata and floating only half submerged.

Key 72. The large shelf iceberg here lies adjacent to normal sized glacier icebergs and shelf icebergs, all of which are beset in sea ice.

Key 73. A and B are new tabular icebergs. Because of A's superior height it is either a firnberg or from less dense or thicker shelf ice than B. C is either a floeberg or from more dense or thinner shelf ice than B. Varied heights are not due to differential melting, but to original thickness and density. D and E are glacier icebergs.



Keys 74 and 75. Calving of icebergs from smooth surface shelf or glacier ice (keys 54 and 71) differs markedly from calving in areas of crevassed and undulating ice masses as illustrated here. Individual convex undulations are first separated from the main ice mass along hinge line depressions. Then deep transverse crevasses aid the sea motion in breaking the undulations into rectangular masses, en echelon.

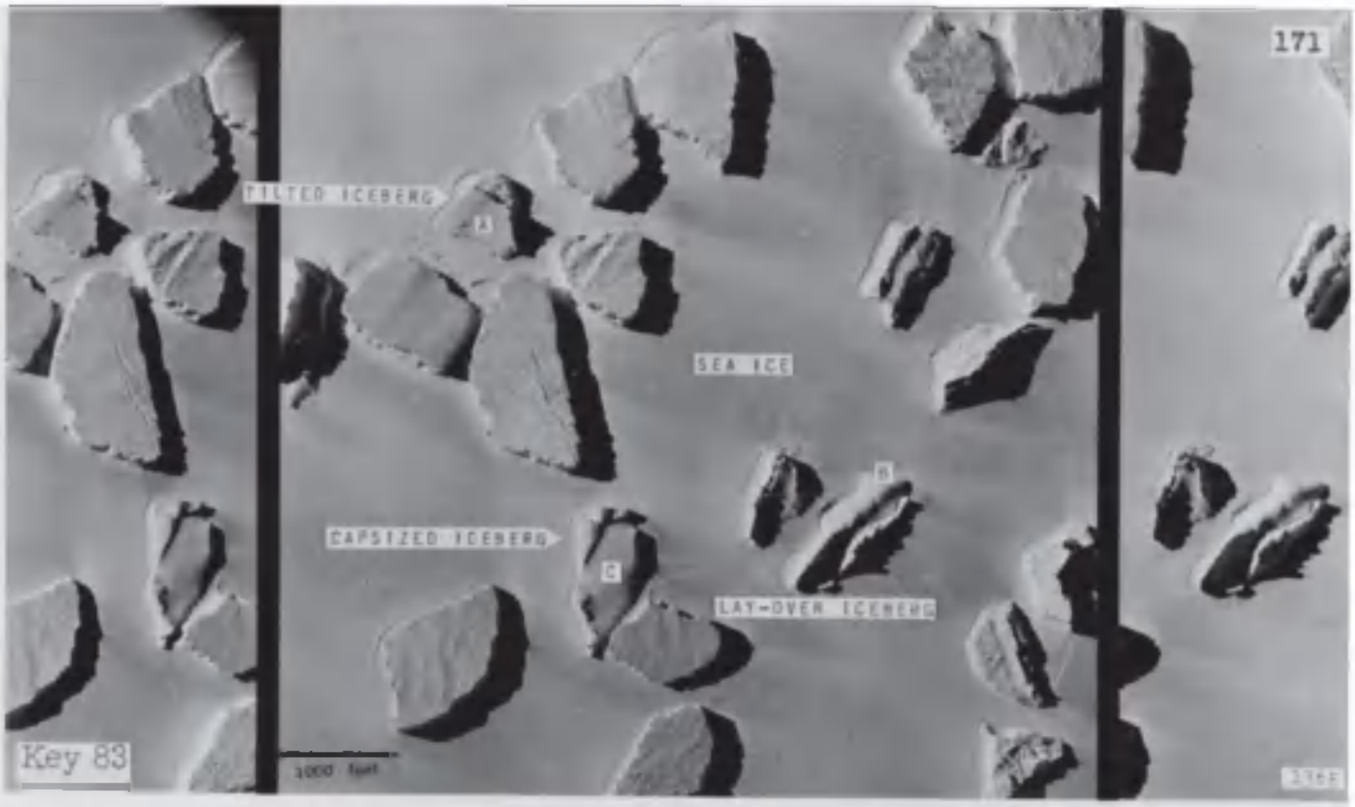


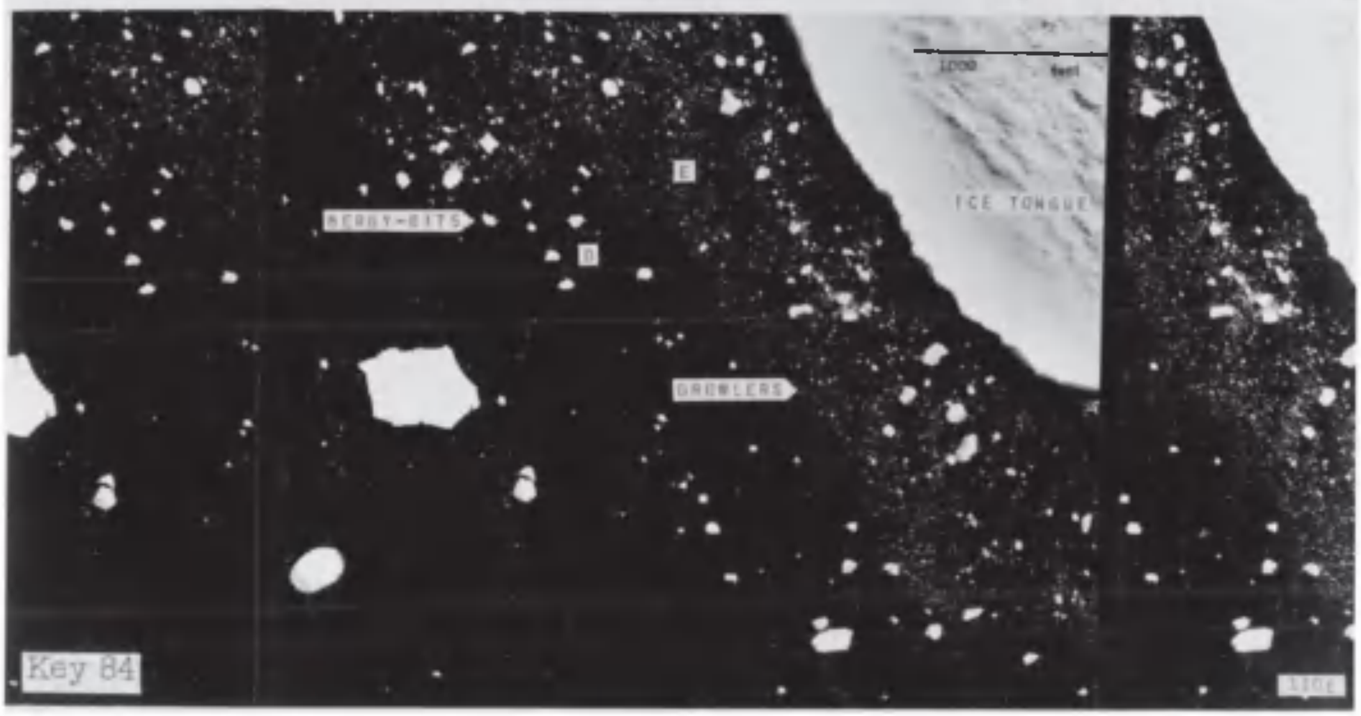
Keys 76 and 77. Icebergs from undulating masses of ice vary with the type of undulation (usually hinge line depressions) and the crevasse system present. Above, the crevasses are almost completely covered; below, they have developed into seracs. Such icebergs usually separate from the main mass in the low portions of the linear depressions and at lines approximately at right angles to these depressions. Thus they possess a shape which appears very much like a cylinder split lengthwise and placed horizontally, convex face up, on the sea. This loaf shape suggests the term BREADLOAF ICEBERG. The type of crevassed surface which appears on the icebergs in Key 77 has already been termed "breadcrust surface" by Gould. These structures cannot be called tabular icebergs since they lack the table shape. They cannot be termed glacier icebergs since they are not always derived from glaciers or glacier ice.

Key 78. Ice-covered islands, like the one on the right, are frequently subjected to misinterpretation as weathered or glacier icebergs. There is no difficulty, however, in distinguishing them from tabular icebergs like that at the left.

Key 79. A caved and rapidly disintegrating tabular iceberg. While caves are not visible on vertical airphotos, a large amount of ice wreckage surrounding an iceberg in otherwise open water is a strong indication of disintegration.

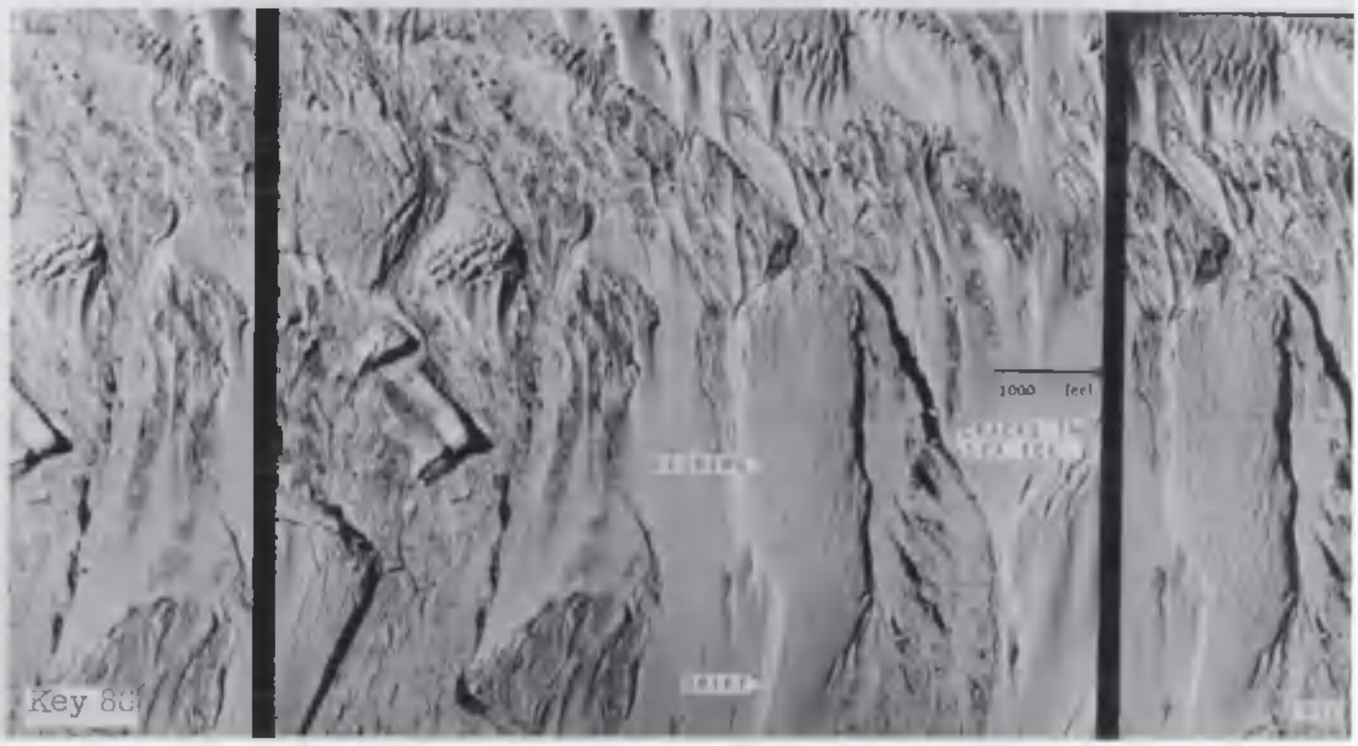
Keys 80, 81, and 82. Differential subaerial and subaqueous erosion result in a loss of equilibrium which causes icebergs to break up or capsize. The typical pinnacle forms, submerged centers and spurs of the capsized icebergs are shown here. A less frequently occuring type of pinnacle is that attached to the normal glacier iceberg at the extreme right in Key 82. Note wreckage, including bergy-bits and growlers.





Key 83. Weathering may produce tilting (A), lay-over (B) or capsizing (C). Smooth, waterworn portions of (A) and (B) stand in sharp contrast to their angular portions which were never immersed. Note the neck at (B) carved at the former water line where erosion is the most effective. Long spurs, dangerous to navigation, form as the upper portions of the iceberg collapse from neck development.

Key 84. Bergy-bits, the smallest remnants of icebergs identifiable without structural analysis, are shown at (D). They are the size of small buildings and are washed free of snow. Growlers (E) are yet smaller and they may also be derived from marine ice forms. Individual bits of brash are not large enough to discern at this 1:12,000 scale.



Keys 85 and 86. Unweathered iceberg (top left) has a flat, pitted and hummocked surface, open crevasses and sharp, jagged, corniced cliffs. Capsized icebergs show smooth surfaces with varying relief, sealed or absent crevasses and no cornices. Below, the same condition is complicated by drift and further disintegration in place. Open water (black) demonstrates thinness of sea ice bond. If the ice fails to break out in the short summers, continued drift may generate the conditions thought necessary for forming a type of shelf ice.

Except for the occasional presence of exposed land, pond ice, hoarfrost and meltwater, the Antarctic continent is everywhere surfaced by one of three substances: SNOW, FIRN or GLACIER ICE.

Snow is composed of minute ice crystals, a product of atmospheric water vapor precipitated at temperatures below freezing. Unlike frozen water, glacier ice is a consolidated mass of irregular ice crystals containing bubbles of occluded air. This opaque, white, bubbly ice results when snowflakes and snow granules are acted upon by changes in temperature, humidity and pressure over a period of time.

During the stages of transition from snow to glacier ice the substance is known as firn or névé. Once fallen, the snow crystals begin the change from flake to granular form, increasing in individual mass but decreasing in total numbers and overall volume. Under the most favorable conditions, the complete transition from snow to glacier ice takes but a few days or weeks, but although statistics are not available, it is quite probable that on the high, dry, continuously cold South Polar Ice Plateau the same development may take many years. The transition may be hastened by such factors as the presence of exposed rock, increased pressure caused by later deposits of snow or firn, variations in humidity and changes in temperature.

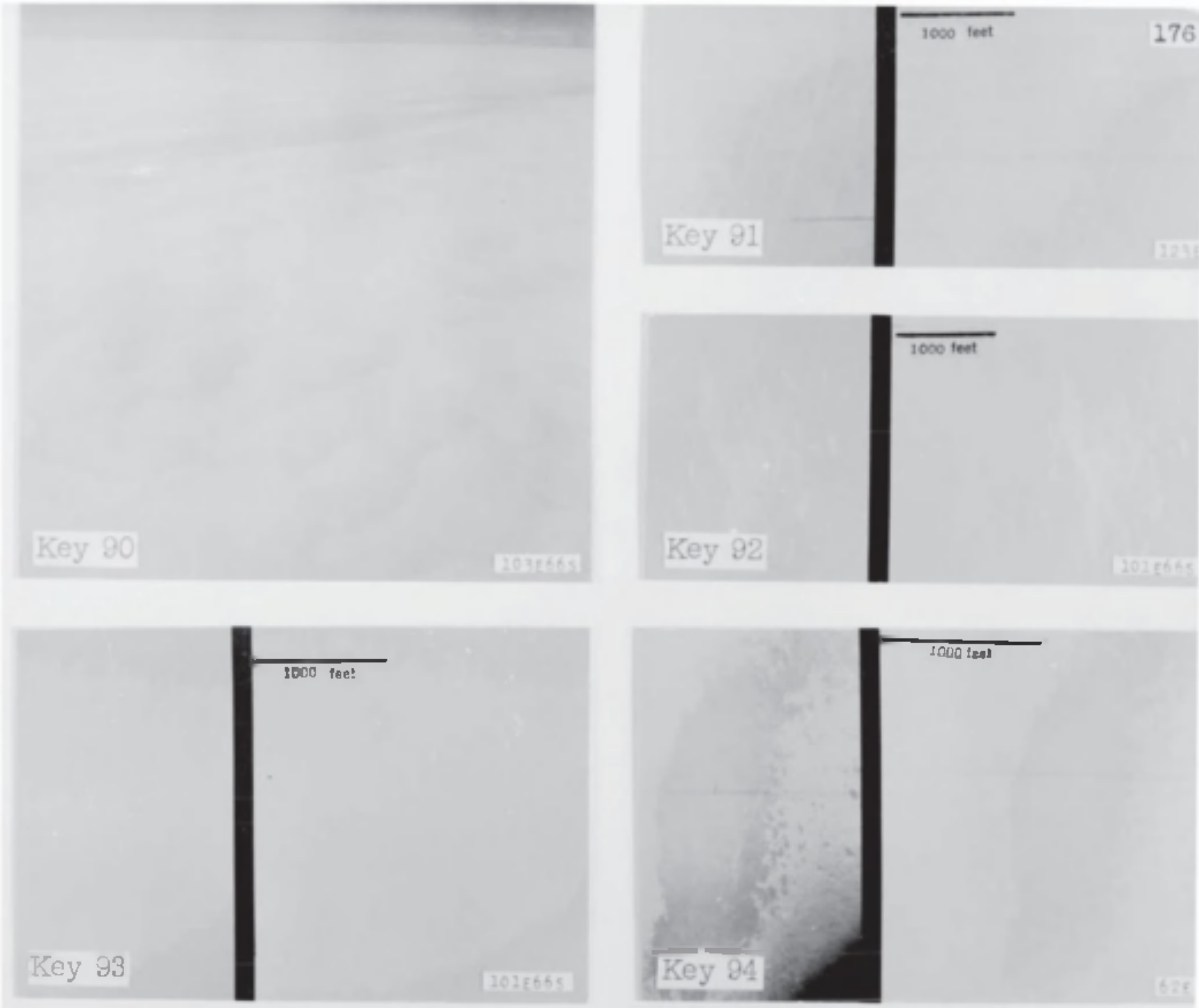
Glacier movement is closely associated with these transition processes. Wright and Priestley (1922) believe that under these conditions a small, outer portion of the individual ice molecules in certain grains may become liquid and transfer itself to adjacent grains, thus allowing the larger and better oriented grains or crystals to grow at the expense of their neighbors. This action "lubricates" the glacier, permitting it to "flow" while maintaining an "apparently rigid structure." This theory does not fully coincide with more modern thought on the theory of glacier movement (Flint and Demorest, 1942). The smaller firn granules gradually change to form larger crystals of glacier ice with the air formerly between the grains of firn included with the crystals of glacier ice.

Photo analysts must be able to recognize snow, firn and glacier ice in order to determine surface conditions and trafficability. Since all three of these surfaces are white and composed of minute particles, the interpreter must rely upon the relative difference in tone values, the surface topography and a knowledge of glaciology for ice recognition.

Key 87. The most difficult task in the interpretation of snow, firn and glacier ice occurs when only one surface tone appears in the photography. The terrain illustrated here might be mistaken for snow, glacier ice, cloud or even improperly exposed film. The faintly visible surface markings preclude the use of stereo examination but indicate this area to be surfaced with firn ice. If this airphoto had been exposed on a "white day" (see keys on phenomena) it could just as certainly be snow or glacier ice.

Key 88. Fresh snow presents a smooth, light-toned and gossamer appearance. The constant Antarctic wind moves the freshly fallen snow into depressions and forms drifts. Here, on a glacier ice tongue, the hinge line depressions are filled with fresh snow. The chasms below are open at their seaward ends (not visible) and air drainage prohibits any significant accumulation of snow therein . Elsewhere the snow has filled in irregularities in the severely crevassed areas between the hinge line depressions. Drifts are forming to the leeward of the projecting crevasse lips and old seracs. Since the glacier ice underneath this thin snow mantle is not directly visible, its presence must be inferred from a knowledge of glaciology or from sufficient photo reading experience to enable the interpreter to recognize a glacier ice tongue or an area of inactive, snow-covered crevasses.

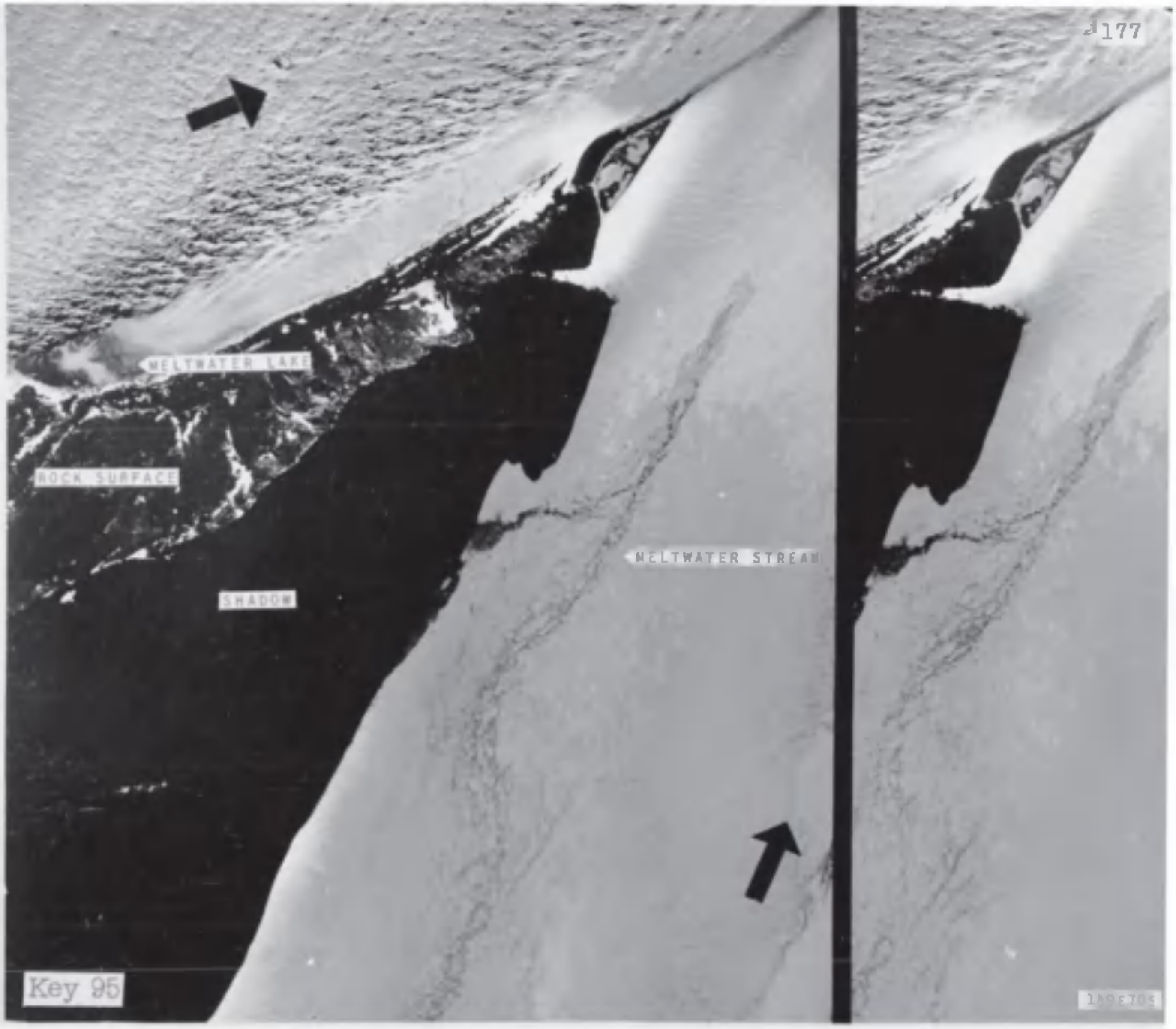
Key 89 Wind not only carries freshly fallen snow, depositing it in depressions in firn or glacier ice surfaces but, in association with critical changes in temperature, humidity and wind speed, it may also pack the snow, harden it and then erode a portion or all of it. Here, the slight depressions are filled with partially eroded snow deposits, the high points are barren of fresh snow and the remaining areas show wind-oriented, linear patches of eroded snow superimposed upon the basic firn surface. Genuine sastrugi occur at right center and at upper left and are oriented from 120°. Note the flat character of this area and that only slight depressions are required for these formations. In this illustration, the dark lines running horizontally across the stereogram and the less definite vertical bandings are photo processing marks.



The change from snow to glacier ice is a gradual process which defies sharp distinction between old snow and young firn or old firn and young glacier ice. The crystalline differences are of the type visible under the microscope, rather than the airphoto stereoscope, but in air photos fresh snow presents an exceedingly light tone while successively darker tones depict young firn, old firn and glacier ice. Although the photo tones are influenced by film exposure and laboratory processing, they maintain this constant relationship. Only relative age may be determined from tonal differences alone, however. When the lightest tone is snow, the determination of whether or not an adjacent, darker tone is firn or ice depends upon the analyst's familiarity with the region and his knowledge of continental glacier surface conditions.

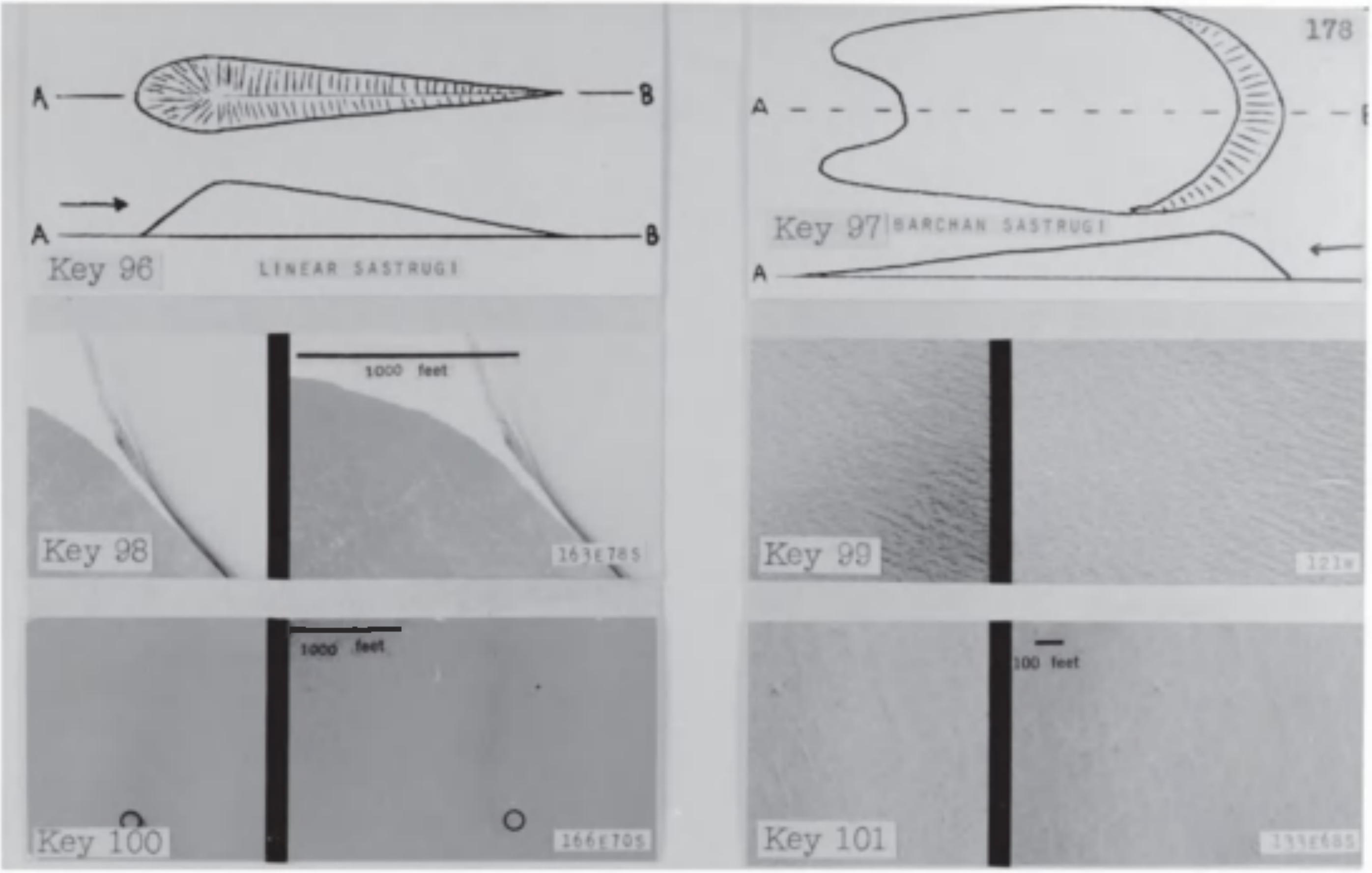
Keys 90 and 91. Old snow and/or young firn drifting over crevassed glacier ice. The presence and orientation of crevasses are clearly indicated by the snow which has drifted into the slight depressions in the crevasse lids.

Keys 92, 93 and 94. Various stages in the drifting of snow to depressions in old firn surfaces and the subsequent removal of the snow. Sastrugi sometimes appear to be continuous over the surface contacts between the younger and older materials. Even under the exaggerated depth perception caused by the lens stereoscope, the depressions are hardly noticeable as such.



Key 95. A variety of surface conditions is shown in this stereogram. Old snow or young firn ice, probably less than a year old, covers a surface of glacier ice which has been partly modified by exposure to meltwater. A stream of meltwater extends into the younger material, saturating a portion of it and causing a corresponding change in tone. The presence of exposed land surfaces frequently results in the formation of meltwater which modifies the adjacent ice by introducing saturation in the summer and ice crystals formed from frozen water in other seasons.

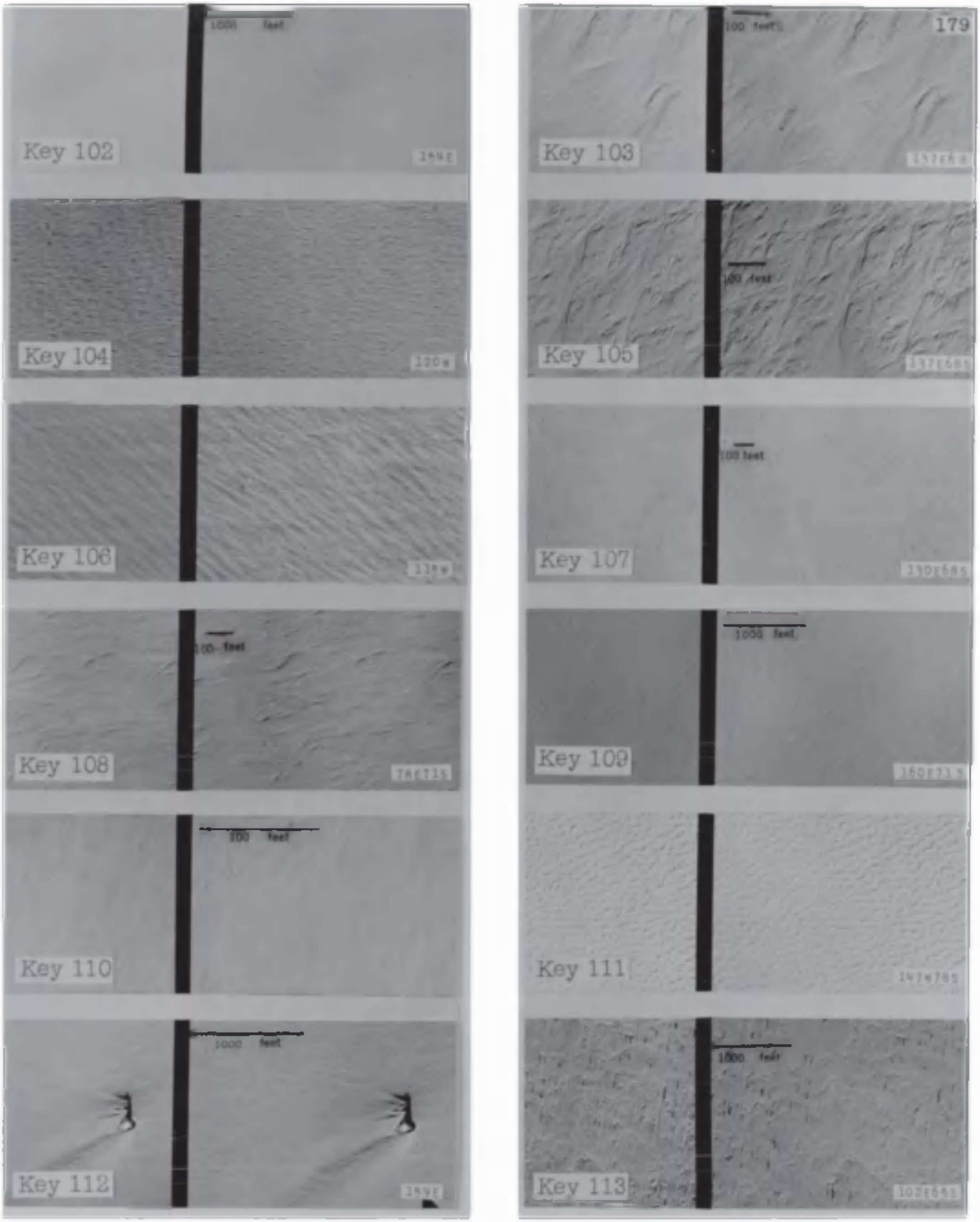
Three conditions account for essentially all the dark or black photo images on Antarctic aerial photography: exposed land, water and shadow. All three are present here. Exposed land occurs in the mountain area and in the boulders which have fallen to the surface of the glacier. Water occurs in the meltwater streams and under the transparent ice of the ponds adjacent to the mountain. Shadow occurs everywhere, but especially in each crevasse and behind each projection of the glacier ice (top). Shadow obscures entirely the near side of the mountain mass (left) from its ridge to a point beyond its base. Cloud shadows are of common occurrence and are illustrated under phenomena.



SASTRUGI consist of snow or firn dunes, wind-formed minor relief features of the glacier surface. The term sastrugi is borrowed from the German transliteration of a Russian word pronounced "zastrugi". The form "sastrugi," though perhaps less correct, is favored in English and American usage.

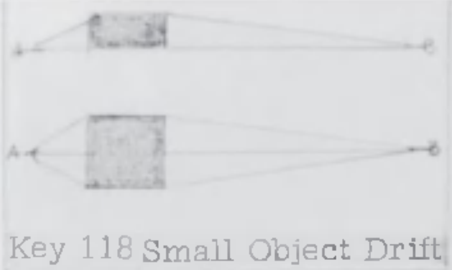
On the surface, sastrugi are sometimes difficult to distinguish from ploughshare ice, ablation pits resulting from the effects of sun and low relative humidity. Sastrugi form as a result of wind deposition, wind erosion or both. The forms they take depend upon the hardness of the surface, moisture content and shape characteristics of the loose wind-blown granules or crystals; the force, direction and variability of the wind; temperature and relative humidity. They are normally linear, however, and aligned with the prevailing wind(s) (Key 99), storm wind(s) or both (Key 101). So constant is the orientation of Antarctic sastrugi, they frequently may serve as aids to navigation.

In some ways sastrugi form similarly to sand dunes, but Hobbs (1911, p. 156) to the contrary, their steep faces normally point upwind at the time of formation (Cornish, 1914, p. 96; Wright and Priestley, 1922, p. 31; Seligman, 1936, p. 231 and Moss, 1938, p. 215). A slight variation in wind direction causes undercutting of one linear side, making the original facing difficult to determine. A more distinct change in wind direction results in multiple, complex or separately oriented sastrugi (Keys 101, 105). Linear shapes (Key 96) are the rule, but barchan shapes (Key 97) may form in favored areas (Keys 107, 109). Moss's studies (1938, p. 217) indicate that the special conditions necessary for barchan formation and their short life-cycle make the presence of barchans more rare than was formerly supposed. When barchans are visible on airphotos, the interpreter may assume them to indicate a hard, flat surface; little loose material; variable, but not gusty, winds averaging 15 miles per hour and good trafficability. Sometimes no sastrugi are present (Key 98) or individual sastrugi appear so similar that stereoscopy is difficult to attain (Key 100).

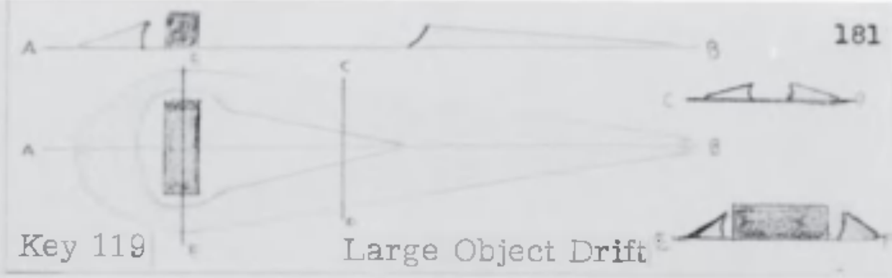


Keys 102 through 113. Variations in sastrugi patterns. Key 112 differentiates between sastrugi and drifts caused by obstructions. Keys 107 and 109 are barchan-shaped sastrugi, but not true barchans. Key 111 reveals undercut erosional sastrugi. Key 113 is sea ice with pressure ridges and hummocks (horizontal) and pseudo-sastrugi (vertical). Plates XCI and XCII of [Wilson] (1908) and plates XII through XV of Wright and Priestley (1922) are surface photographs of sastrugi.

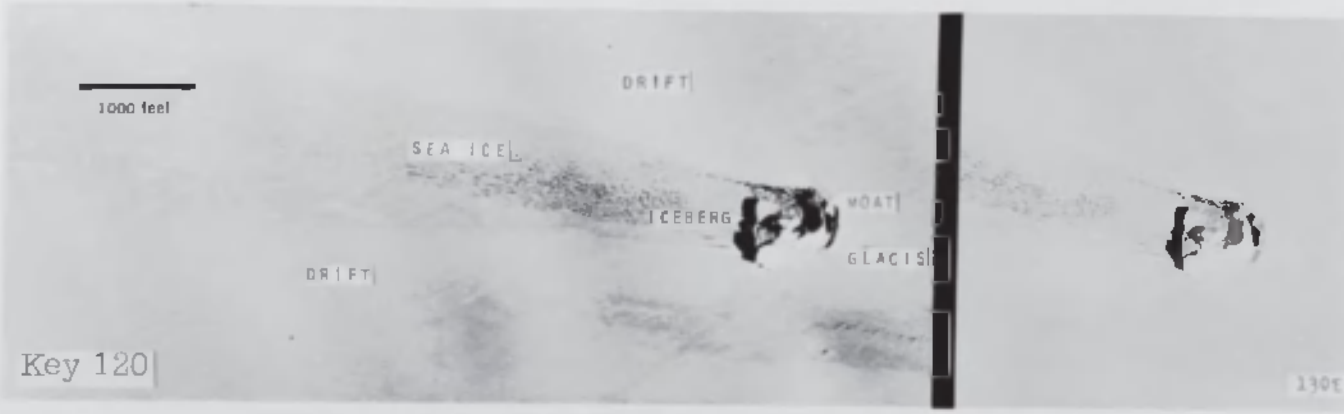
Keys 114, 115, 116 and 117. The ubiquity and complexity of sastrugi are difficult to comprehend from the surface. A diligent search of more than 300 surface photos taken the same day the two oblique airphotos above were made failed to reveal any better pictures for illustrating sastrugi than the two examples shown below the obliques. Low height, sprawling shape and highlights and shadows against a neutral background make sastrugi more evident to the pilot and the airphoto interpreter than to the ground observer. Sir Charles Wright who made comprehensive studies of sastrugi on Scott's last expedition (Wright and Priestley, 1922) was much surprised upon seeing some of these airphotos and being informed that some sastrugi measured 800 feet in length. His experience had left him with the impression that they were almost always less than 20 feet long. Compare the size of the small sastrugi here with the DC-3 transport aircraft and the tops of the half-buried personnel tents.



Key 118 Small Object Drift



Key 119 Large Object Drift



Key 120

Key 121

SNOWDRIFTS are caused or influenced by all factors previously ascribed to depositional sastrugi, by the critical windspeed for each general type of snowcrystal or snow granule airborne and by the shape and the size of the obstruction about which they form. Taylor (1922, p. 74) divides the typical drift structure into four parts: glacis (windward drift), moat (scoured hollow about the obstruction), the obstruction and the drift (leeward snowdrift). Wright and Priestley (1922, p. 37) describe snowdrifts occurring about small and large obstructions (Keys 118 and 119). The fact that these sketches differ markedly from the small-obstruction snowdrifts in Keys 125 through 137 and from the large-obstruction snowdrifts here illustrated indicates that snowdrifts are imperfectly inventoried, understood and classified.

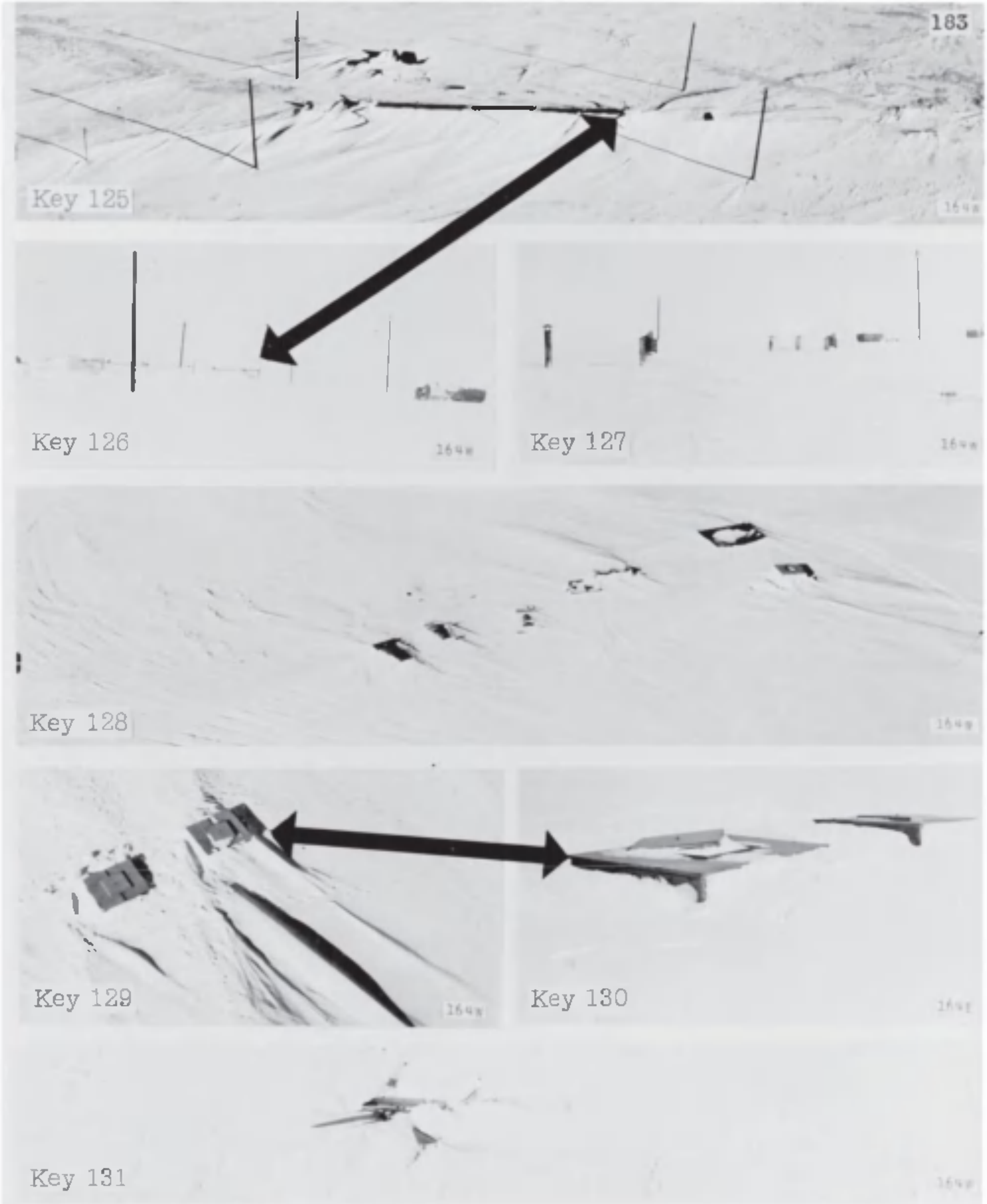
Key 120. A common type of iceberg snowdrift, including a windward glacis; a moat, normal at top and right, closed at bottom and ever widening to the leeward (left); and split leeward drifts (left). Wind-blown granular snow and firn has scoured the moat floor so thin that the ocean is first exposed at this point when thaw permits.

Key 121. Another common type of iceberg snowdrift with glacis (right), frontal moat partly concealed by shadow and a leeward drift constant in width but gradually thinning.

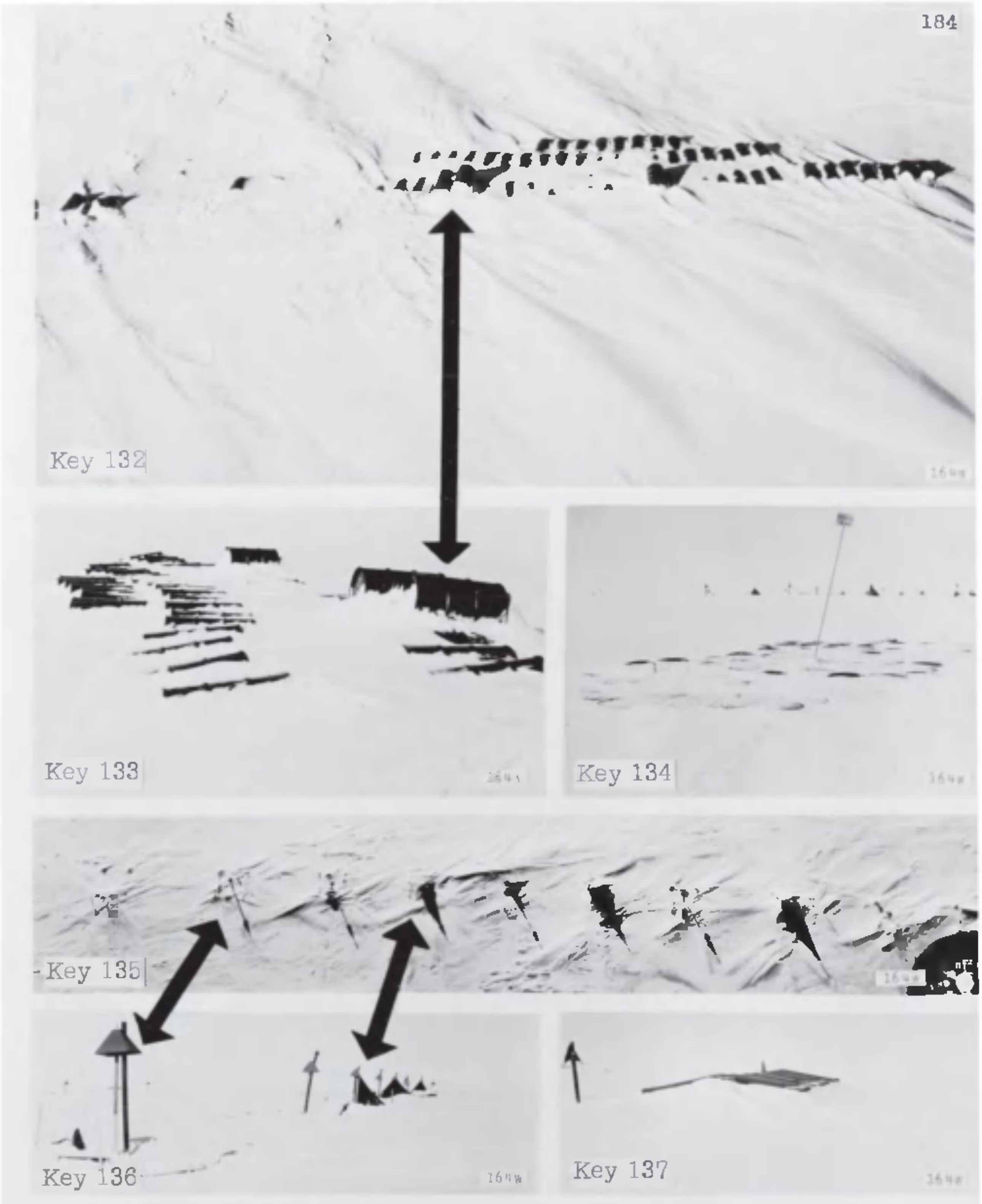
MULTIPLE, COMPLEX SNOWDRIFTS is the phrase which best describes the drifting that occurs about a group of large, irregular obstructions.

Keys 122 and 123. Fast-frozen icebergs provide a nucleus for multiple, complex snowdrifts. Incipient glaces, funnels and frontal moats are visible but lateral and lee moats are generally absent with the drift piling up to the sides and rear of the obstructions. Meltwater pools occur at all levels from the tops of the icebergs to the moats, which, along with the complexity of the drifts, indicates that this area has not broken up and drifted out for a considerable period of time.

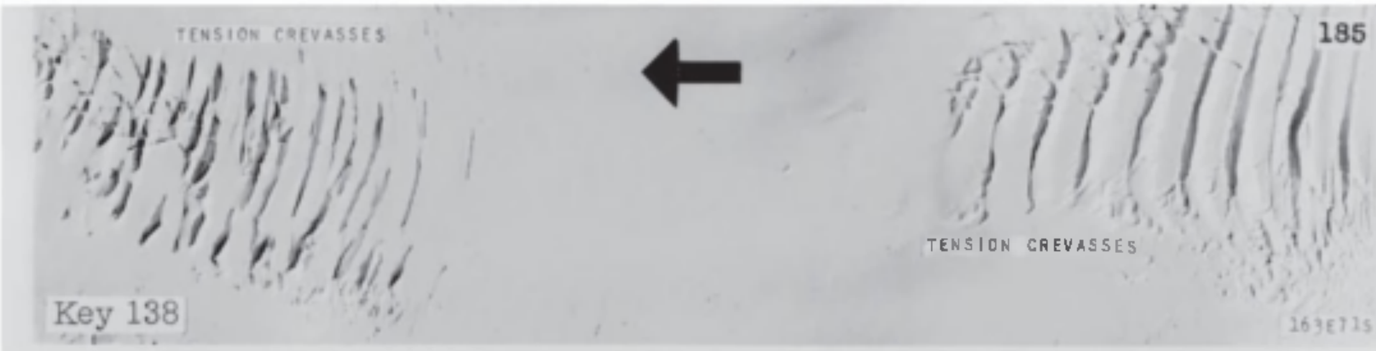
Key 124. A uniform and very thick snow cover over the adjacent sea ice obscures the configuration of this fast-frozen iceberg. None of the "typical" features of drift are apparent.



Keys 125 through 131. Small obstructions, other than poles and similar objects, tend to drift sharply to their tops within one year and completely disappear within several years. From top to bottom the keys show: oblique and surface views of a double Quonset Hut after one year, ventilators of a building erected eight years previously, motor vehicles and huts after one year's exposure, oblique and surface views of the cabtops of giant tractors and a view of a streamlined DC-3 airplane. Note that the airplane which offered less wind resistance to the wind failed to drift over. Note also that Key 129, an airphoto, shows drift formations whereas in Key 130, a surface photo, they are difficult to detect.



Keys 132 through 137. Shape, not size, determines the drift habits about small obstructions. Above, a store of 55-gallon drums remains partly uncovered since the drum shapes offer less wind resistance (Key 132), but a similar store of drums placed on end and massed together loses this streamlined characteristic and drifts to the very top (Key 134). Below, there is a difference in drift formations about tents and about the tentpoles where some tents have caved in.(Keys 135, 136). At bottom right is a canvas, framed hut drifted to its top (Key 137). Keys 125 through 137 show one-year accumulations of drift. The average annual snowfall here is less than three feet (Wade, 1945, Fig. 14).



CREVASSES are the most dangerous surface features in Antarctica and the most significant ones as well because of the information they reveal about glacier structure, glacier movement and sub-glacial topography. Antarctic glaciologists like Gould (1940, p. 734) are impressed by the meager evidence of movement in some heavily crevassed areas. Crevasses here may reflect slight movement in rigid ice rather than rapid motion in more flexible glacier ice or firn.

Generally unimpressive in airphotos because of a lack of comparable objects of known dimensions, crevasses are found to be miles long and tens or even hundreds of feet wide when measured by photo interpreters. Origin, size, shape, pattern, location, covering and other significant characteristics are more readily, quickly and safely determined from airphotos than surface survey because: (1) crevasse fields are too extensive and untrafficable for surface evaluation, (2) cameras record differences in tonal values not apparent to the unaided human eye which permit the analysis of crevasse lids, (3) the vertical view is easily converted to correct spatial relationships, and (4) crevasse systems are readily recognized from the air.

TENSION CREVASSES are the most common type of crevasses in Antarctica. They form perpendicularly to the line of flow and are often found in series, particularly where the glacier changes gradient, changes direction of flow, rounds an obstacle, passes over a submerged bar or is subjected to a sudden, severe change in temperature which may cause the ice to contract. Upon resumption of the former conditions, the crevasses may close, cement themselves, drift over and disappear from view.

SHEAR CREVASSES form as a result of differential ice movement. They occur between stagnant and moving segments of ice and between segments moving at different rates of speed. Generally oriented in the direction of flow, they have a torn appearance and are commonly narrow, since lateral pressure tends to keep the sides from spreading far apart. Surface features on opposite sides of these crevasses often fail to match because of the displacement of the sides in relation to each other.

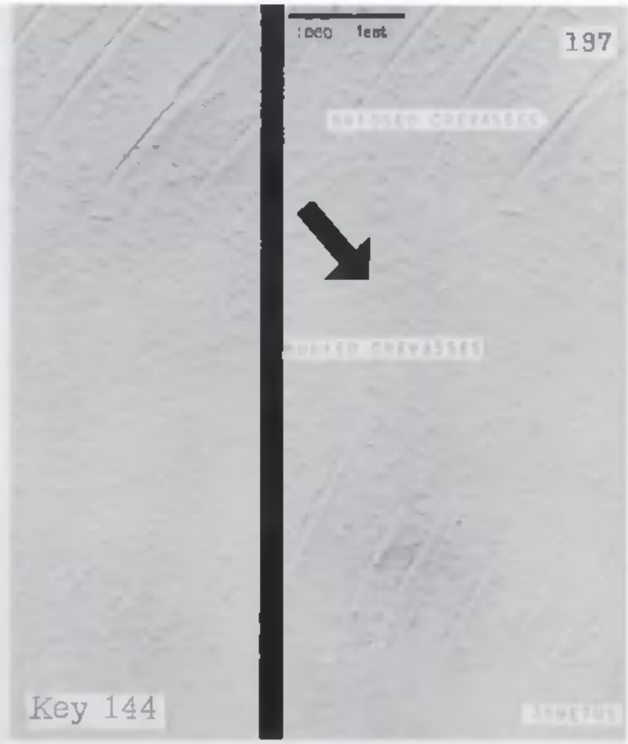
SERACS develop when tensions become strong enough to create crevasses which are of greater width than the original surface areas remaining between them, thus forming ridges or pinnacles. Seracs may be clean cut or modified by such elements of ablation and gravity as thaw, wind-chiseling or cave-in. Gradients too steep for seracs produce ICE FALLS in which the ice mass breaks up, avalanches and reforms at the bottom.

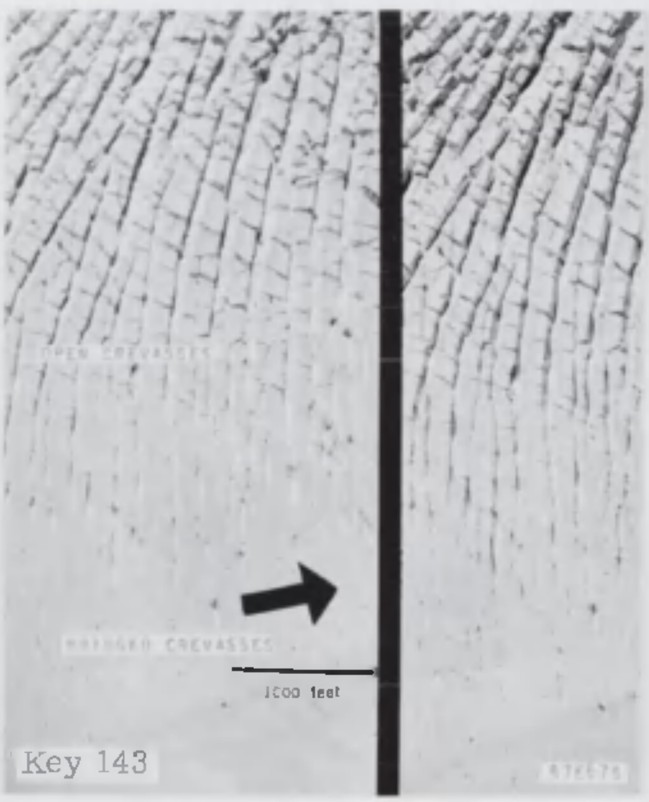
Key 138. Sharply defined tension crevasses form over an upstream submerged glacier bar or change in subglacial gradient (right), then close, drift over, disappear, reappear at a downstream change in subglacial gradient, reopen in ragged secondary formation (left), close, drift over and disappear downstream.

Key 139. This multiple crevasse and serac pattern appears at first glance to be oriented from left to right on the illustration. Stereoscopic analysis, however, reveals this to be an optical illusion produced by the drifting snow. The principal axis of the crevasse system is actually from top to bottom of the picture. Stereoscopic study also discloses the reasons why airphoto analysis is superior to surface survey for many aspects of crevasse research (see the preceding page).

Key 140. Tension crevasses in rapidly moving ice.

Key 141. Drifted snow or loose firn fills or bridges tension crevasses. Note that drifts are oriented at right angles to the crevasses.





Keys 142 and 143. Oblique and enlarged vertical airphotos of crevasses and seracs forming an impassable "skauk" (Icelandic for crevasse field, Taylor, 1922, p. 87 and p. 187). The thinly bridged crevasses at the bottom of Key 143 are very dangerous.

Key 144. Crevasses a hundred feet wide and miles long are here filled or bridged with drift. Sastrugi crossing the crevasse lids indicate that they are almost flush with the glacier surface. These crevasse scars are often not readily apparent from the surface, particularly under snowblinding or overcast conditions.

Key 145. Crevasses typical of those which form on escarpments.

Regardless of size, shape or orientation, all crevasses arise from stresses or strains which cannot be absorbed by the relatively rigid molecular framework of glacier ice. Since low temperatures reduce the power of molecular adjustment of ice to tension (Wright and Priestley, 1922, p. 253), it is probable, all other conditions being equal, that glaciers in the Antarctic are more intensively crevassed than elsewhere in the world. Appearances are deceptive, however, for most of the Antarctic crevasses are hidden beneath crevasse lids, sealed by pressure, filled with snow and firn or covered by drift.

Key 150. Ice troughs many times the width of normal crevasses tend to develop where independently moving segments of shelf or glacier ice abut.

Key 151. This stereogram, illustrating the formation of floating fissures, presents some of the differences between genuine crevasses which are formed over land and the formation of somewhat similar features in floating ice. Each stage in the process of floating fissure formation is shown from the original depression in which the former crevasse system is exposed and sastrugi are absent (top) to the lens-shaped rift with a floor of sea ice and debris (bottom). The specific cause for the formation of these features is unknown but it is probably assignable to differential ice movement in areas of unconfined, floating ice or by submerged obstructions in the path of the floating ice. Features of this general type have been termed rifts (English), barrancas (Spanish) or dongas (Zulu) by Antarctic explorers, but the usage of these terms has been too vague for application to this feature.

Key 152. A large floating fissure in shelf ice. It is 2,000 feet wide and two miles long. The fissure floor is composed of shelf ice debris in a matrix of sea ice and drift. (See Key 49.)

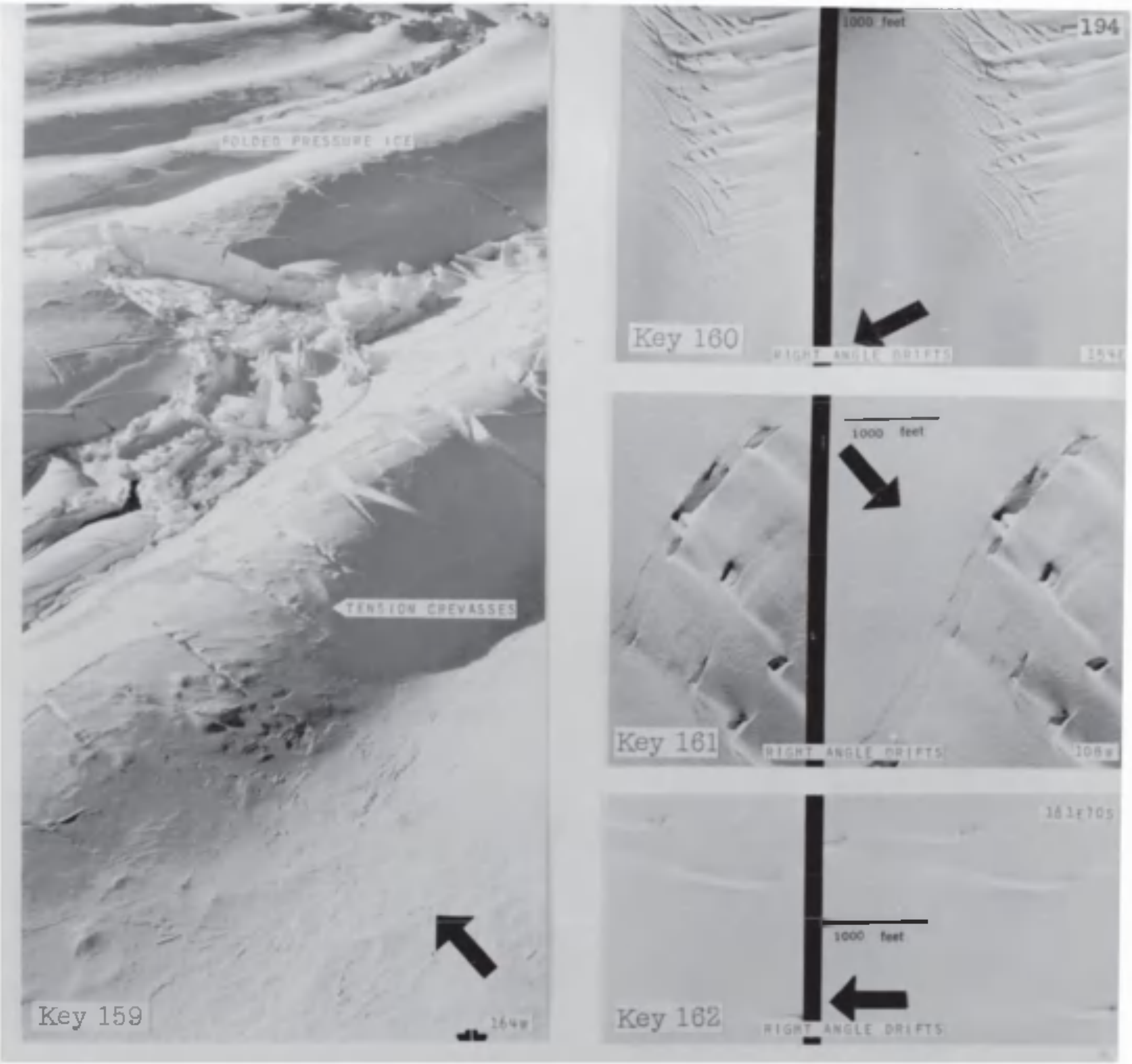
Keys 153 and 154. Key 154 is an oblique view of a series of floating fissures cutting old tension crevasses nearly at right angles. Key 153 is a vertical stereogram of a fissure which is located adjacent to and toward the reader from the one in the foreground of Key 154. These floating fissures are a product of shear as evidenced by their serial alignment, the shear crevasses at left (thin arrow) and the disturbed lids of the tension crevasses. Some of the floating fissures have joined ends to produce icebergs miles inside the floating ice coastline. Note the open sea in the distance.

REENTRANT RIFTS form in all types of floating glacier or shelf ice. They result from tension, shear or marine influences.

Keys 155 and 156. Reentrants caused by ice tension or marine influences invade both sides of a glacier ice tongue.

Key 157. A giant tension reentrant on the unexplored east coast of the Shackleton Shelf Ice. The straight, horizontal, black line is a tear in the photo negative; the irregular, vertical line is the shadow of the barrier cliff on the sea ice floor. Black, open water appears near the lower left corner. The scale is less than 1:40,000 in the foreground.

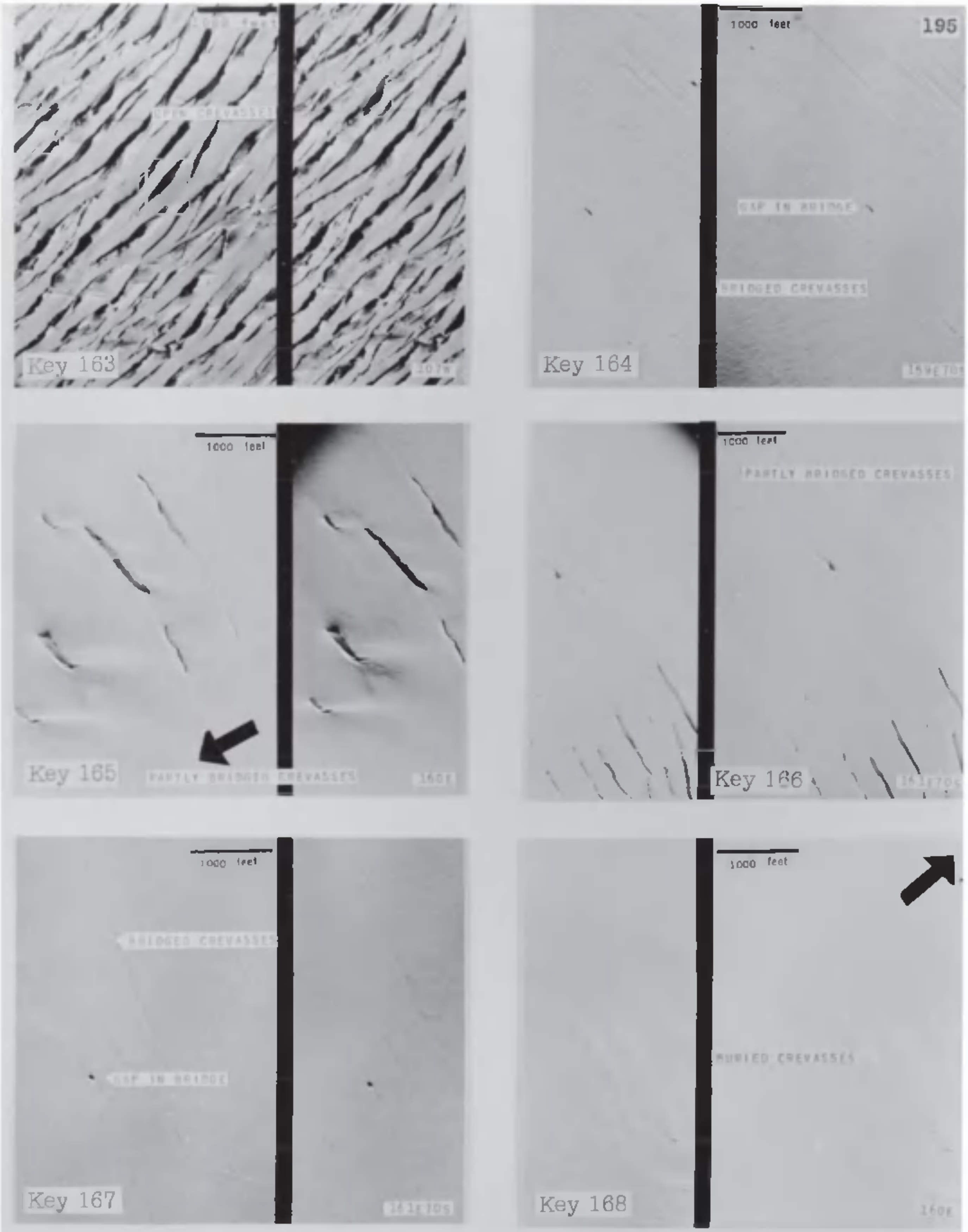
Key 158. A shear reentrant rift caused by the shelf ice passing an obstruction (island). The rift is now controlled by marine influences. The tiny black spots in the shadow are Weddell seals.



BRIDGED CREVASSES, difficult to see from the surface, are easily identified on airphotos by the lighter tone of drift snow in the depressed bridges (Key 91), shadow and sun reflection on opposing lip-lid contacts, lid holes, distant exposed portions of the crevasse system and/or right angle drifts. Investigators differ sharply on crevasse lid formation. (See, for example, Wright and Priestley, 1922, p. 31, p. 256; as contrasted with Poulter, 1950, p. 89.) All students agree, however, that the lip-lid contacts are the weak points. Sledging experience has indicated that lids of less than 20 feet in width are apt to be the most dangerous. Sledge or ski crossings are made at right angles to the crevasse.

Key 159. Open tension crevasses occurring in pressure ice (foreground). Wide, flat-bottomed crevasse and orientation of ice debris (background) indicate that this ice is waterborne.

Keys 160, 161 and 162. The life cycle of RIGHT ANGLE DRIFTS includes their formation at crevasse lips (Key 160), extending from lid holes, here 200 feet wide (Key 161), and as the sole remaining evidence of completely covered crevasses (Key 162). The last stage is the same as the lenticular holes photographed by Ronne and described by Knowles (1945, p. 175) but there is no relationship to waterborne ice as Knowles indicated.

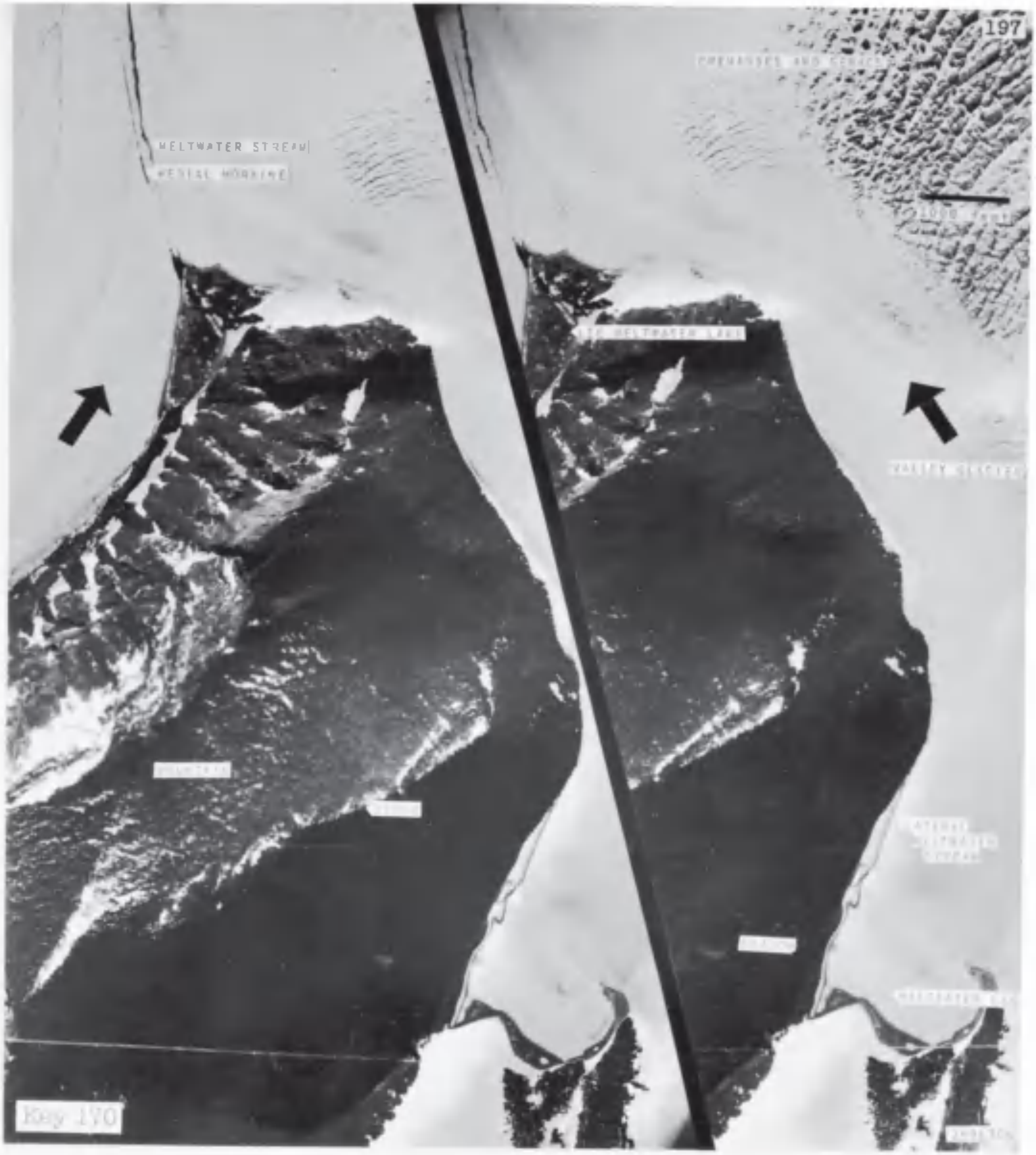


Keys 163 through 168. Contrast the sharply defined, open crevasses (Key 163) with the several varieties of filled and bridged crevasses illustrated. Note that the crevasses are plainly visible from the air view, even when covered. Note also that right angle drifts do not always form, even if the prevailing winds, as shown by sastrugi, are favorable.

RADIATION of heat from exposed bed rock, moraines, scattered debris, erratics or dust may modify adjacent glacial surface features considerably. Although the average annual temperature of the Antarctic littoral is assumed to be near zero degrees F. and the average summer temperatures in the mid-twenties F., black bulb temperatures of 154° F. have been observed (Taylor, 1922, p. 47). Rock absorbs a far greater amount of solar radiation than does ice. This absorbed energy is then reradiated in the form of long (heat) waves into the adjacent air and ice, causing both ice evaporation and thaw to occur.

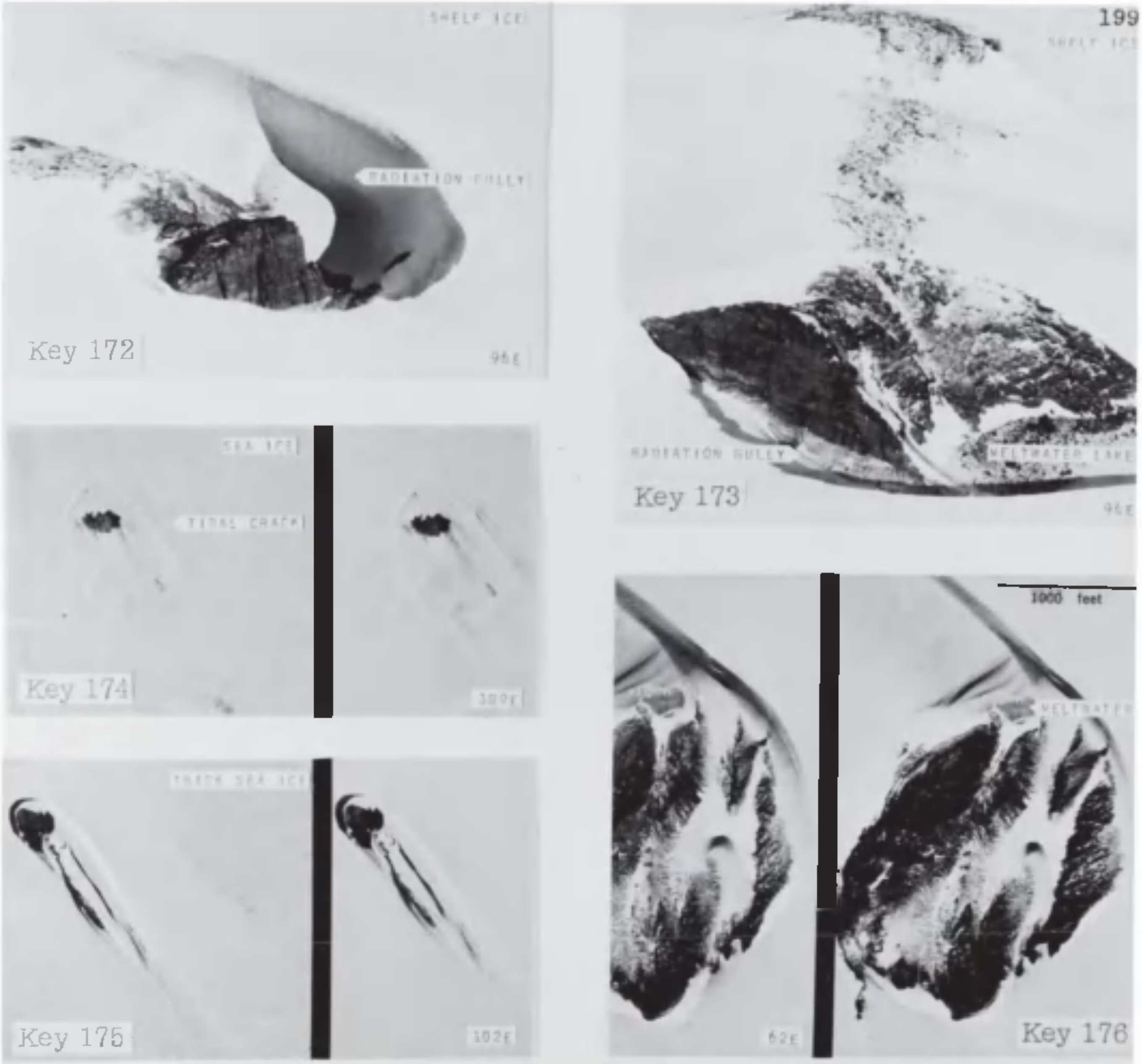
Rock material on glacier surfaces, such as moraines, erratics or wind-blown dust, occurs either as dispersed particles or concentrated deposits. This distinction is important, for it determines the manner in which the rock affects the underlying ice. Radiated heat from scattered rock particles or extremely thin rock cover creates depressions in the ice surface by evaporation or thaw. Wright and Priestley (1922, p. 283) found that a few grains of sand may cause the evaporation of a depression seven inches in diameter or that 0.1 gram of sand may melt 300 cubic inches of ice in one summer. Conversely, if the rock cover is continuous and at least a few inches thick, the long wave radiation from the upper surface is not only prevented from reaching the ice, but normal ice dissipation by wind, low relative humidity and direct solar radiation are likewise prevented. (See Keys 199 and 200).

Key 169. At top is a glacier ice surface marked by many meltwater channels. Below, the presence of moraine and bed rock creates a drainage system in which the meltwater streams are made more prominent because of their greater activity, which is caused by the radiation, and the presence of rock particles in their channels. Note meltwater lake.



Key 170. Radiation from this large mass of exposed rock has produced lateral meltwater streams and two lee lakes. The latter are meltwater lakes found on the downglacier sides of nunataks and exposed land masses. The lee lake at top left is covered by black (transparent) ice, while that at bottom right is partly fringed by black ice. This fringe may be caused by the partial thawing and refreezing of the lake or by the arrival of fresh meltwater. Meltwater streams are active in mid-glacier, at extreme left. The medial moraine extending downglacier from the glacier junction is typically paralleled by a meltwater stream which presents an appearance similar to that of the moraine, but which on close inspection is found to exhibit characteristics quite distinct from it.

Key 171. (The stereogram is oriented so that its bottom lies at the right margin of the page.) At bottom, radiation gullies and meltwater streams are found adjacent to exposed skerries. Above, a section of sea ice is covered by wind-blown particles. Radiation from these has made an impassable ICE MORASS. At top is a similar area of sea ice exposed to the same solar radiation but without morainal particles.



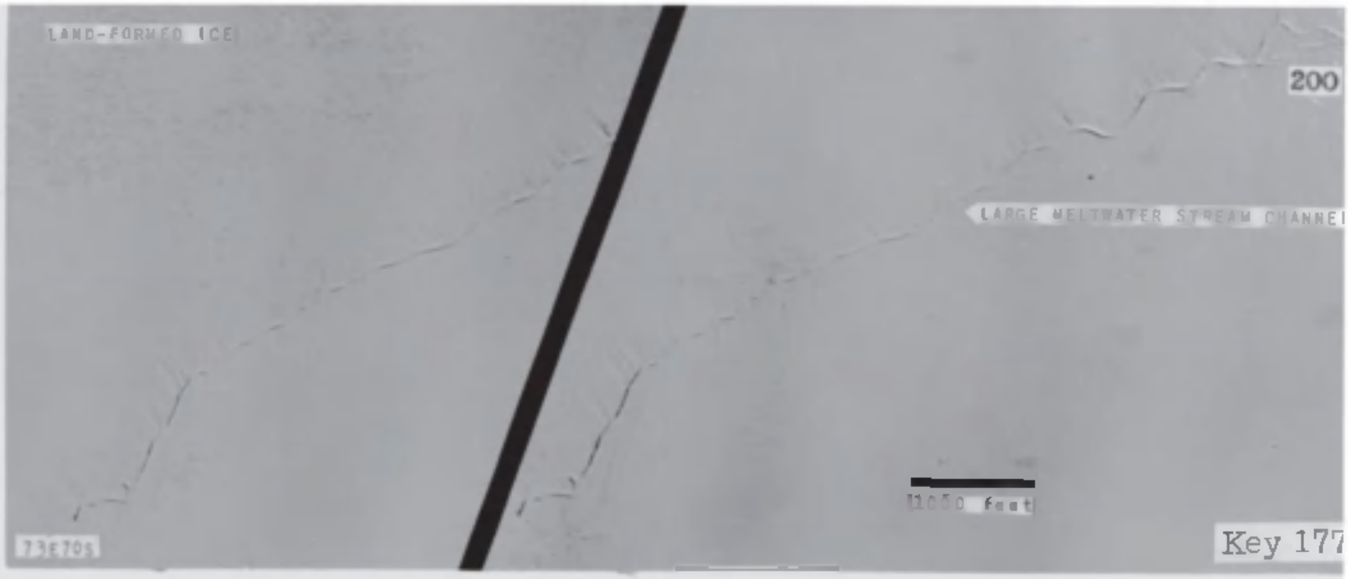
Keys 172 and 173. Two oblique views of a combination drift moat and radiation gully about an island in shelf ice. Frozen meltwater from radiation is visible on the moat floor in both illustrations.

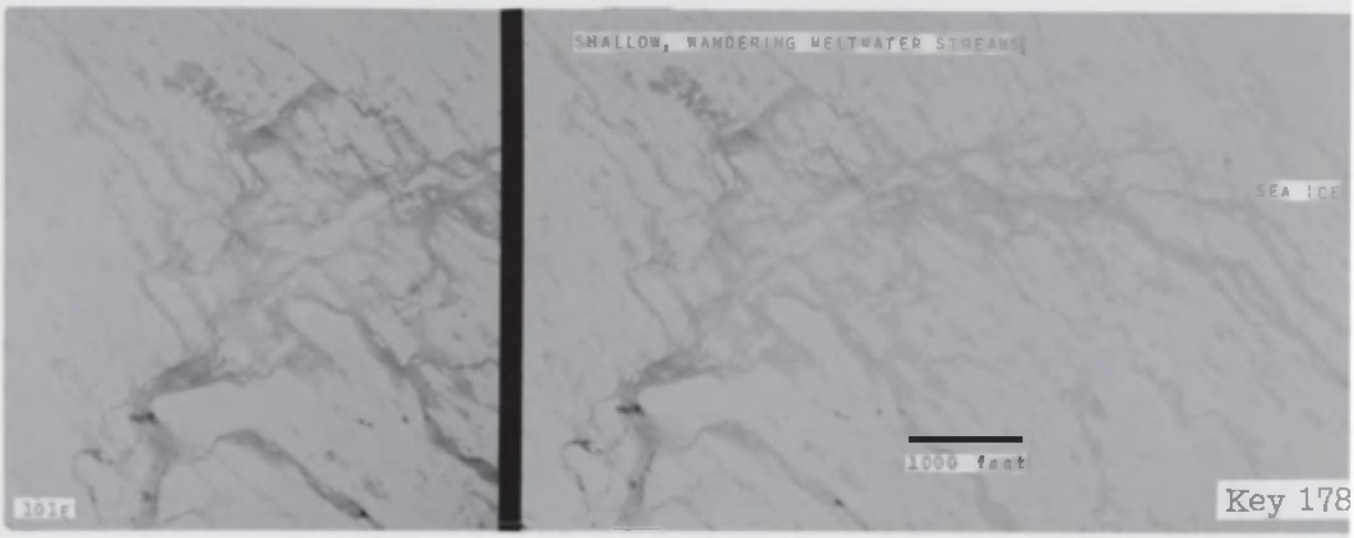
Key 174. An exposed skerry with small meltwater pools at its base. The sea ice here is too thin to permit the formation of a radiation gully.

Key 175. An exposed skerry in thickly covered sea ice exhibits a moat caused by wind scour, ice evaporation and thaw. Meltwater areas are just above the sea ice level. Evaporation is probably as important a cause of ice removal as thaw but its process is invisible.

Key 176. A nunatak with associated meltwater lake and radiation gully. The drift atop the nunatak has its own meltwater pond. The ice surface in the upper level of the moat, top left, probably resulted from radiation caused melting and refreezing in situ. Note that ice surfaces are illustrated in three photo tones (see Keys 87-95).

Many examples of solar radiation and the iceforms it produces are evident in the next sixty keys.



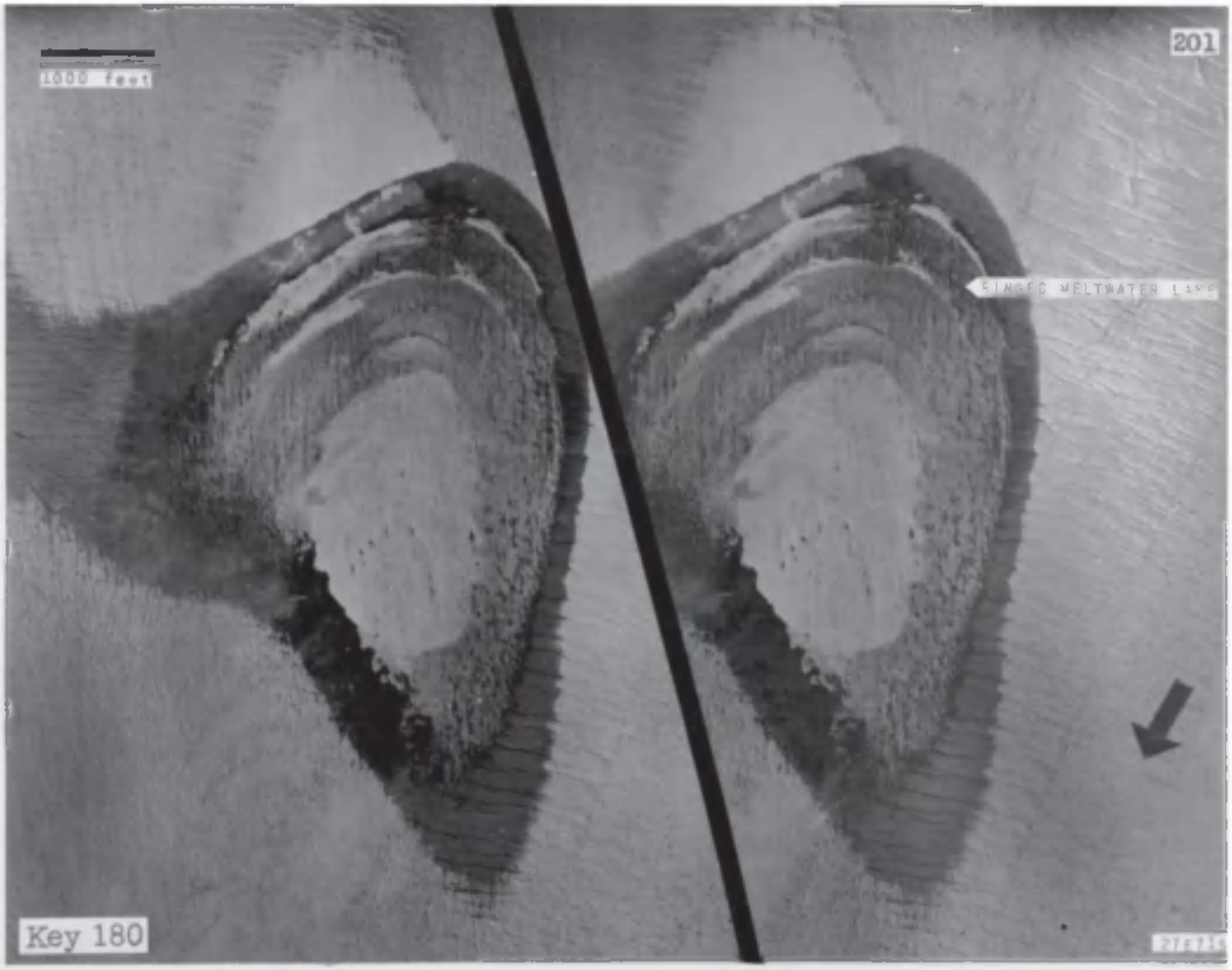


GLACIAL STREAMS AND LAKES behave differently than their terrestrial counterparts in that they generally lack erosional tools, enlarge their channels chiefly by solution and are inactive (frozen) most of the year.

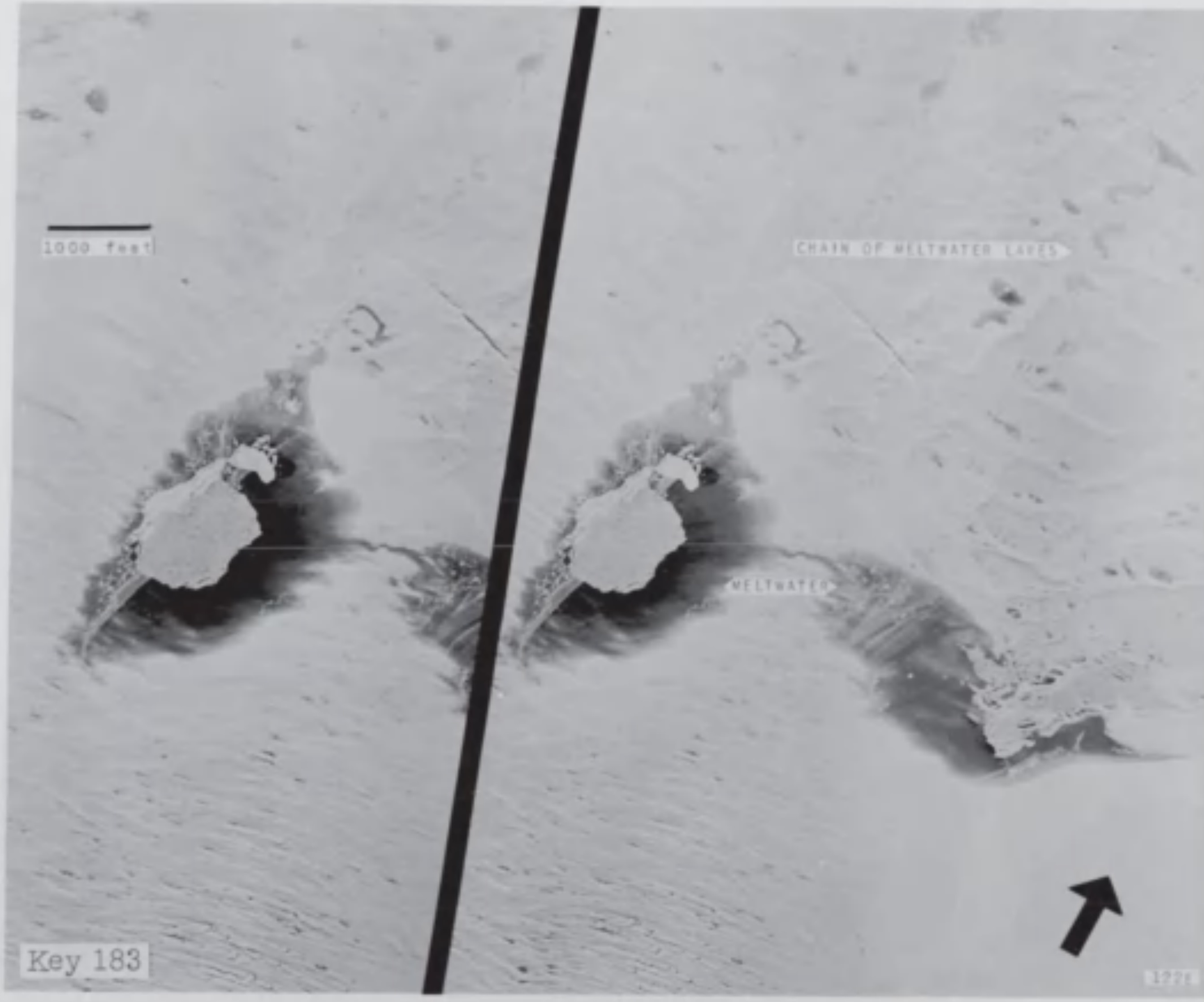
Key 177. Contrast the fine net of thaw streamlets with the single, deep 50-foot-wide meltwater channel that disappears into the glacier. Low ice temperatures make englacial streams relatively rare. Low meltwater temperatures cause deep surglacial channels to be infrequent.

Key 178. Meltwater on thick, flat sea ice characteristically appears puddled, with shallow, wandering, blue-colored channels frequently 200 feet in width.

Key 179. Thousands of tiny, white meltwater channels, most of which are not more than a few feet wide and a few inches deep, extend down the continental glacier slope into an arm of the sea.



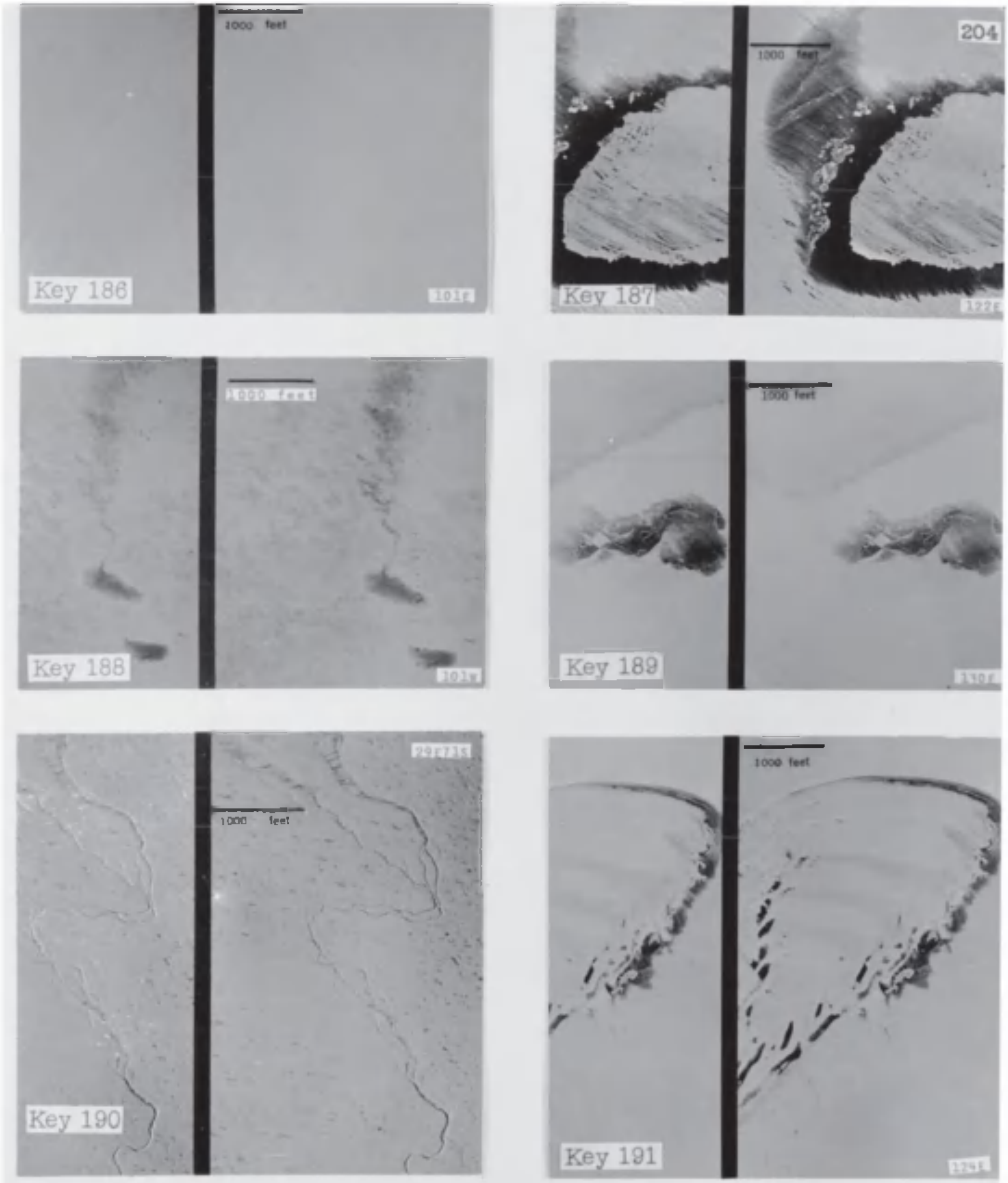
Keys 180 and 181. Meltwater lakes thaw centerward from shallow edges and frequently leave inner cores of ice frozen to the bottom. The series of rings illustrated in Key 180 are common. They could result from the arrival of fresh meltwater before the lake thaws, from seasonal meltwater increments or because the summer thaw extended successively shorter distances toward the lake center in each of several successive seasons, partly as a result of the lake being enlarged each season from the addition of fresh meltwater. The transparent outer ring permits airphoto analysis of crevasses and other elements of glacial structure which otherwise might be covered with snow or firn. The crevasses in the lake bottoms are sealed by frozen meltwater accumulated in previous years. Light-toned snow, above at top, is a typical cover for frozen meltwater lakes. Note the "drowned" sastrugi which appear on the ice near the center of the lake in Key 180.



Key 182. Meltwater lakes are distinguished from cloud shadows with ease in the foreground but with difficulty in the background on oblique aerial photos. New, transparent ice is forming on the main lake, which is several miles in length.

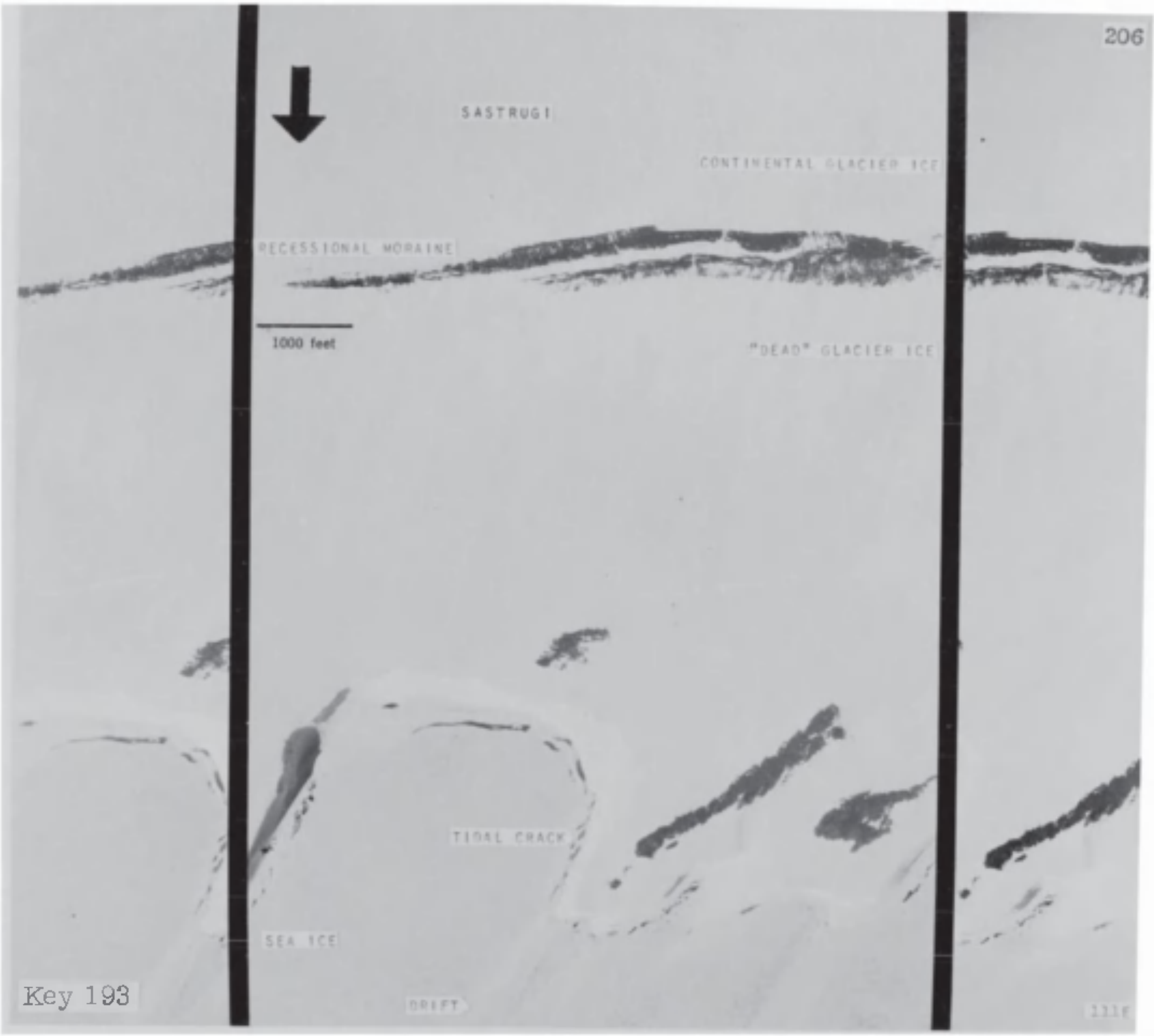
Key 183. This meltwater lake may be sufficiently deep for the center ice core to be afloat and to have drifted to its present position. The ice topography at upper right has caused the meltwater stream to form a chain of new lakes in a chain of old lakes.

Keys 184 and 185. Frozen meltwater lakes here occupy crevasses on a floating ice tongue. The absence of meltwater streams indicates the lakes were formed from melting ice in situ. Since the lake belt coincides with the intensely crevassed channel glacier, the action of solar radiation on the north sides of the seracs may account for the individual crevasse lakes.



Keys 186 through 191. Six stereograms illustrating various aspects of typical Antarctic meltwater features including streaks of blue ice (186), crevasses under meltwater lake (187), meltwater surface (188), partly snow-covered meltwater lake (189), braided meltwater stream on puddled surface (190). The triangular meltwater lake (191) is formed in the same manner as the ringed lake in Key 180. These lakes do not thaw completely every summer.

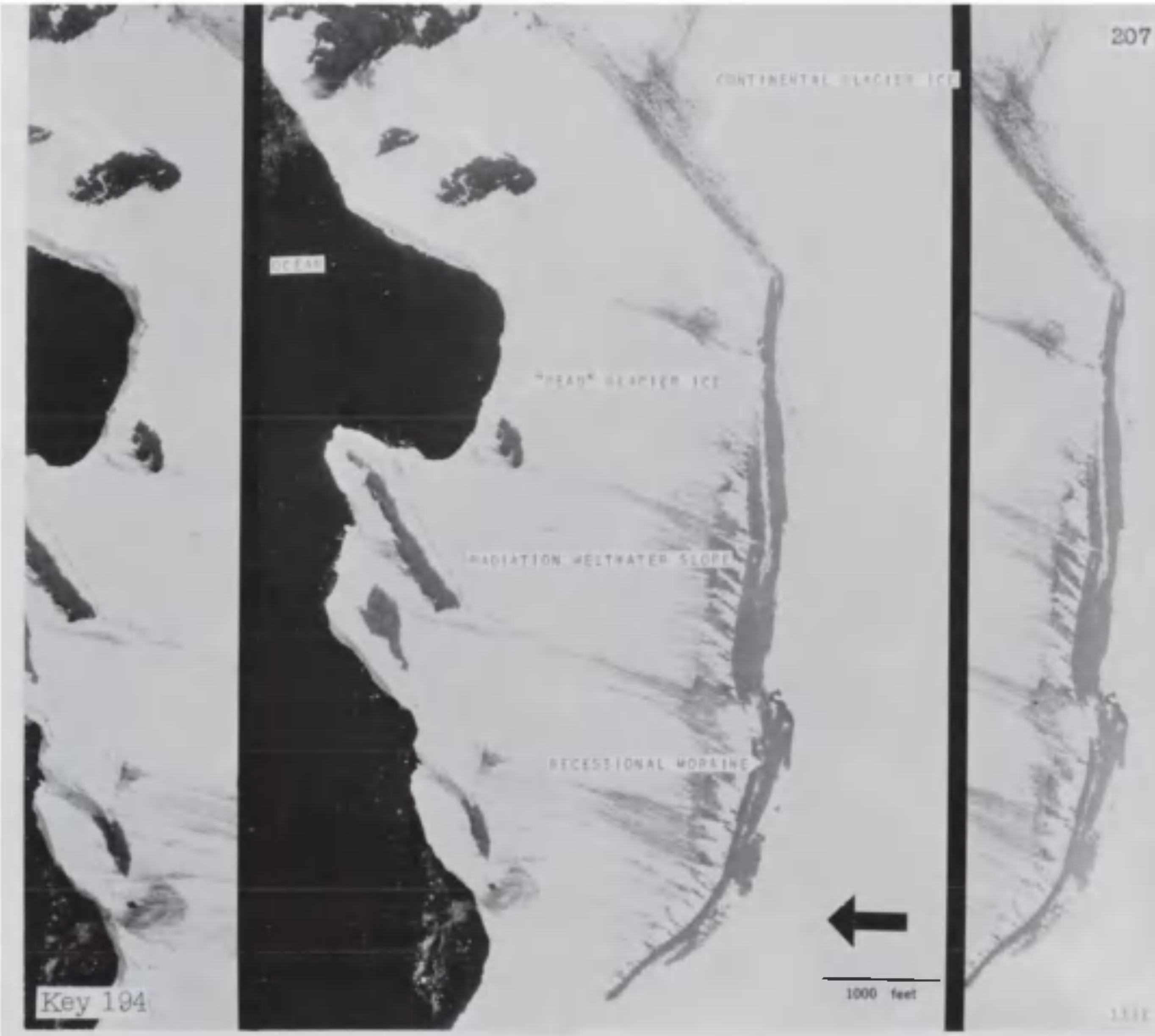
Key 192. A slight change in Antarctic summer temperatures may cause radical variations in local iceforms. Here nunatak-radiated heat produces radiation gullies and forms lakes adjacent to the land masses. The medial moraine tapers off and disappears as it extends downglacier because its individual rocks radiate sufficient heat to melt themselves into the adjacent ice, sometimes forming cryoconite holes. The light-toned meltwater streams darken, enlarge and change character after passing over the moraine at center. Two meltwater lakes, produced without benefit of rock radiation, each with its major tributary meltwater stream, are visible at right center. The white, snow-covered, frozen meltwater lakes in the background should be differentiated from the water marks from the negative of this print. Many ponds and puddles occupy the foreground.



The presence of land in Antarctica is indicated by exposed or evident-though-covered moraines, mountains, coasts and islands. Crevasses which indicate subglacial topography are considered separately.

Surface moraines are conspicuous by their small number, especially in relation to the vast areas of glacier ice in Antarctica (Taylor, 1922, p. 126; Wright and Priestley, 1922, p. 224; Gould, 1940c, p. 732). This occurs for at least five reasons: deposition of terminal moraines in the ocean, high ratio of ice-covered to exposed rock, submergence of the surface moraines caused by solar radiation, excess precipitation and drifting snow and firn, and lack of erosive power caused by the slowness of the ice movement. Arcuate (semi-circular), lateral, medial, recessional and ground moraines are all present in Antarctica and illustrated in these keys. Moraines occur in surglacial, englacial, subglacial or in fossil form. Surface moraines originate in four ways: accumulation from valley walls, accumulation from nunataks, emergence of subglacial material and the re-emergence of surface moraines which were submerged from the effects of radiation upon the surrounding ice or from being drifted over by snow or loose firn.

Key 193. Midsummer view of a recessional moraine. Note change of ice slope at the moraine.



Keys 194 and 195. Late summer view of the upthrust recessional moraine in the preceding key and an oblique of a similar moraine. Note the meltwater streams, absence of sastrugi, change of ice slope at the moraine. The sea ice has broken up and drifted out to sea.

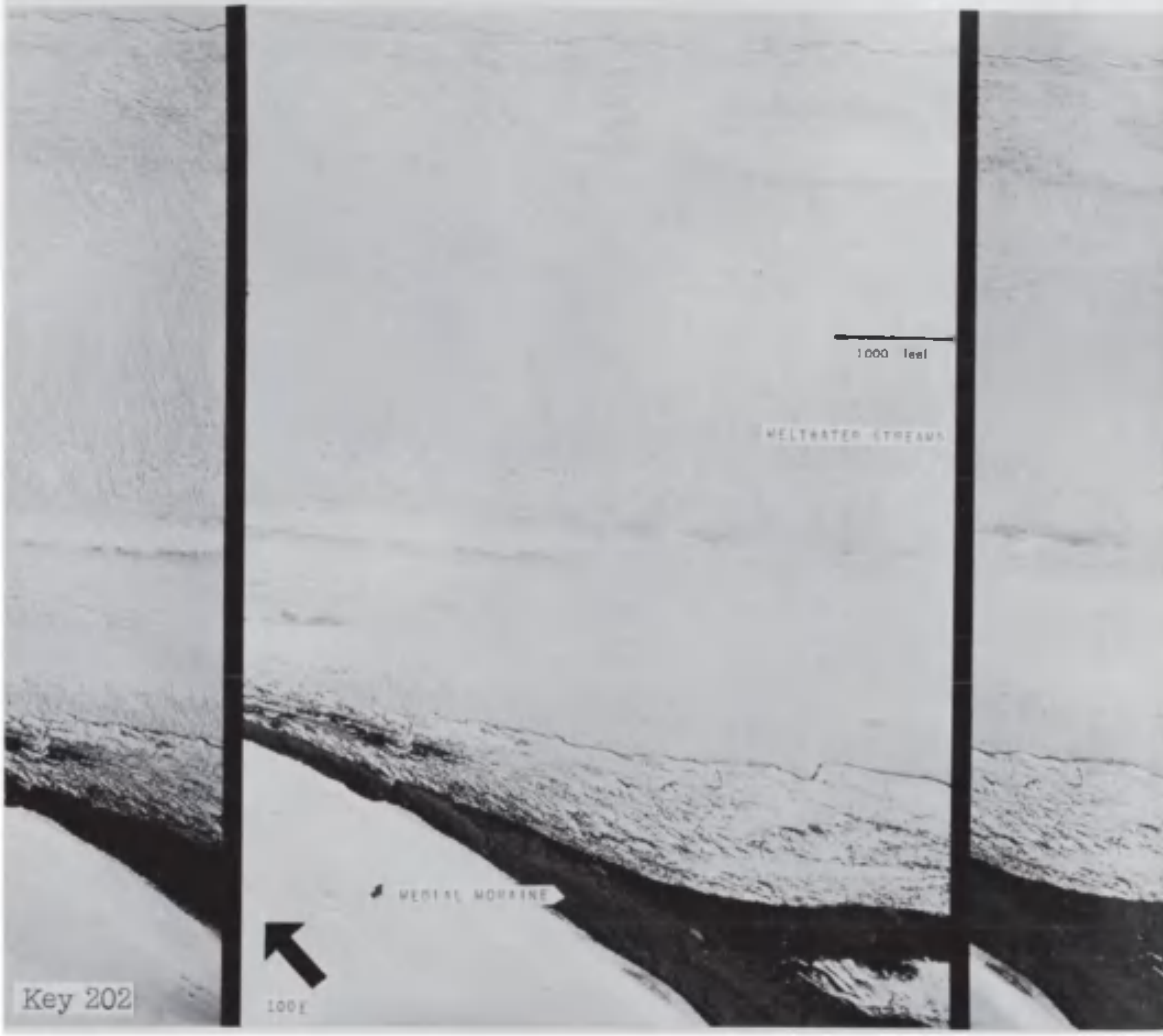
Keys 196, 197 and 198. Arcuate or semi-circular moraines may occur where constriction or sudden change in subglacial slope increases ice velocity or at cirque lips. In these keys note also the moats, medial moraine (bottom left), fallen rocks and drift pattern. The glacier ice and the drifting snow and firn are moving in different directions.

NATIONAL ANTARCTIC EXPEDITION, 1901-1904. PLATE CII

Keys 199 and 200. These illustrations, from photos by R. W. Skelton in 1902, appeared in the Album of Photographs and Sketches of the (British) National Antarctic Expedition, 1901-1904, published by the Royal Society, London, 1908.

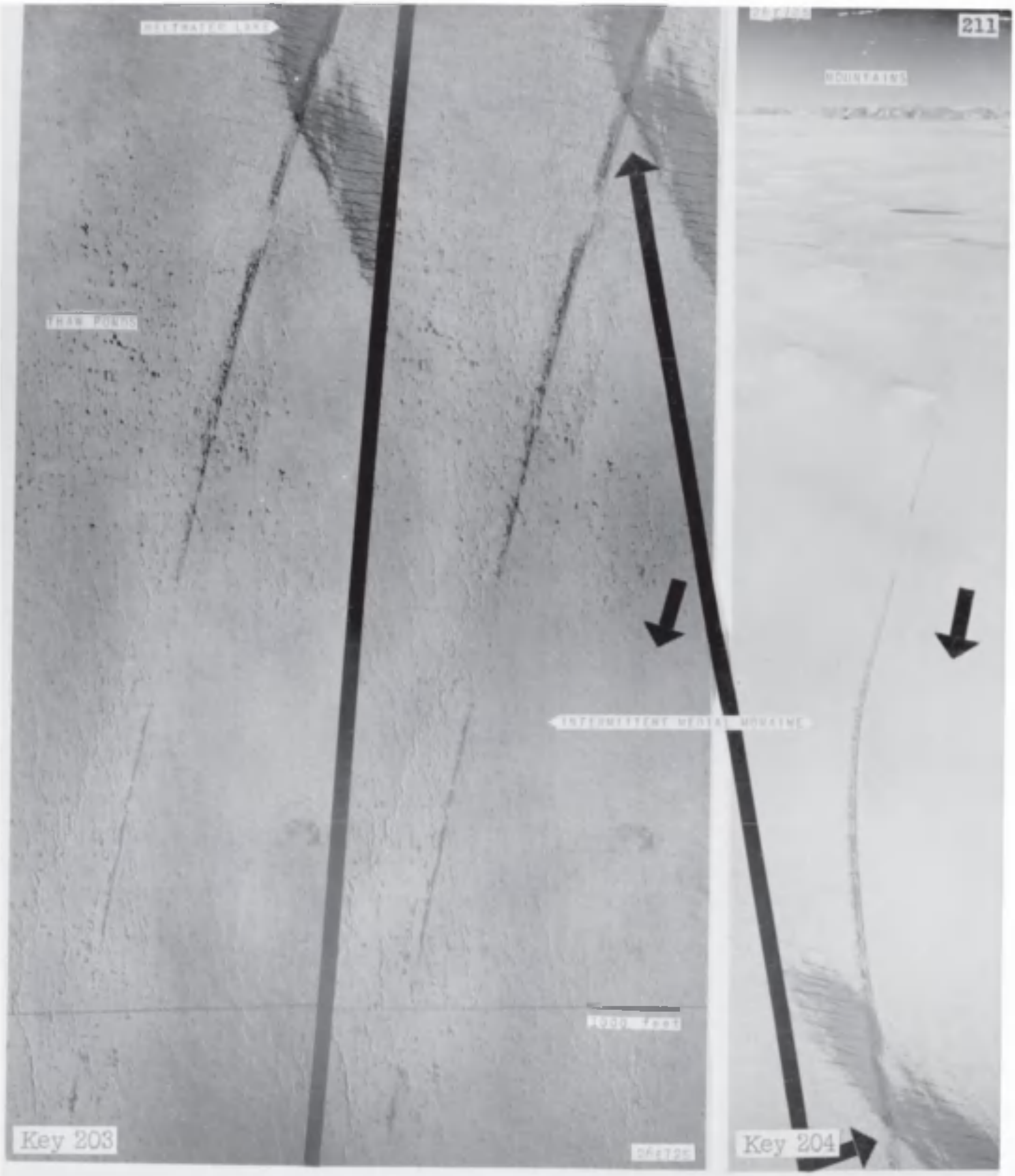
These photos show no bed rock, only moraine-covered ice. They illustrate, as no high altitude, vertical airphoto could, the phenomenon of morainal debris deposited on an ice surface in sufficient thickness to protect the ice beneath from radiation, evaporation, wind erosion and thaw. The level of the unprotected ice adjacent to the moraine may be gradually but considerably reduced by these erosional agents. As the level of the ice at the edge of the moraine is lowered, morainal debris roll or slide to the lowered surface. This process may continue until the moraine-covered ice becomes a ridge or a linear series of cones. The morainal material may then roll or slide away from the ridge, eventually exposing ice at this point. The ice exposed at the ridge may then be eroded by the same agents to form either an ice- or debris-covered trough in place of the former ridge. At any stage in the process a change in the meteorological conditions resulting in excess precipitation over ablation may cause the whole moraine to become ice-covered. (Keys 29 and 30 may represent this state or may simply show pressure ridges. See also Key 205).

Surface moraines are difficult to evaluate either from airphotos or from field examination without digging, drilling or sounding.

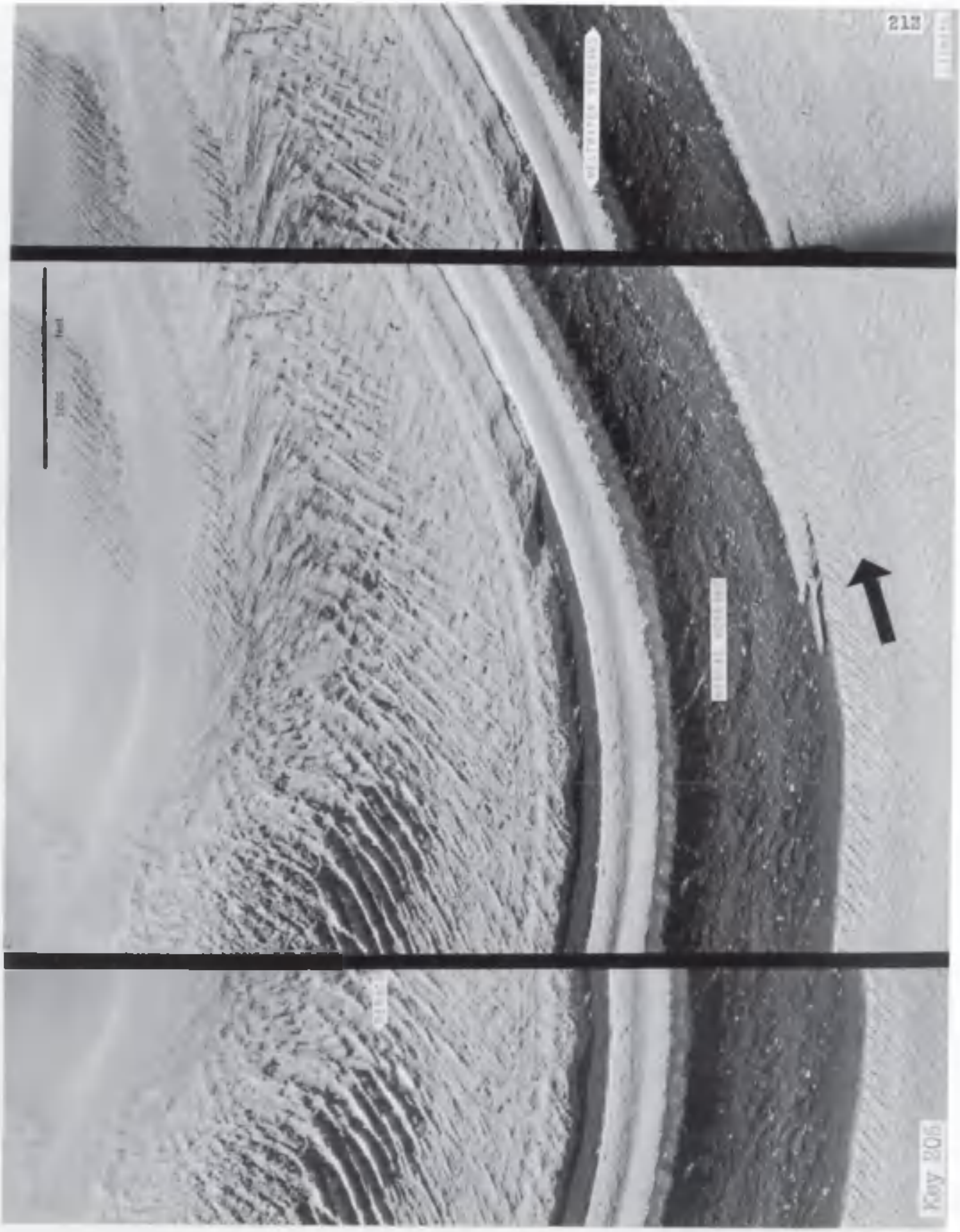


Key 201. Lateral moraines consist of rock debris which have fallen to the glacier surface or which has been corraded laterally at subglacial levels. The extreme Antarctic cold is unfavorable to their formation. Note talus slopes as the primary source material of this moraine.

Key 202. Medial moraines, products of joined lateral moraines, frequently disappear into the ice shortly after forming. The two chief causes of morainal submergence, drift and solar radiation, may not apply here since this area is obviously being denuded by thaw and the moraine here appears sufficiently thick to prevent radiation to the ice beneath. Ice-covered moraine ridges border the exposed portions. The detailed topography of the glacier surface is revealed by the meltwater drainage pattern.



Keys 203 and 204. Some medial moraines bear a distinct resemblance to railroad beds because of their linear shapes and their long, graceful, railroadlike curves and also because they stand above the adjacent terrain like railroad tracks on gravel fill. This medial moraine, probably formed by a junction of lateral moraines from valley glaciers in the mountains (background) is intermittent in character, first being submerged through drift and radiation and then reappearing downglacier as a result of ablation. Note the straight lines and graceful curves of this moraine as contrasted with the meandering channels of the meltwater streams and the irregular character of the crevasses. Note also the thaw lakes in the background.



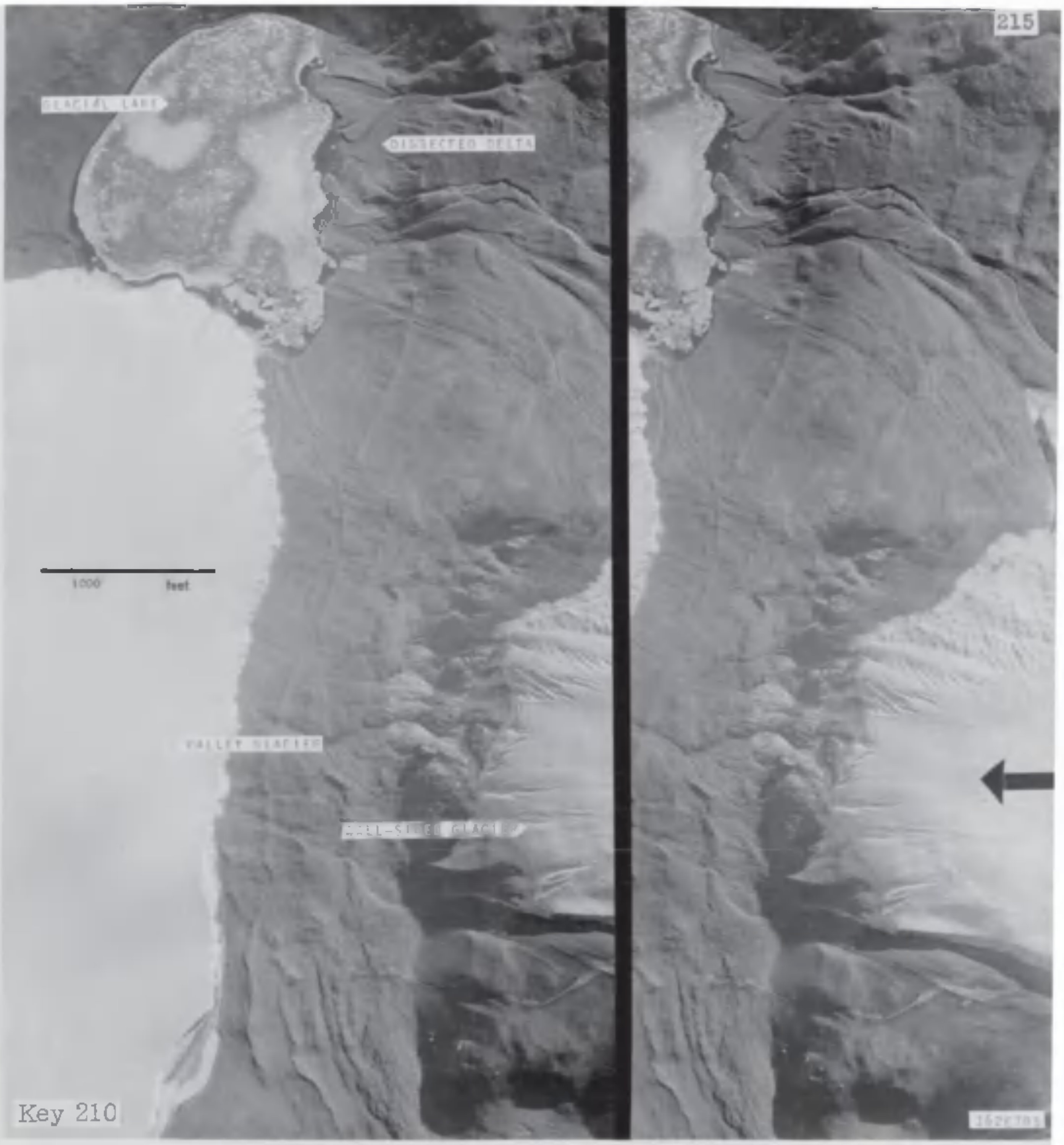
Key 205. A large medial moraine in a valley glacier which originates in the South Polar Ice Plateau and discharges into the Ross Shelf Ice. Morainal ridges with meltwater streams occur in both ice-covered and ice-free forms. (Stereogram is oriented with its bottom at the right margin.)

Key 206. A composite, trimetrogon, vertical and oblique view of several exposed and ice-covered medial moraines, each denoting one or more tributary glaciers or nunataks upglacier. Pressure from the large tributary at right causes several individual medial moraines to coalesce into a single, compound moraine. The depressions between the ridges of moraine contain meltwater streams and ponds which are formed in part as a result of radiation from these same moraines. The meltwater is lighter in photo tone and smoother in photo texture than the morainal debris. Cirques, arêtes and cols occupy the right foreground. (See Key 18.)

Key 207. The diminished continental glacier is no longer able to supply this valley glacier with sufficient ice to maintain itself. The valley floor is covered by ground moraine left in place as the glacier melted back. It consists of unconsolidated and unstratified rock debris partly channeled by meltwater. A recessional moraine occurs at the ice edge.

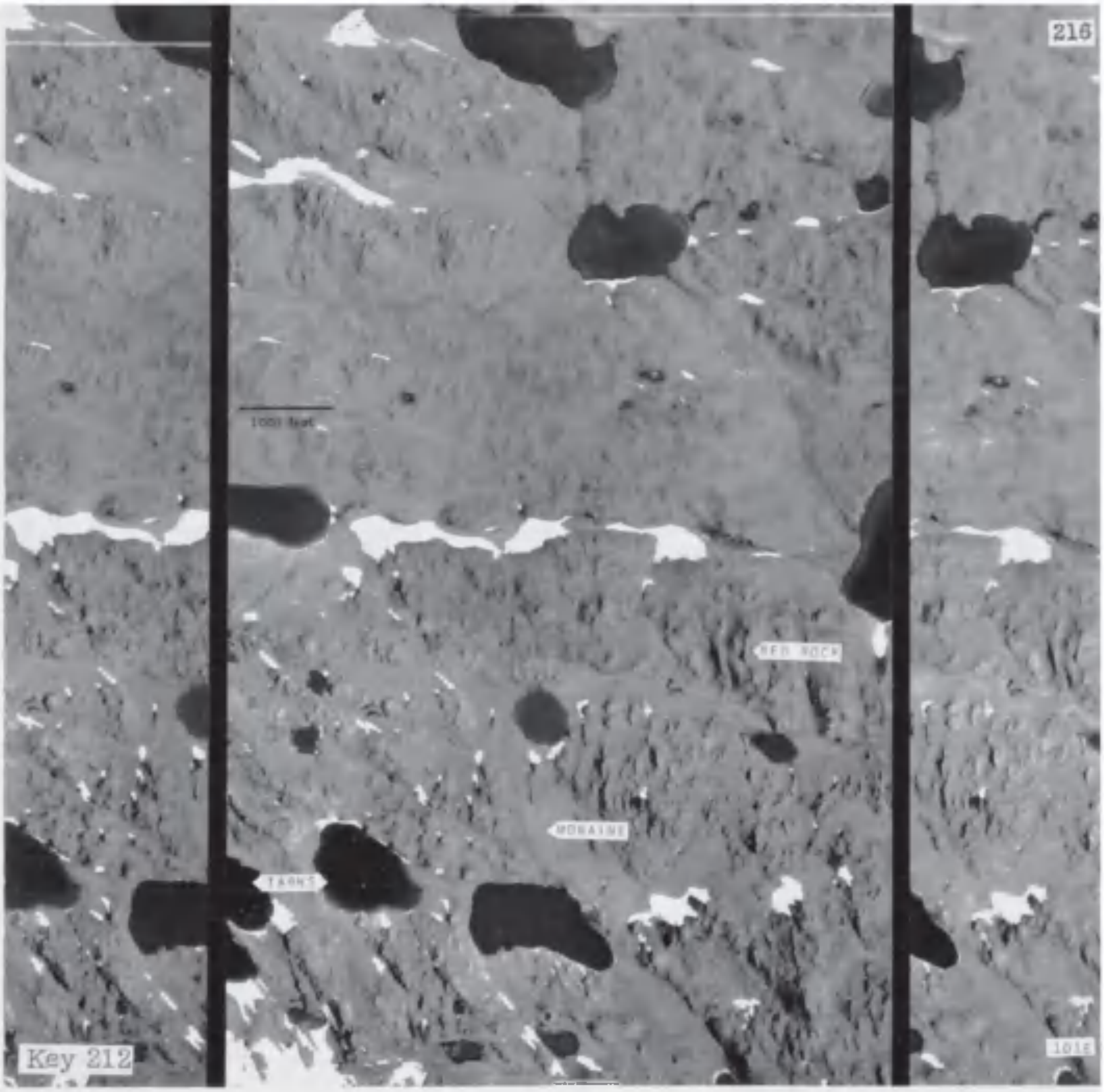
Key 208. A later stage than illustrated in Key 207. Here, the ice has retreated entirely from the area and has left a "dry valley" in its wake. The relatively smooth appearance of this morainal material from the air is misleading since any method of surface transport would be most difficult over this mass of loose rock debris. Although the valley and the mountain peaks are "dry," highland ice still survives on the uplands, from which several tongues of wall-sided glacier ice, one with a large ice apron, extend over the valley side. (See Key 21).

Key 209. Glacial recession results from: (1) a more rapid rate of ice dissipation than ice advance at the glacier front and (2) a general lowering of the glacier surface through the processes of ablation. Above, the latter type of recession has lowered the ice surface in the main channel (left), exposing nunataks at the head of its distributaries (center and right) and their medial and associated ground moraines. Two arcuate moraines appear to be emerging in the nearest distributary. Snow and loose firn have drifted into the shallow depressions and lee areas behind rock projections. The darker ice tones are areas of glacier ice.



Key 210. Ice recession exposing valley is evident from marginal lake with elevated, dissected deltas which indicate former, higher lake levels. Note the snout of a wall-sided glacier with fringing ice aprons, ridges of former lateral moraines, vertical valley glacier walls and moat with small stream but no conspicuous lateral moraine. (The glacier at right is shown in Key 21.)

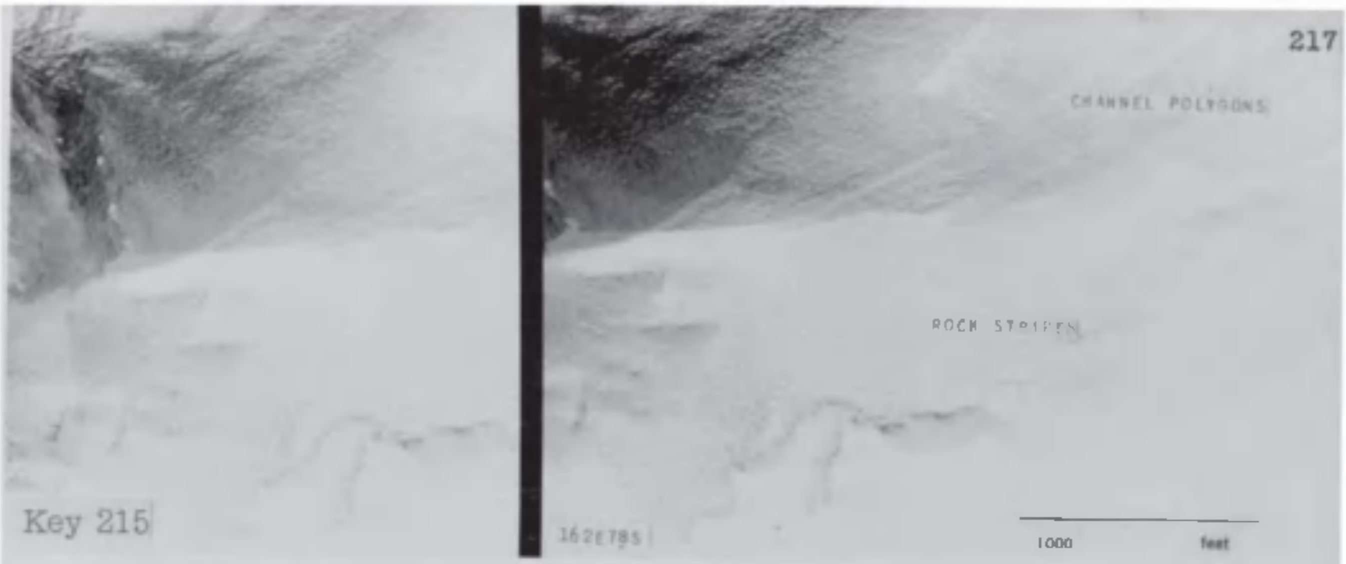
Key 211. A valley exposed by the recession of its glacier from lack of ice supply.

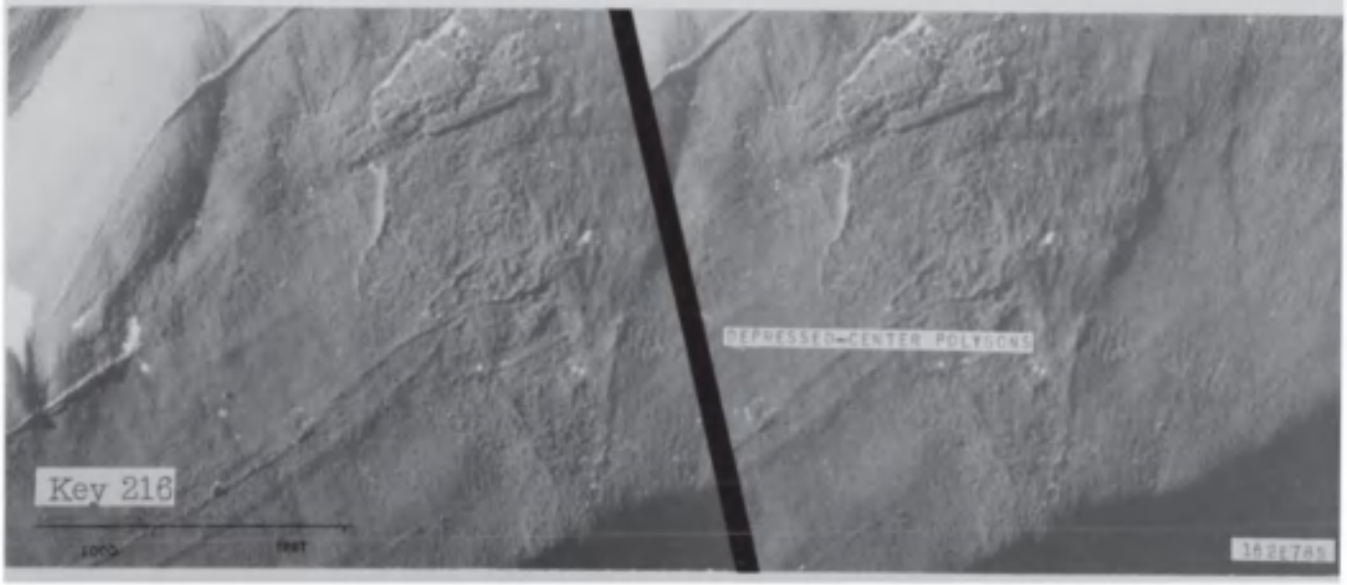


Key 212. Not only is land being exposed by the retreat of valley glaciers, but in certain areas it is being exposed by the retreat of the continental glacier itself. Tarns, south slope snowdrifts, meltwater streams, bed rock (rough texture) and moraine (smooth texture) are apparent in this airphoto.

Key 213. Tarns are brackish as a result of excessive evaporation, except when surface or subsurface outlets are present. Tarns are frequently colored by the presence of algae.

Key 214. The smooth appearing moraine in Key 212 above looks like this from the ground. The black boulders are two feet in diameter.

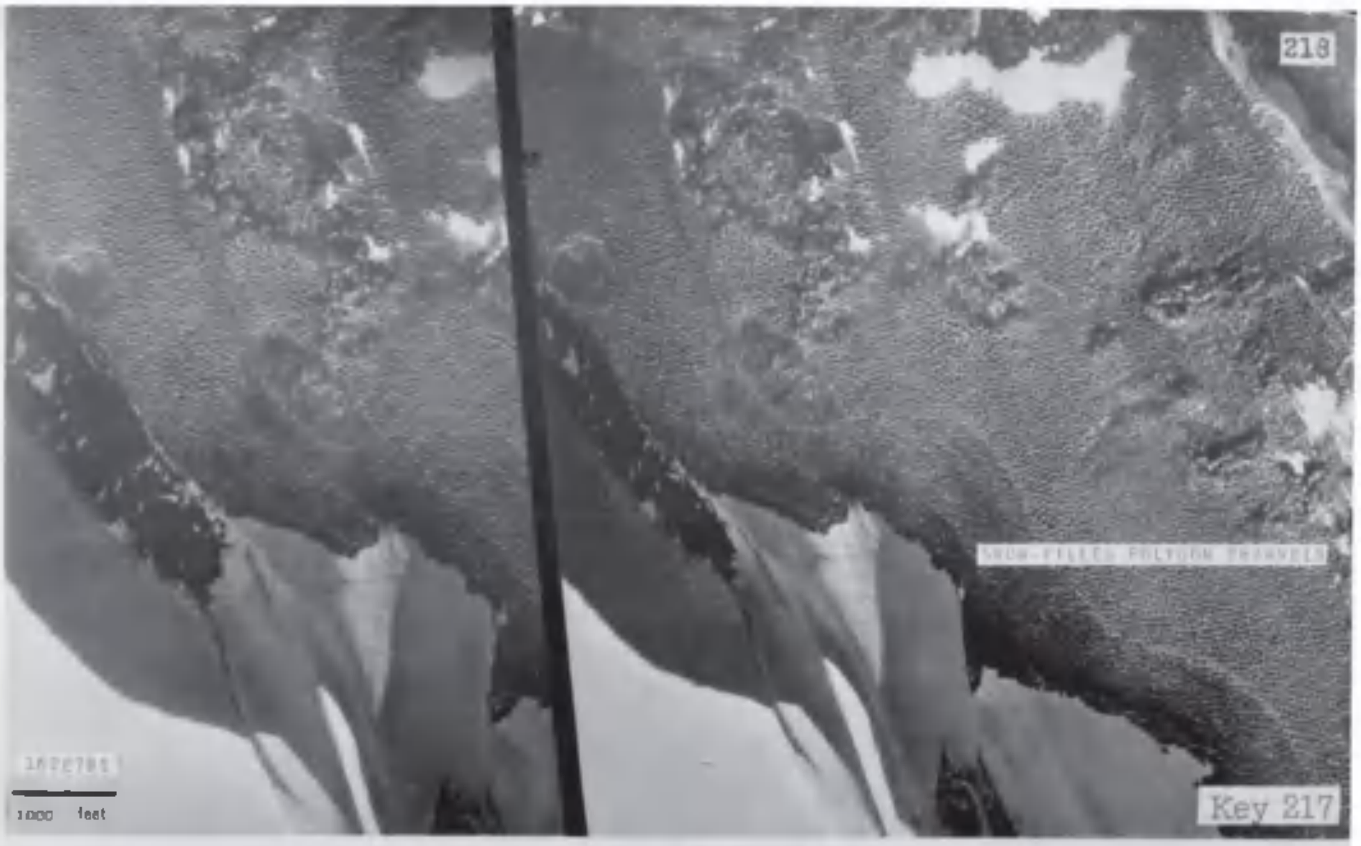


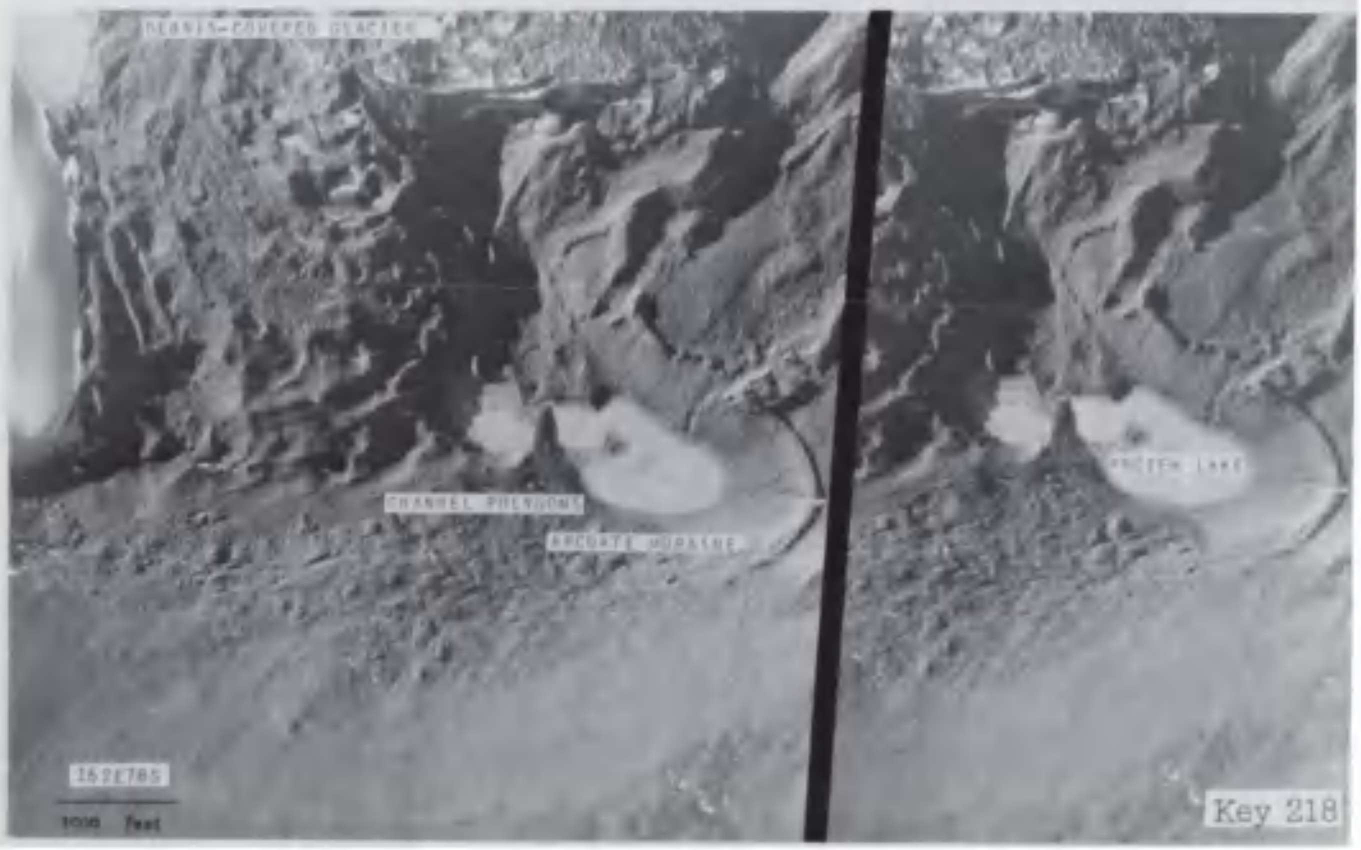


POLYGONAL TERRAIN occurs but occasionally in Antarctica since the conditions necessary for its formation (semi-plastic, waterlogged mantle rock, silty to gravelly in texture, and temperatures that fluctuate about freezing) are infrequently present. In some favored areas, however, the forces of frost, thaw and gravity combine to produce solifluction. Cracks, which become filled with ice wedges, radiate in three directions from points of strain. The cracks from adjacent points unite to form hexagons suggestive of suncracks in mud or columnar basalt formations. Both depressed-center and raised-center (channel type) polygons are present, the precise form depending in large measure upon the character of the earth material. Antarctic polygons differ from their northern counterparts in their larger size, fewer varieties, locations on steeper slopes and the absence of vegetation. This last condition facilitates the airphoto study of microrelief in polygonal areas. Polygons indicate the presence of mantle rock, seasonal temperatures which fluctuate about freezing, presence of permafrost (permanently frozen ground) beneath, poor trafficability and sometimes ice wedges which may melt and become moats in the summer. (See Key 254).

Key 215. Snow-covered, channel-type polygonal patterns grading into rock stripes with changes in gradient.

Key 216 Depressed-center polygons situated in rock waste. Note shadow of mountain at bottom right.





Key 217. Lodgment of wind-blown snow in the channels accentuates the polygonal pattern. Note the presence of polygons on the steep slopes and their absence on outcrops of bed rock.

Key 218. Channel polygons formed in a recessional moraine. Note pattern alignment on steeper slopes, arcuate moraine, moraine-covered glacier ice (top) and soil flow (left).

MOUNTAIN PEAKS, CLIFFS and ESCARPMENTS, which in some instances are wholly or partially barren of ice, account for much of the ice-free land in Antarctica. Latitude, altitude, precipitation, humidity, wind, gradient, orientation of slope and rock color all seem to play a significant part in determining whether or not a particular peak or cliff will be ice-covered. The relationships between these factors are so complex, however, that feasible formulae for determining whether they will permit any individual type of peak or cliff to be exposed, partially exposed or ice-covered do not yet exist.

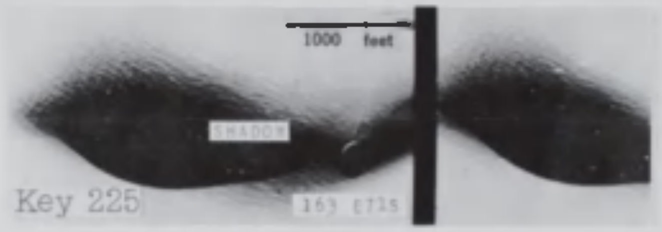
Key 219. Two small peaks near the coastline (top left), one of which appears to be completely covered while the other exhibits steep, bare, northern slopes to the leeward.

Key 220. Mount Erebus is the only Antarctic volcano which is definitely known to be currently active. Its 13,000-foot elevation dwarfs the ice cliffs at the water's edge. Much of its black cinder and lava surface is ice-free but may contain buried ice lenses.

Key 221. These mountain peaks are entirely ice-covered. Irregularities in the ice surface (left foreground) result from the relief of the underlying rock structures which may include completely buried peaks and ridges.

Key 222. Although not apparent at first glance, stereographic examination of the illustration will reveal four distinct mountain ranges. The relatively level summits and some slopes are ice-covered. The medium gray photo tone (foreground) is the crevassed, ice-covered summit of a mountain protruding from the upper surface of an extensive cloud bank (middleground) in a similar manner to the more distant mountains (background).

Key 223. These mountains have ice-covered slopes facing the camera and ice-free slopes on their opposite sides. Note the great size of the shadows, a typical feature of the Antarctic which results from the position of the polar sun low on the horizon. Note also the presence of meltwater streams descending from the mountain ridge (center) and the tension crevasses (foreground).



Key 224. The tonal difference between shadow and exposed rock is less in the left than in the right print of this stereogram. The latter was properly processed for photo interpretation use; the former was not.

Key 225. Dark tones on ice are not always indicative of rock debris. Crevasses, meltwater, cloud shadows, shadows of adjacent land masses and, as in this illustration, the shadows of ice ridges are also dark in tone. The crevasse proves this dark tone to be shadow rather than rock.

Key 226. Mountains in the distance are difficult to distinguish when cloud formations meet the ice on the horizon. The dark tones at left may be mountains while those at right are among the clouds.

Key 227. A jointed, massive, bed rock formation outcrops on the coast. The scale is best indicated by the presence of men on the summit.

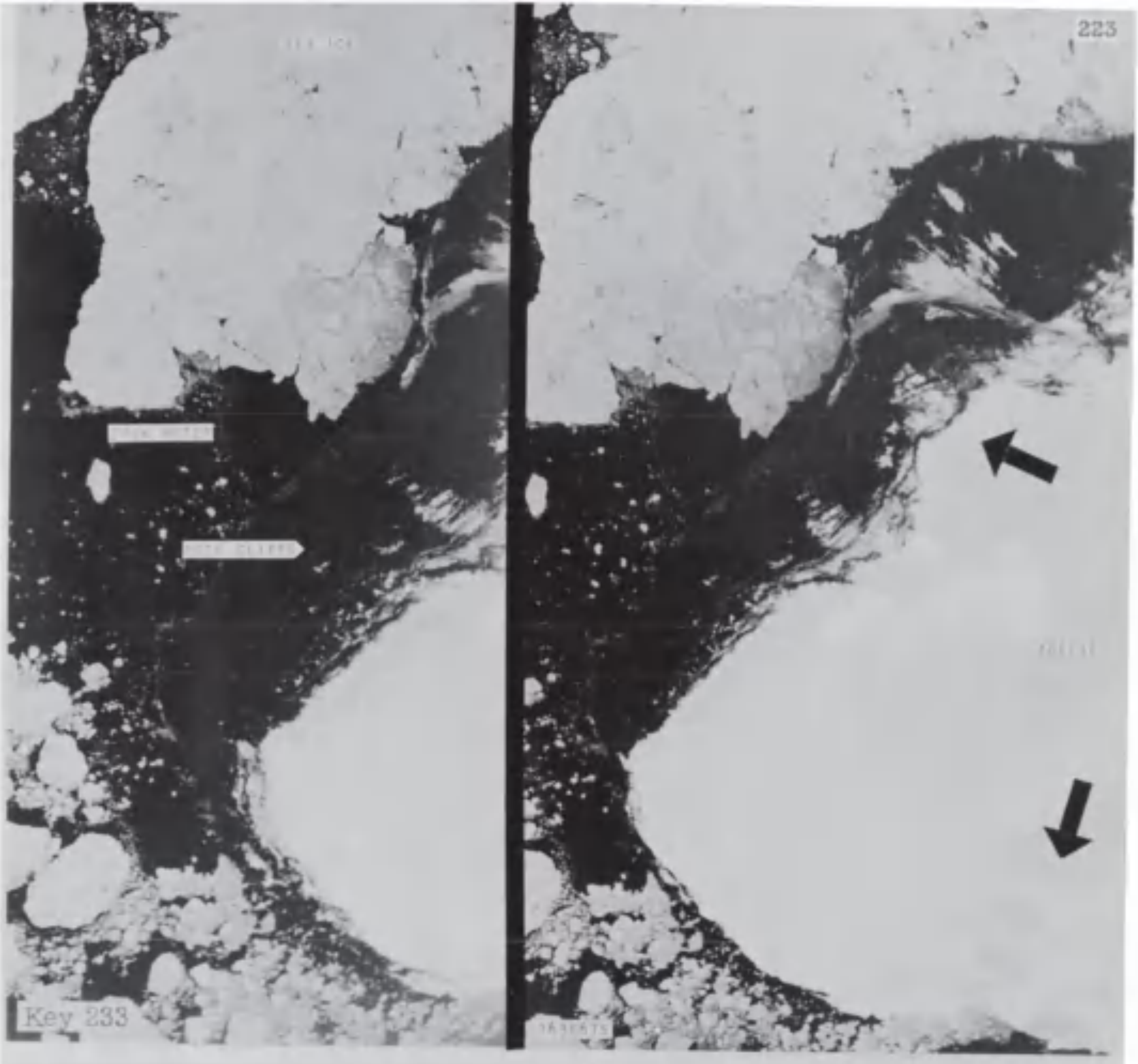
Key 228. Ice-free mountains which form a segment of the Antarctic coastline. Large and small outliers form islands.

Ice-free areas in the Antarctic certainly account for less than one per cent of the known terrain. The presence of land beneath the ice, however, is evident quite frequently. Mountains and coastlines are the chief places where ice-free land occurs and where the presence of land beneath the ice may be most easily inferred from its surface character.

Keys 229 and 230. Parallel and transverse views of ice-covered mountain ranges with protruding peaks and ridges. Low lying, level, darker-toned areas in the backgrounds are clouds, not sea ice, a fact readily determined by stereo examination of such prints.

Key 231. Although the precise shoreline cannot be distinguished, the presence of land with relatively rugged relief under the crevassed ice surfaces is unmistakable.

Key 232. Antarctic coastal cliffs are ice-free when they are sufficiently vertical to avalanche their ice-cover to the sea below (middleground). If the cliffs are less steep, the ice will cascade downslope (foreground). If there is little or no ice movement, the cliffs may assume a drifted-over appearance (background).

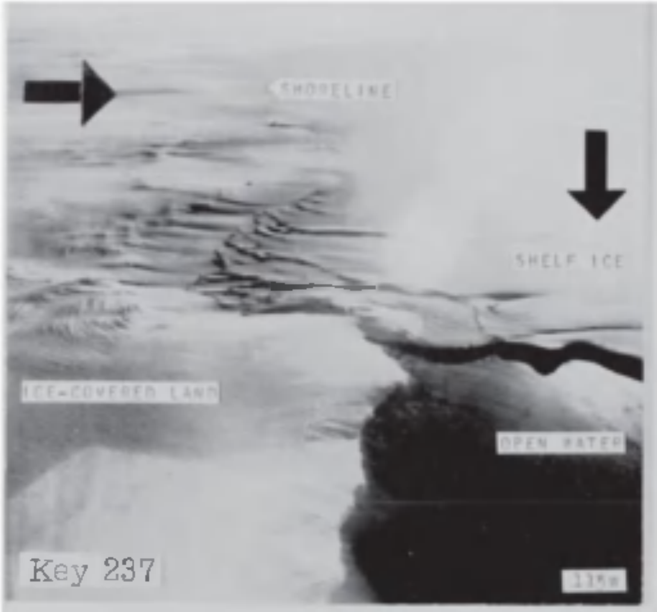


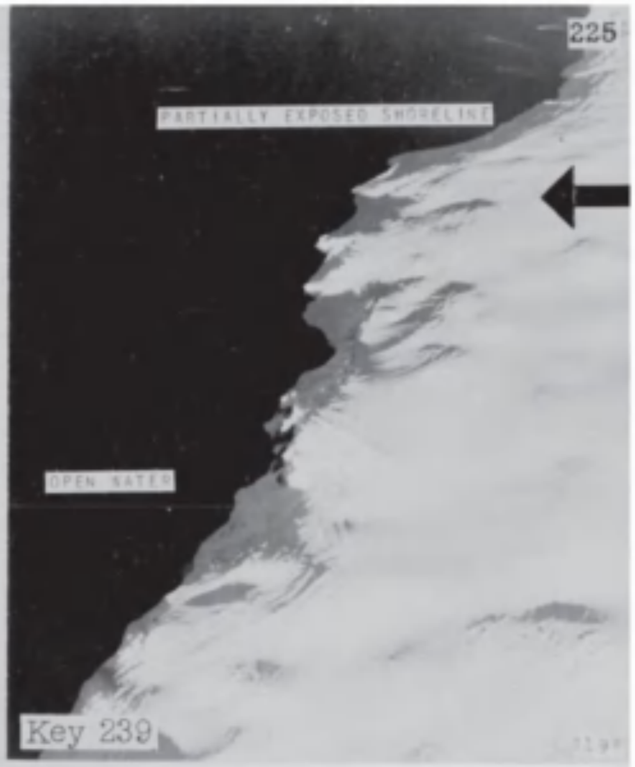
Key 233. This rock cliff coastline is too steep for lodgment of ice without support at its base. Note similarity in photo tones of the dark rock and open water, as well as the differences in texture and pattern.

Key 234. This shoreline was once completely covered with ice but glacial recession has uncovered the cliffs, though the ice still reaches the sea over some of the less steep portions of the coast.

Key 235. A mile-high cliffed mountain coastline with avalanche ice-foot glaciers. The icebreaker (foreground) is 269 feet long.

Key 236. Heavy icecap on a rock cliff coast.



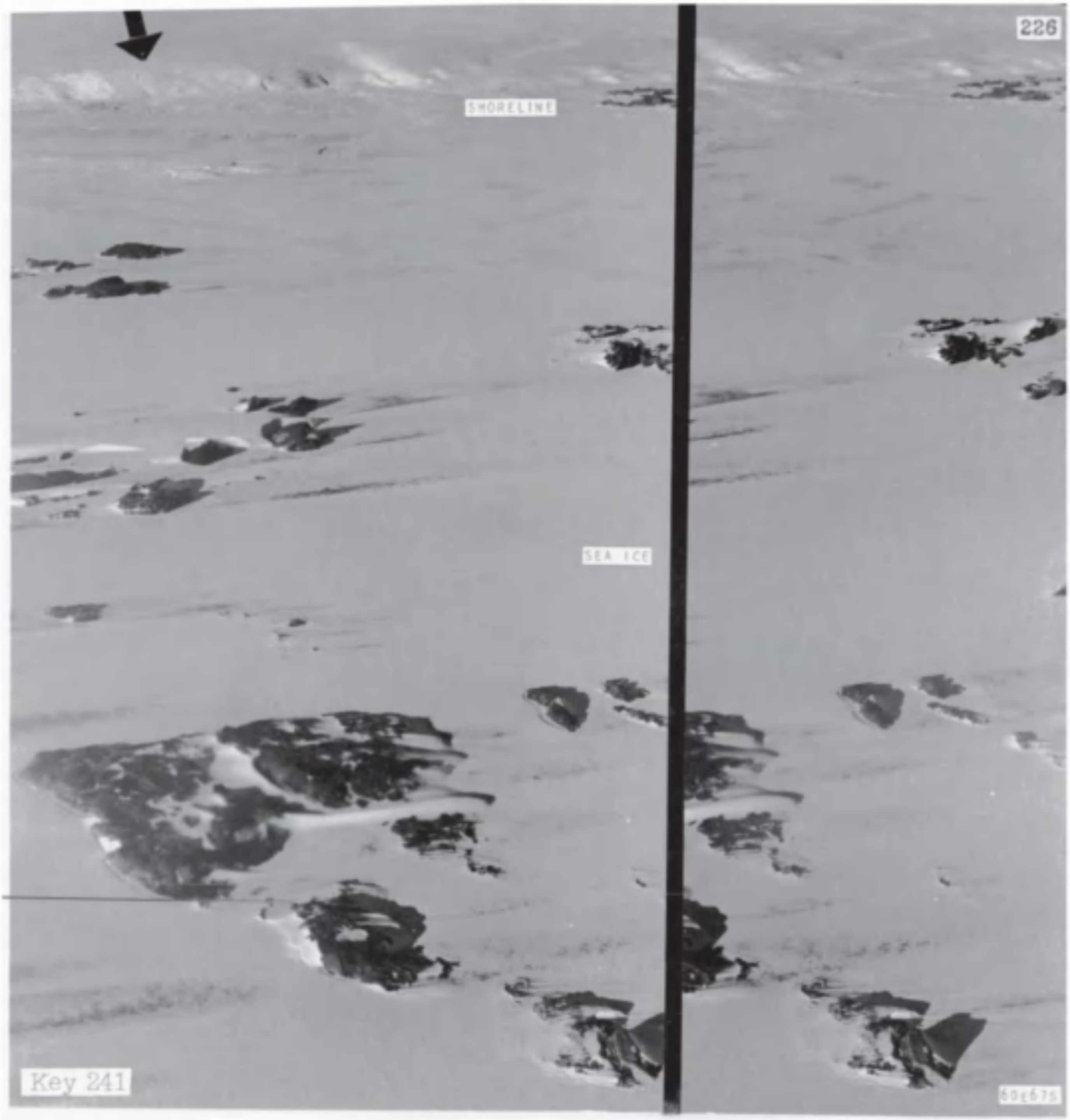


Key 237. The presence of an ice-covered coastline (left) is clearly evident from the character of the ice topography. A triple junction occurs where the ice-covered land (left) meets the shelf ice (top right) and the open sea (bottom right). Light-toned, polygonal shapes are flare spots from the sun's reflection in the elements of the lens.

Key 238. The precise shoreline is concealed by the floating edge of the glacier ice (center). The existence of land under the ice is, nevertheless, a certainty (left). Icebergs, sea ice and open water are also present (right). Volcanic Mount Siple on the horizon rises two miles above the ocean.

Key 239. Contrast the appearance of the coastline concealed by glacier ice afloat in Key 238 with the situation here where glacier ice extends to, but not beyond, the coastline. Portions of the rock coast are visible through openings in the ice.

Key 240. This coastline is revealed by a recessional moraine and sediment laden meltwater streams. Numerous bed rock islands with adhering fast ice flank the coast. Similar groups of offshore islands completely covered by thick ice may easily be mistaken for ice-covered portions of the continent.



Key 241. Numerous, glaciated, ice-free rocks, skerries and islands occur offshore the Antarctic continent, reminders of an even greater ice age in Pleistocene time. Unlike their northern counterparts, many of these islands are situated in relatively deep water, thus allowing easy access to large-draft vessels in years when the sea ice conditions permit. Uncharted, submerged peaks remain a danger, however. These islands are frequently used by the birds and seals for their rookeries. The coast, covered by the continental glacier (background), and the end of a glacier tongue (near top left) are visible. A typical drift pattern has formed about the islands (foreground). The sudden ending of some of these drifts is caused by the periodic dissipation of the sea ice. Note how the long, dark shadows exaggerate the size of the islands.

Key 242. Nunataks in glacier channels normally cause medial moraines to appear on their downglacier sides. Here, however, the channel glacier is afloat, the nunataks are really islands and the erosional rock debris are deposited on the ocean floor. Since lateral pressure which occurs in land-supported ice is absent in ice tongues, the islands are able to split the floating glacier, forming moats with scalloped glacier-ice borders and covered with sea ice. The ice disturbance in the right foreground is caused by another island out of view near top right. Similar disturbances in shelf ice and glacier ice afloat which seem to occur without any apparent reason are often caused by insular obstructions which do not project themselves above the ice surface. Note the similarity in photo tones but the differences in texture and pattern of the clouds in comparison with the ice.

Keys 243 and 244. While smaller islands are frequently ice-free (below), many of the larger ones are so completely ice-covered that they may never be seen by modern man (above). The arrows are aligned in the direction of ice movement and point to the barrier edge of an hourglass-shaped island completely covered by a flat dome of island ice which here rises to an elevation of approximately 1,000 feet. This is the climax stage of island glaciation.

ICE-BLINK and WATER-SKY

Keys 245 and 246. A white or yellowish-white glare just above the horizon is often the first sign that one is approaching areas of ice-covered land or water. This phenomenon, known as ice-blink, is caused by the reflection of light from the ice surface to the underside of extensive cloud layers or a hazy sky. Snow-blink is brighter than ice-blink.

Key 247. Conversely, when in the ice, the first sign that one is approaching open water may be a dark streak above the horizon. This is water-sky, the antithesis of ice-blink. It is caused by the absence of reflected light on the underside of a cloudy or hazy sky.

Land-sky, also caused by a lack of reflected light to the overcast or hazy sky, is not as dark as water-sky since open water absorbs more light. Land-sky is relatively rare in the Antarctic because of the lack of exposed land. Sometimes the line of demarkation between water-sky and ice-blink is sufficiently sharp to provide the navigator with a sky chart of the ice edge.


Key 248


Key 249


Key 250


Key 251

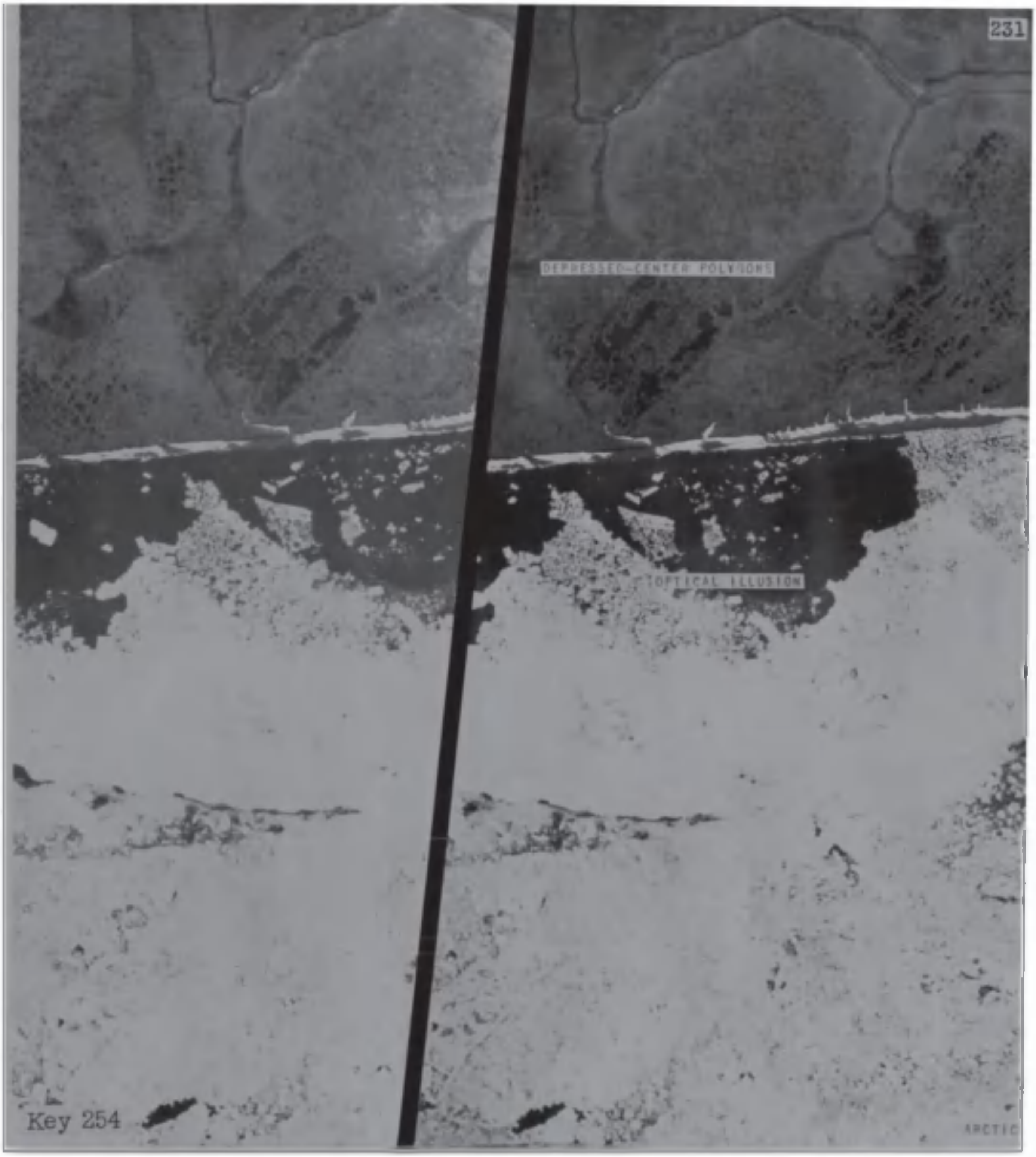

Key 252


Key 253

WHITE DAY

The white day is an Antarctic phenomenon caused by the occurrence of a completely overcast sky over an area that is completely ice-covered. Much sunlight is diffused through the overcast and reaches the ice surface where most of it is reflected back to the underside of the overcast. Many of these rays are in turn reflected earthward from the lower layers of the clouds. This process may continue until the diffused sunlight lighting any individual iceform may exceed the amount present on a clear sunlit day. This large amount of diffused sunlight equally lights all sides of individual iceforms, prohibiting the formation of any shadows. The omnipresent whiteness causes the ice and sky to look alike and the horizon to disappear. Such weather is one of the greatest flying hazards in Antarctica. Flying in it is somewhat like flying in a thick, dense, white, never-ending cloud. No surface feature is visible. The pedestrian even stumbles over the sastrugi.

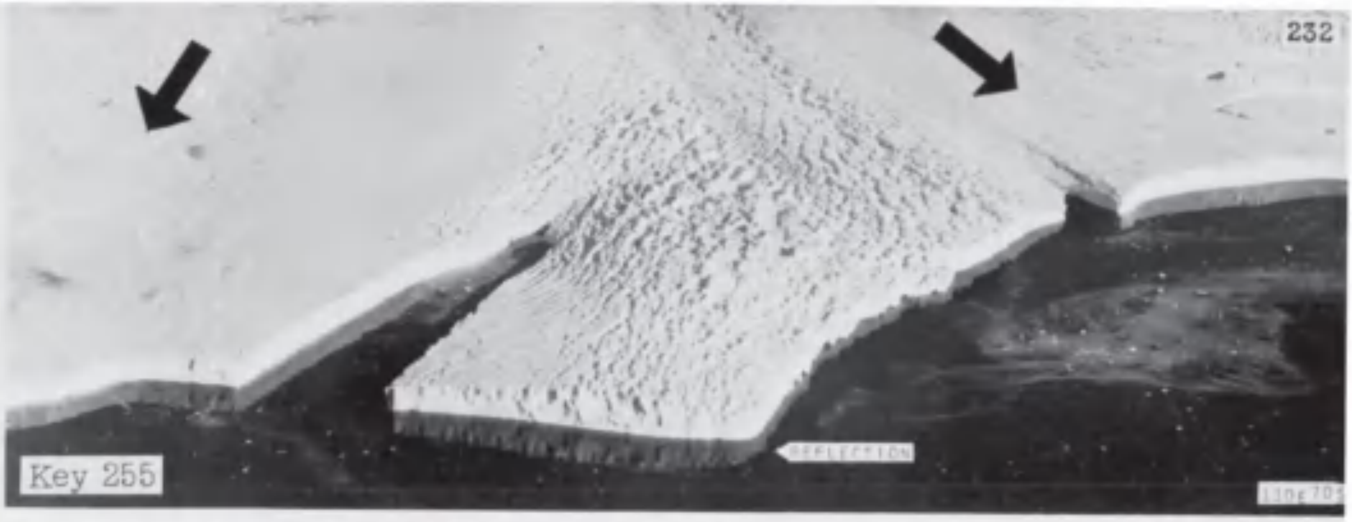
Keys 248 through 253. These illustrations represent six combinations of exposure and processing used in an attempt to record the horizon on a white day. There are five objects in each of the pictures: a man, two ten-foot poles, the ice and the sky, but no matter how the photographs are exposed or processed, both masts and man appear as if suspended in air and no horizon is visible.

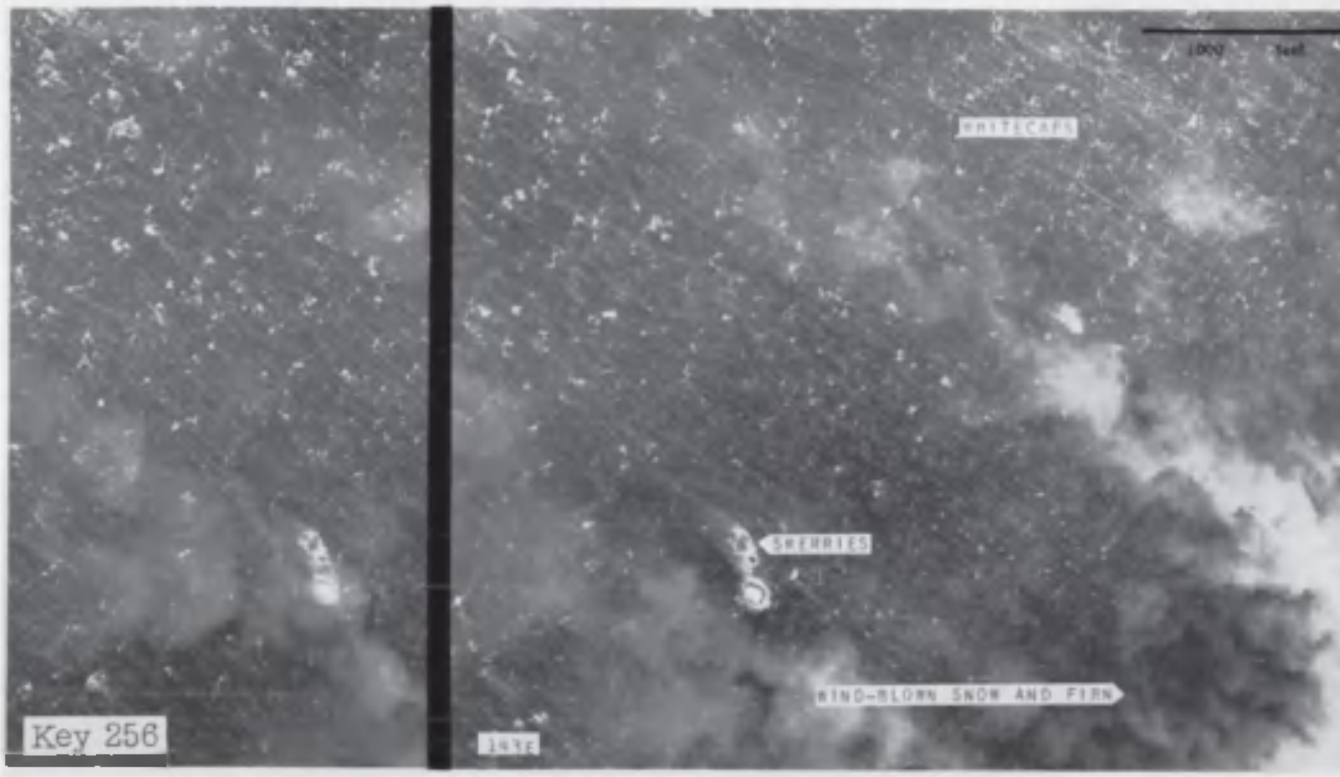


OPTICAL ILLUSION

Key 254. Differential rates of ice movement on clear, smooth, dark-toned water may create the optical illusion of ice floating at various levels. Although there are several apparent slopes in the sea ice, individual ice cakes do not seem to be tilted. While in this instance the photographs were taken in the Arctic, the phenomenon also occurs in Antarctica (Key 233).

Compare the polygons shown here with those in Antarctica (Keys 215-218). These particular polygons are more variable in diameter (30 to 160 feet within the same general area), rectangular rather than pentagonal or hexagonal and covered by vegetation. Note their influence on drainage.





CALMS and GALES

Key 255. The open water of the Antarctic seas within the pack ice is frequently calm and without waves or swell. Here the calm results in a mirrorlike surface permitting the reflection of a cliff on a floating ice tongue. Such reflections should not be confused with photo images of submarine portions of the ice cliffs, since the camera is able to penetrate the surface layers of the calm Antarctic waters in certain instances.

Key 256. Open water within the pack ice becomes quite rough when gales blow from the continent. The little white specks here are white-caps which are not subject to stereo fusion with standard aerial photography. The "clouds" are actually streamers of snow and loose firn blowing off the Antarctic coast (bottom right). Wind, as an erosive force, plays an important part in the transport and modification of snow, firn and even ice. Many typical Antarctic blizzards result wholly from wind without any precipitation being involved.

GALES

Keys 257 and 258. The amount of loose firn and snow carried to the open sea or deposited on sea ice during a typical year in Antarctica must be tremendous. It would be difficult to estimate the number of cubic miles of potential glacier ice dissipated in this manner. From such blizzards fast ice in favored localities may be thickened to produce floebergs or perhaps even shelf ice.

LENS REFLECTIONS

Keys 259 and 260. In the Antarctic, it is frequently necessary to take photographs directly into the low sun. Since ice topography is revealed by shadows on the white ice surface (which are not visible to one facing away from the sun), this practice has certain merits not inherent in ordinary landform photography. If the sun's rays strike the lens elements, they cause multiple reflections (Key 259). If the sun is photographed, it will show as a bright spot accompanied by one or more circles, hexagons and linear patterns (Key 260) which make interpretation of minor relief features, like sastrugi, quite difficult.

CLOUDS and CLOUD SHADOWS

Clouds bar photo analysis in several ways. They may partially or wholly obscure the earth's surface. They may form high overcasts leading to white day conditions, which makes ice photography useless and photo flying dangerous. Finally, cloud shadows may prevent adequate photo interpretation.

Key 261. Ice-covered mountains protrude above white clouds which are sometimes difficult to distinguish from snow and ice.

Key 262. This stereogram shows a ridge of the same mountains with clouds below on one side (left) and a summit ice field on the other (right). Note the similarity in appearance

Keys 263 and 264. Here are vertical and oblique views of clouds and their shadow effects on the ice surface.

Key 265. Belts of crevasses (shown here) and meltwater (Key 182) sometimes appear similar to cloud shadows from a distance.

CLOUDS and CLOUD SHADOWS

Banks of clouds may form over the ocean, over the continental ice, about the mountain summits or be omnipresent, according to the local atmospheric conditions at a given time. Clouds are thought to form less often in the continental interior, away from the marine influence.

Key 266. A bank of clouds over the land surface may act as an aid to the photo interpreter by providing him with a clue to the steepness of the ascent of the ice surface. This is evaluated by measuring the varying distances between the cloud and its shadow on the ice surface. Note calving icebergs and lens reflection.

Key 267. Stereoscopic examination of this illustration indicates that the cloud formations (middle and background) occur only over ice-covered terrain and that the sea-ice areas (foreground, left, and between middle and backgrounds) are cloud-free. The direction and slow progression of the clouds is evident from the way they pile up to the windward of the peaks.

Key 268

Key 269

Key 270

Key 271

FLORA and FAUNA

Plant life in Antarctica is conspicuous by its scarcity. Rock crevices and tarns may swarm with microscopic animals and plants. Where the sea is quite shallow, lush growths of marine vegetation may occur. Hundreds of species of algae, lichens and mosses are known. Bacteria occur in bird and seal droppings. But except on the northward extending Palmer Peninsula, no grasses or flowering plants are to be found. Nowhere is there vegetation of sufficient density and extent to be viewed by the aerial camera, although tarns are sometimes colored by algae. Plankton, the basic marine flora and fauna, consists of myriads of tiny plants and animals. Among these the diatoms are especially numerous, often staining the sea ice yellow. These low forms are fed upon by krill, the shrimps upon which the higher types of marine life and avafauna depend for food.

The emperor and Adelie penguins breed along the shores of Antarctica. There are six species of sub-Antarctic penguins. Some 36 species of flying birds nest in the Antarctic or sub-Antarctic, including albatrosses, gulls, petrels, shags, sheathbills, skuas and terns.

Keys 268-271. Various aspects of penguin life. Emperor penguins (268) may weigh 50--90 pounds and stand over three feet high. Adelie penguins weigh about 14 pounds (269-271). These illustrations show penguins on the ice, in the pack, swimming and in the rookery.

ADELIE ROOKERIES are situated on rook outcrops on islands and along the coast of the continent. After long periods of use, a sort of "soil" develops in the rookeries composed of some mantle rock, much guano, penguin, chick and egg remains, bacteria, mites and other forms of microscopic life. **Emperor** penguins establish their rookeries on sheltered portions of the sea-ice edge and breed during the long, cold winter night. The remains of their rookeries are carried out to sea when the fast ice breaks up.

Key 272. Adelies nest almost everywhere. Some pebble nests are in the meltwater at lower left.

Key 273. Generally all penguins in a rookery, except those engaged in courting, nest-building or fighting, face the same way. Note sentinels.

Key 274. Massed penguins or penguin "soil" may cause their rookeries to be visible as far as the eye can see. Massed penguins may make the rookeries appear dark (above); guano appears lighter than most rocks.

Key 275

Key 276

Key 278

Key 277

Key 279

Keys 275 and 276. The skua is the only Antarctic bird, other than the penguin, whose presence can sometimes be determined by aerial photo interpretation. This determination is by association, since skuas may be found nesting adjacent to all Adelie penguin rookeries during their common breeding season. The skua does not build a nest. Skuas are predatory and cannibalistic. They are also scavengers and one of the very few forms of Antarctic life that can recognize food out of water. Their occasional inland flights make them the world's southernmost-ranging animal.

Key 277. The emperor penguin and his tracks. Tracks made while walking are at right, tracks made while "tobogganing" are at left.

Keys 278 and 279. The killer whale, the most dangerous Antarctic animal, hunts in packs and is recognized by the high dorsal fin and buff patches on his head (278). He feeds on any of the higher forms of animal life and especially on penguins, seals and porpoises. Baleen whales, not shown here, are many times larger than killers but feed on tiny krill.

Key 280

Key 281

Key 282

Key 283

Key 284

Five kinds of seals inhabit Antarctica: Weddell, crabeater, elephant, the rare Ross and the dangerous sea leopard. Tiny herds of once numerous colonies of fur seals exist on some sub-Antarctic islands.

Key 280. A Weddell seal suns itself on the fast ice.

Key 281. Sea leopards eat penguins and other seals. Note jaws.

Key 282. A crabeater makes tracks on the pack ice.

Keys 283 and 284. Three herds of seals on the sea ice. Their presence is dependent upon the crack in the ice; their source of food is the ocean below.

Key 285

Key 286

Key 287

HUMAN OCCUPANCE

There are no permanent settlements or inhabitants in the Antarctic. The current force of the whaling fleet is, perhaps, 5,000 men, but the employment of the whalers is seasonal and their normal area of operations is close to the outer edge of the pack ice, tens or even hundreds of miles offshore. A mere handful of explorers, scientists and government representatives constitute an occasional population. These men seldom remain for longer than two years at a time. Antarctic transportation is provided by ships, boats, aircraft, motor vehicles, dog sleds, skis, snowshoes and boots.

SHIPS

All transportation to and from the continent is provided by ships. Whale-oil tankers and ships which do not enter the pack are frequently designed along traditional lines. Ships which navigate in the ice are generally of wooden construction which accomodates the ice pressures more readily. Modern icebreakers are of especially designed steel construction with rounded bottoms, heeling tanks, shallow forward draft, deep stern draft and without keels.

Keys 285 and 286. Oblique and vertical airphotos of wind-class icebreakers. Icebreakers may be identified by their exceptionally broad beams (length-beam ratic of about 4:1). Destroyers, by comparison, may be twice as long and only half as wide. Note the slatted helicopter flight deck and the seaplane, the Greenland cruiser, the whaleboats and the cranes for handling these vehicles. Ships of this type are too expensive for individual or commercial operation.

Key 287. A wooden ship of a type used by explorers.

Key 288

Key 289

Key 290

Key 291

Key 292

Key 293

BOATS

Keys 288 through 293. Small boats provide good transportation for areas near open water. The Greenland cruiser (288) was especially designed for polar use. The motor whaleboat (289) is useful in fair weather. The rubber raft (290, 291) is efficient for short distances, shallow-draft exploration, fording meltwater and pack-ice travel. The iceboat (292) is not generally useful for working purposes. Vessels of all sizes can be moored to the ice by burying and freezing-in a "dead man" with a toggle cable attached (293).

Key 294

Key 295

Key 296

Key 297

AIRCRAFT

The modern polar vehicles are aircraft which may be based on land, at sea or on the ice. Their great range permits some of them to cover thousands of miles in one day. Others are designed for maneuverability and may take off from almost any kind of a surface.

Keys 294 and 295. Such planes as these R4D transports and PBM flying boats can perform exploratory or photo flights from shore bases or seaplane tenders, respectively. When they are fully laden with fuel, camera equipment and survival gear, they may require a jet-assisted take-off (JATO) as shown here.

Keys 296 and 297. Helicopters are ideal for short-range field work and surveying. Along with cub planes they provide a medium for hand-held cameras. Note that helicopters with wheels (295) and floats (297) are illustrated here.

AIRCRAFT WRECKS and RESCUES

Keys 298 through 301. A crashed airplane. In this case weather conditions ("white day") caused a PBM to plow into the flat ice surface (298). The wreck was partially covered with drift during the two weeks of foul weather which ensued before it was located. Open water was but eight miles distant (300) but not directly visible to the survivors, pointing to the importance of knowing ice topography and water-sky.

Trails over the continental ice, shelf ice or sea ice are almost always plainly visible, regardless of the vehicle used. Key 301 shows a trail made by five walking survivors of the crash above and a sled. The individuals, their shadows, the sled and the trail are all clearly discernible. This mishap occurred on Operation Highjump in 1946-1947.


Key 302


Key 303


Key 304


Key 305


Key 306


Key 307

RUNWAYS

Runways are generally unnecessary for ski-equipped aircraft, which may land on level, uncrevassed glacier ice, shelf ice, frozen lakes or sea ice. The critical factors are the weight of the aircraft per square inch of ski and the initial landing shock. Skis may freeze to the ice from the film of meltwater produced by landing unless they are run up on a plywood, canvas or similar surface placed on the airfield for this use.

Keys 302 through 305. An experimental runway on shelf ice. It is shown during its construction and after a period of one year.

Key 306. Float-equipped helicopters may land almost anywhere. Canvas tarps are sometimes employed as a temporary measure to designate helicopter landing fields or to guide pilot to a safe landing area.

Key 307. Food cases are usually stacked outside building walls and permitted to be drifted-over, thus providing additional protection from the weather. Freshly-baked bread stored in this "deep freeze" will taste as fresh the day it is unfrozen as the day it was baked.

Key 308

Key 309

Key 310

Key 311

Key 312

Key 313

Key 314

Key 315

SURFACE VEHICLES

Keys 308 through 312. Wheeled vehicles, even jeeps with chains (308), are useless in snow and loose firn but may operate on areas with ice surfaces. The "cat" tractor with tracks widened for use on firn surfaces is a useful workhorse. Here it transports personnel (310) and fuel (311) and supplies from the ship (312) through areas of pressure ice. (The pressure ridge has been cut and paved with pierced planks.)

Keys 313, 314 and 315. Amphibious tractors have a useful range of several hundred miles over many kinds of glacial surfaces.

Keys 316 and 317. The "weasel" is a sort of tracked and amphibious jeep. It is useful for carrying and towing personnel, food and equipment both in camp and in the field.

Key 318. Dog sled, time-honored method of polar travel, is still the mainstay of long hauls over unexplored ice surfaces.

Keys 319 and 320. Skis are faster and generally more useful than snowshoes in Antarctica. The soft snow surfaces of the Arctic and sub-Arctic which require snowshoes are less common here.

SETTLEMENTS

Settlements in Antarctica may be classed as semipermanent, seasonal or temporary. There are no permanent settlements on the continent, although a few government bases, mostly on the outlying islands, are currently maintained on the rotation plan, with complete changes in personnel every two years. The semipermanent shelters, built to last for several years, are usually prefabricated. Facilities for a single summer season generally consist of prefabricated huts, floored tents and similar shelters. Temporary shelters, for use in field travel, are limited to small tents.

Keys 321, 322 and 323. Three views of Sir Ernest Shackleton's camp which had stoutly resisted 40 years of Antarctic blizzards when these photos were made. From a distance the prefabricated building blends into the terrain (arrows). The building was occupied for five years by members of two Shackleton expeditions. It consists of double walls, floors and roofs. Even though the roof is reinforced and wired down, one of the outer panels is missing from the opposite side. Packing cases of food and supplies, piled about the house for additional protection, have been toppled by the strong winds. Similar cases once formed a stable for Manchurian ponies on the lee side of the structure. Dark rock and the lack of snow and ice surfaces, except for hillside patches and the frozen pond (foreground in 322), have caused sufficient radiation to supply the heat and moisture necessary to spoil some of the food stores and rust some of the iron equipment.

Keys 324, 325 and 326. Three views of a temporary camp on ice taken from successively lower altitudes. Although most of the camp equipment stands in sharp contrast to the glaring white ice, the camp is so small that it might easily be overlooked from higher altitudes. The white and dark-green tents emphasize the importance in tonal contrast for locating, recognizing and analyzing objects.

Keys 327 and 328. All semipermanent settlements in Antarctica are located near the sea. Above, helicopters visit the base of Scott's last expedition (1910-1912) which consists of a main working-and-dwelling unit with several attached sheds. Below, a pony stable forms a long lean-to shed against the dwelling. Note cross on horizon.

Keys 329 and 330. Little America IV, a one-season settlement on shelf ice. Some of the chief airphoto recognition characteristics of new camps are the relatively dark appearing structures, extensive and unchanneled track activity and the lack of accumulated drift. Three ships may be seen in the Bay of Whales (background) from which tracks lead first to Little America IV (1946-1947) and then to a new building atop the drifted-over semipermanent settlement at Little America III (1939-1941). The vents of the latter and a new tunnel leading to it are visible at the right of the new building. Tracks within the new camp area have not yet conformed to a distinct pattern as is the case in older camps.

Keys 331 and 332. Photos of Little America IV, taken during its construction and one year later, show nearly all of the abandoned tents to be blown down or caved in by the weight of the drift.

Key 333

Key 334

Key 335

Key 336

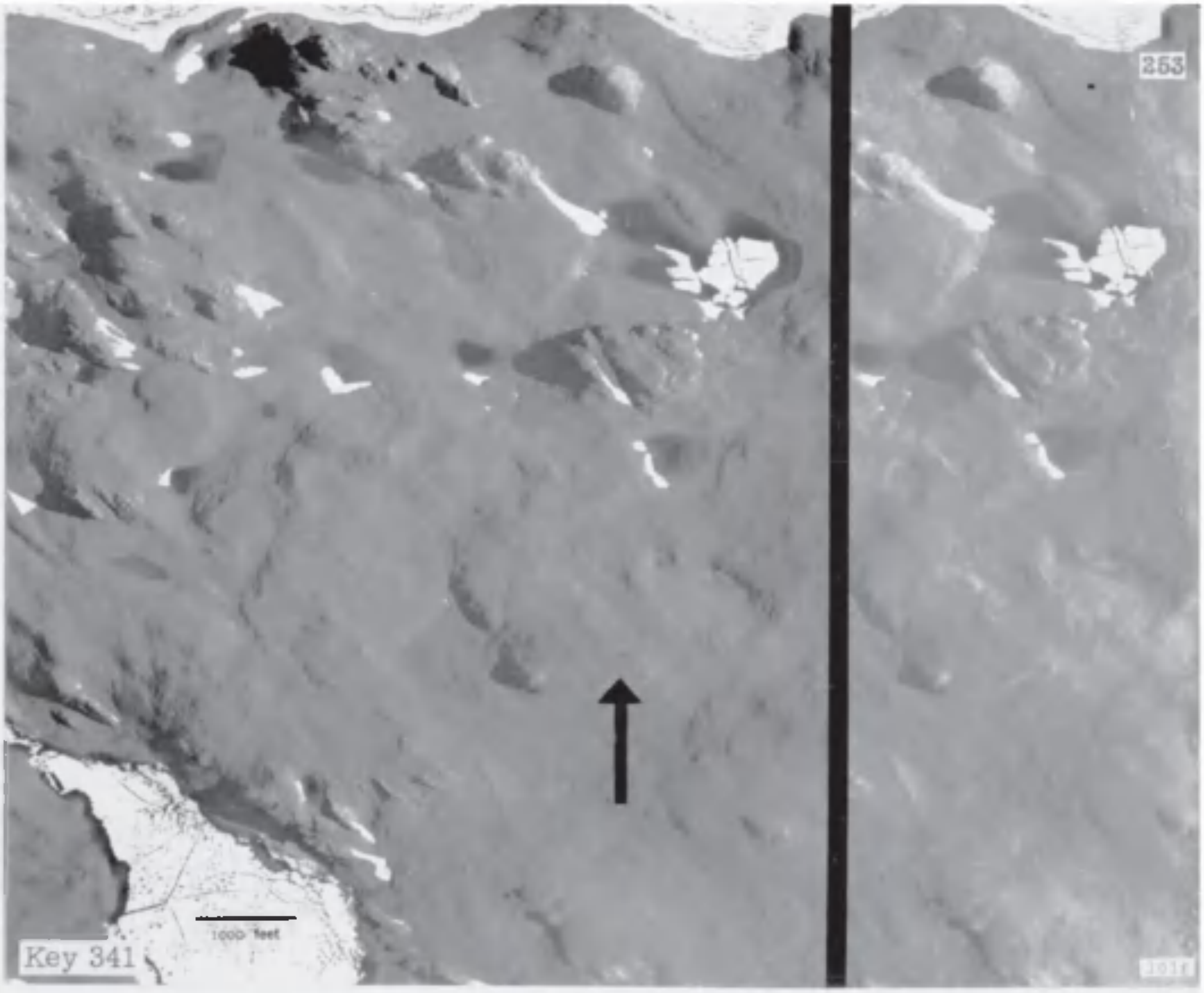
Keys 333 and 334. Masts of Little Americas I and II (333) and the vents and masts of Little America III (334) are the only visible remnants of semipermanent settlements built 19, 14 and eight years before these photos were made.

Keys 335 and 336. Tent poles and stores are still visible at Little America IV after one year. Note shape and height of marker on stores.

Keys 337 and 338. A semipermanent camp is shown immediately after its construction (337) and one year later (338). Although the double Quonset hut has drifted to its ridge, the level of the surrounding ice terrain has risen only three feet.

Key 339. "Weasel" tracks reveal the drift accumulation of a few weeks.

Key 340. Semipermanent British (left) and American (right) camps on Stonington Island. Although the American camp was eight years old when this photo was taken, no permanent drifts have developed here.



Key 341. Temporary camps on recently-deposited ground moraine are difficult to identify on aerial photographs because the blending of all sizes, shapes and colors of rocks forms a natural camouflage. The camp (arrow) consists of three green and two white tents and two helicopters with rotating blades flashing in the sunlight. The tidal crack (top) permits distinction between ice-covered ocean inlets and ice-covered lakes (below).

Key 342. Same camp, two white tents, one helicopter.

Key 343. The "smooth" appearing helicopter landing area in Key 341 looks like this from the surface.

CHAPTER VI

THE INGRID CHRISTENSEN COAST

AN APPLICATION OF RECONNAISSANCE PHOTOGEOGRAPHY

This chapter presents original geographical data obtained by applying the photogeographical method to the reconnaissance aerial photography of a complex Antarctic coastal area never visited by geographers. These data have been obtained through the use of analogous geographic photo interpretation keys, such as those presented in the previous chapter, and the author's field experience acquired in similar regions in Antarctica.

Present state of knowledge of the area. A number of short notes in newspapers and polar periodicals mention the passage of whaling vessels or expedition ships off the Ingrid Christensen Coast (Maps 9, 10, 11). Aside from these, not more than about a dozen brief references to the geography of this area can be found in the literature. In these, the coast is described variously as extending approximately from 73°E. to to 81°E,,from about 74°E. to 81°E. and from 76°E. to 79°E.[1] All investigators agree that the coast generally trends southwesterly from the West Shelf Ice to Sandefjord Bay (Map 3). The literature also describes this coast as being for the most part ice-free and backed by mountains, allegations which are shown, later in this chapter, to be erroneous.

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[1]These descriptions occur respectively in: U.S.H.O. No. 138, Sailing directions for Antarctica, 1943, p. 235; U.S. Board on Geographical Names, Special Publication No. 86, 1947, p. 182; and British Admiralty, The Antarctic Pilot, 1948, p. 306.

The principal areas of exposed land along this coast have been sighted and named, although there is a considerable divergence of opinion among the authorities concerning the locations, the extent and even the names of certain of these areas (Appendix II).

More precisely, the coast (Maps 9, 10, 11) is described in current literature as ice-cliffed, with occasional rock outcrops, trending southwest from the West Shelf Ice for about 60 miles (Map 9), after which the coast is ice-free for 40 miles and is backed by the Vestfold Mountains (Map 10). This ice-free coast terminates at the Sörsdal Glacier (Map 10), which is approximately nine miles wide. Beyond this, the ice-free coast is said to reappear, backed by the Ranvik Mountains (Map 3). For the next ten miles, the coast is described as ice-covered, after which there is another ice-free stretch backed by the Larsemann Mountains (Map 11). The coast then remains ice-covered for its last 40 miles, as far as Mount Caroline Mikkelsen at the head of Sandefjord Bay (Map 11). Three groups of islands, the Rauer, the Svenner and the Söstrene, are mentioned as being located offshore respectively from the Sörsdal Glacier, the ice-covered coast between the Ranvik Mountains and the Larsemann Mountains, and the Larsemann Mountains. All mountains and islands are noted as being ice-free, but the presence of ice at the base of the Larsemanns is mentioned. The area is said to be accessible to ships for a brief period each summer (Map 4), although only three ships are known to have visited the general area, and although Sir Douglas Mawson (1930, 1932) failed to gain access in the 1929-1930 and the 1930-1931 seasons.

According to notes in the <u>Geographical Journal</u> (1939, 94:207), the coast was first sighted from a very great distance by Mawson while he was participating in an exploratory flight from his ship on 9 February, 1931, and named by him Princess Elizabeth Land. The actual discovery of the coast is generally credited to a whaling captain, Klarius Mikkelsen, who made a brief landing there and named it Ingrid Christensen Land after the wife of his employer who, herself, flew over the area two years later in 1937.

The negligible amount of exploration performed in the area has occurred largely in the form of by-products of other missions, such as whaling. During the 1936-1937 whaling season, Lars Christensen and his wife, Ingrid, together with the pilot and aircraft manufacturer, Viggo Widerøe, and the aerial photographer, Nils Romnaes, accompanied Captain Mikkelsen on the Thorshavn, a tanker in Christensen's Antarctic whaling fleet. Widerøe and Romnaes made airphoto reconnaissance flights over the Ingrid Christensen Coast and some 2,000 kilometers of adjacent coasts. The only attempted landing in the area was foiled by a sudden change in the weather.

The Wyatt Earp, carrying the fourth Antarctic expedition of Lincoln Ellsworth (with Sir Hubert Wilkins aboard), was off the Ingrid Christensen Coast from the second to the fifteenth of January 1939, searching for a suitable stretch of fast sea ice to serve as an airstrip for a ski-plane flight toward the interior of the continent. The ship was based near the Rauer Islands (Map 10) during all but two days of this time. Seven of the many islands off the Ingrid Christensen Coast were visited (Ellsworth, 1939b, p. 138; Bayliss and Crumpston, 1939). On 11 January, Wilkins (1939, MS diary, 3 Jan.) went ashore for a flag-raising ceremony on what he considered to be a part of the mainland in the Vestfold area (Map 10).

In 1946, Hansen's Atlas over dele av det Antarktiske kystland was published in Oslo. These maps of parts of the Antarctic coastal area were based on the oblique aerial photos made by Widerøe and Romnaes on the Lars Christensen expedition in 1937. The coverage of the Ingrid Christensen Coast is completely without ground control and is placed on the terrestrial graticule by association with the nautical observations from the Thorshavn offshore. This atlas is an anomaly in that it presents some of the best Antarctic maps for some of the least explored coastal regions. This, in itself, must stand as a tribute to the value of aerial photography in geographic reconnaissance.

In 1947, the U.S.S. Currituck, seaplane tender and flagship of Task Group 68.2, lay outside the pack ice more than 150 miles off the Ingrid Christensen Coast. From there, two trimetrogon photo reconnaissance flights were made over the Ingrid Christensen and adjacent coasts at an altitude of 10,000 feet, producing vertical photography of parts of the area at a scale of 1/20,000 and obliques of the remainder at increasingly smaller scales. A portion of the interior was obscured by clouds. As far as can be determined, no use has been made of this photography except in the study at hand.

In spite of the visits mentioned, reliable and specific geographic information concerning the area is lacking. This is due primarily to the fact that no explorer or geographer has ever focused his interest on this area. Mawson was never able to approach close enough to the area to examine it. Mikkelsen and Christensen were mostly concerned with whaling and with photographing the entire "Norwegian Coast" from the air. Ellsworth (1939a) and Wilkins (1939, MS diary) were preoccupied with the flight to the American Highland, and later with the care of a ship's officer who had to be rushed back to civilization for medical aid for a knee crushed by floating ice.[2] Finally, U.S.N. Task Force 68 was occupied with the reconnaissance aerial photography of the entire Antarctic littoral and certain portions of the interior.

With first interests always elsewhere, it is but small wonder that so little is known of the precise geography of the Ingrid Christensen Coast. Appendix II shows how little agreement there is among the authorities as to the location, extent and general appearance of the area. The rock outcrops of the eastern end of the Vestfold area (Map 10) have been recorded as sedimentary by the Mikkelsen shore party (Polar Record, 1935, 10:128) and as igneous by Ellsworth (1939a, p. 3; 1939b) and Wilkins (1939, MS diary, 11 Jan.). Although Mikkelsen and Wilkins both collected rock specimens, no published accounts of the analysis of either of these collections are known to exist. Moreover, personal communications (1951) from H. U. Sverdrup, Director of the Norsk Polarinstitutt, and Sir Hubert Wilkins indicate that a petrologic examination of these collections by competent specialists has probably never been performed.

Mikkelsen's shore party also reported that no vegetation was seen (Polar Record, 1935, 10:128) whereas Wilkins (1951, personal communication) states that not only were lichens and mosses present but that some grasses resembling those of Grahamland (Palmer Peninsula) existed in protected areas.

Furthermore, Mikkelsen's group described the coastal area as one of ice-free rock, commonly capped by a deposit of penguin guano approximately

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[2]Five years later, the Polar Record (1944, p. 114) noted that: "Attempts to obtain authoritative information about the discoveries of this expedition have been unsuccessful". Aside from newspaper articles, a very brief popular account in the National Geographic Magazine (Ellsworth, 1939b) seems to be the only published record.

one meter thick, forming the floor of penguin rookeries which extended as far as the eye could see. (Polar Record, 1935, 10:128-129). Mikkelsen also commented on the presence of large numbers of seals and penguins. In contrast, Ellsworth (1939a, p. 3) stated that after two days in the area (more time than Mikkelsen had spent there) he had observed only two killer whales, a few small rookeries of Adelie penguins, no emperor penguins and no seals.

Incongruous as these widely divergent reports may be, they constitute the only known first-hand accounts of the Ingrid Christensen Coast. While it is to be expected that a coastline nearly 400 miles in length will vary considerably in character from place to place, Mikkelsen's and Wilkin's accounts indicate that their landings on the Antarctic mainland must have been within a very few miles of each other.

In summary, then, it may be said that our knowledge of the geography of the Ingrid Christensen Coast is quite meager. The reports on the geology, flora and fauna of the area by the two parties that have landed in the area differ considerably. There is no evidence that the rock collections have been critically examined. The coastal descriptions in the various sailing directions and pilots are not in agreement. Moreover, there is not a single, precise geographic position recorded within the area. More encouraging are Hansen's presumably fairly reliable maps (Maps 9, 10, 11) which, however, are yet to be tied to the terrestrial grid, and the availability of the Norwegian and American airphotos to scientists who may be sufficiently interested in the area to perform airphoto analyses.

Purpose of this study. It is the purpose of this chapter to demonstrate that by virtue of sound professional training, by use of pertinent regional and analogous photo interpretation keys, and by application of field experience acquired in similar regions, it is quite feasible to derive considerable original and significant knowledge concerning an area which one has never visited, or even an area which has never been examined by professional scientists of any description. The Ingrid Christensen Coast of Antarctica has been chosen as just such an area.

It is not suggested that the photogeographic method replace geographic field work in polar regions; but rather, that it be used as a tool for the rapid accomplishment of geographic reconnaissance and preliminary inventory that would otherwise be impractical to perform because of the lack of accessibility and the vastness of the area to be covered. It is suggested, however, that the employment of aerial photography for planning polar field activities and as a method for collection and synthesis of data while performing field work in polar areas will result in the acquisition of more complete and more accurate geographic data than would otherwise be the case.

It will be noted in the work which follows that not the least of the contributions of photogeography is the possibility of isolating in this manner problems which require intensive field analysis. It is generally agreed that in most Antarctic regions there are so many problems that they cannot be solved simultaneously. Therefore, reliable methods are required to determine where research efforts may be expended with the greatest expectation of worth-while returns. Reconnaissance photogeography is one such reliable method.

THE COASTAL AREAS

General description. The precise location of the southwestern extremity of the Ingrid Christensen Coast (Maps 12, 13, 14, 15) is unknown but it occupies nearly ten degrees of longitude along the northeast--southwest trending Antarctic coastline between 70°27'S., 71°26'E. and 67°57'S., 81°06'E.[3] Its airline length is not less than 270 statute miles, while the general conformation of the coast is at least 392 miles. The exact lengths of both the de facto[4] and the true shorelines are considerably larger, partly because of the closely spaced peninsulas and fiords in the ice-free areas.

Southwesterly from the West Shelf Ice (Map 12) along the general conformation of the de facto shoreline, the following coastal areas are met with and will be considered in turn: Prydz continental ice coastal area (93 miles, Maps 12, 13; Figs. 1-3, 8); Westfold Hills coastal area (32 miles, Map 13, Figs. 5-34); Sörsdal Glacier Tongue (11 miles, Map 13, Figs. 28-35a); Rauer insular coastal area (15 miles, Map 13, Figs. 39-45); Ranvik Ice Tongue coastal area (32 miles, Map 13, Figs. 44-50); Svenner insular coastal area (41 miles, Map 13, Figs. 36-38, 51-57); Larsemann insular coastal area (30 miles, Map 14, Figs. 38, 58-73); Publication Glacier Tongues (50 miles, estimated as average; in 1947, it was 75 miles, Map 14, Figs. 66-67, 72-90); Sandefjord insular coastal area (23 miles, Map 14, Figs. 87-95); and Baker Three coastal area (more than 65 miles, Map 15, Figs. 96-101).

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[3]Since the true position of this coast has yet to be determined by precise geodetic means, fractions of degrees are not considered significant in defining absolute location. They are used throughout this paper, however, to define relative locations within the coastal area concerned.

[4]The term "de facto shoreline" is suggested to indicate the line along which sea or sea ice abuts land or land ice, as opposed to the true shoreline which would exist if there were no ice present.

Unless otherwise noted, the coastal areas here described have been seen or could have been seen, but were not landed upon, by the following expeditions: (1) Mikkelsen (1935) from the sea, (2) Christensen (1937) from the sea and the air, (3) Ellsworth (1939) from the sea and the air, and (4) U.S. Navy Task Force 68 (1947) from the air. Airphotos were made of the coast by the Christensen Expedition and the U.S. Navy. No expedition remained within the 392-mile coastal area for more than part of one day, except that of Ellsworth, whose ship cruised off the coast for nearly two weeks while looking for a suitable area of sea ice upon which to launch a ski-plane and while waiting out poor flying weather.

Maps and Airphotos. Maps 9, 10 and 11 are sheets from Hansen's Atlas over dela av det Antarktiske Kystland, which have been photostated at a slightly reduced scale. Maps 12, 13 and 14 are the same maps overprinted with pertinent information resulting from this study. Maps 9, 10 and 11 and the appropriate portions of the 12 paragraphs which comprise the atlas text appear to form the nearest approach to literature of a scientific nature pertaining to the Ingrid Christensen Coast. Map 15 has been prepared especially to show an area in the Ingrid Christensen coastal region which has not been mapped previously.

The airphotos made by the U.S. Navy Task Force 68 in 1947 show the Norwegian maps to be adequate insofar as relative locations of insular groups, glaciers and coastlines are concerned. They do not appear to be as accurate with regard to elevations, which may be somewhat overestimated; however, heights are not nearly so exaggerated as those previously reported from nautical observations.[5] The most common errors in these maps include

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[5]Mount Caroline Mikkelsen (Fig. 95, lower left) was reported from nautical sources as being about 1,500 feet in elevation (U.S.H.O. 138, 1943, p. 235, 1,475 feet) (British Admiralty, 1948, p. 306, 1,500 feet). It is shown on Map 11 to be but half this height, or 762 feet.

the frequently incorrect delineation of individual islands within island groups, the inaccurate differentiation between islands and peninsulas and the similarly inaccurate differentiation between lakes and fiords. The most serious error is the complete omission of the Baker Three coastal area (Figs. 96-101). The inaccuracies undoubtedly arose in part from the obliquity of the photography and the presence of sea ice and snow drifts at the time of photography. Obliquity permits areas to remain in defilade behind rock hills and islands, which no amount of rectification will eliminate, while the sea ice and snow drifts tend to prevent accurate delineation and plotting of insular shorelines. A significant deficiency of the Norwegian maps is the lack of any glacial detail other than ice contours (formlines) and the names for two glaciers. Ice tongues, for example, are not indicated, nor differentiated from the glaciers in which they originate, even though these facts are clearly visible on the aerial photographs and are of significance to the geographer, glaciologist, explorer, whaler and mariner alike.

By and large, however, the eastern and central parts of the Ingrid Christensen Coast are better mapped for reconnaissance purposes than most of the explored or unexplored parts of the Antarctic coast, other than the relatively small areas around the bases of some of the former expeditions which were surveyed with geodetic control. Maps 12, 13, 14 and 15 should be referred to constantly when reading the following pages, for although nearly all of the coast has been illustrated, it is not feasible to reproduce here detailed, three-dimensional, airphoto coverage of the entire 392 miles of coast.

<u>The East and West Ingrid Christensen Coasts</u>. For effective analysis, the region has been divided into three sectors:

The eastern portion (Maps 12 and 13) of the coast is about 136 miles long, consisting of the Prydz continental ice coastal area, the Vestfold Hills and the Sörsdal Glacier Tongue. Within this area may be found all of the major morphological features which appear in the more extensive West Ingrid Christensen Coast. Specifically, these features include the coasts formed by (1) the continental glacier spilling into the sea, (2) the recession of the continental glacier exposing ice-free insular, pseudo-peninsular and peninsular areas as well as (3) the presence of fast-moving ice streams within the continental glacier which result in the projection of large, floating ice tongues. The hinterland for all these forms is basically the same and is described in the section relating to the East Ingrid Christensen Coast.

The West Ingrid Christensen Coast (Maps 13 and 14), about 191 miles in length, contains many interesting variants of these same morphological types, but is analyzed as an entity rather than by smaller units.

The Ingrid Christensen Coast extended. A "new" coast, extending southwest from the Ingrid Christensen Coast has been designated as the Baker Three coastal area (Map 15). It is revealed by the 1947 aerial photography. No mention of this coast has ever appeared in the literature. It is bound by land-formed ice for its entire length, which exceeds 65 miles.

The division of this study into coastal sectors permits a more detailed reconnaissance treatment of each morphological type as it is first met with on the East Ingrid Christensen Coast. The variants occurring in the two other sectors are then treated only insofar as they differ from their eastern counterparts, thus permitting a more complete analysis and a more lucid description while avoiding unnecessary duplication. Photo-geographical discoveries regarding the geographic delineation of the coastal areas and recommendations for the principal changes in place names made necessary by such changes, are presented for each of the sectors.

THE PRYDZ CONTINENTAL ICE COASTAL AREA

General description. As a physiographic unit, this area, which represents nearly a fourth of the Ingrid Christensen Coast, is simplicity itself. It consists of a 93-mile line of contact between the continental ice and the Indian Ocean extending from the West Shelf Ice (Norskbarrier) on Map 9 to the Vestfold Hills (Vestfold Fjella) on Map 10.[6] No significant glaciers, ice tongues or areas of shelf ice are present. Likewise, mountains, ice-free coastlines, surglacial moraines and soils are completely lacking.

Maps and airphotos. Two-thirds of Maps 9 and 12 and one-third of Maps 10 and 13 are devoted to the Prydz continental ice coastal area. The "featureless" coast is partially covered by American airphotos and more fully covered by the Airphoto reconnaissance of the Norwegians, although the exact print numbers of the latter are unknown (Map 6).

TABLE 1. PRYDZ CONTINENTAL ICE COAST: AIRPHOTO COVERAGE

Print Nos	Angle	Roll	Mission	Agent	Alt/T	F/L	Scale	Date
63-80/1	LAV&R	67	M26 AAW	Amer USNTF68	10000	6"	20000	1 Mar 47
1-35/1	LAV&R	66	M26 AAW	Amer USNTF68	9800	6"	19600	1 Mar 47
703-7??	Obl		D	Norw Widerøe	6550	8¼"	-----	26 Jan 37

Geographic delineation and place names. Insofar as can be determined from the 1947 photography, there are no errors of moment in the delineation of the continental ice coast under consideration. A place designation is required for this feature, however, if only so this feature can be referred

6Mileages are based upon Maps 9 through 15 and the U.S.N. Task Force 68 aerial photography of 1947.

to in this work. The term "Prydz continental ice coastal area" for this area bounding on the Prydz Bay is suggested since this is the only sizable section of the continental glacier which forms direct contact with the sea along the Ingrid Christensen Coast.

The continental ice. Here, the continental ice (Figs. 1, 2, 8) possesses a character similar to that in many sections of the Antarctic (Map 2) where the ice moves over the surface of the continent and into the ocean without forming channel glaciers, ice tongues or shelf ice. The edge of the ice is afloat, forming precipitous ice cliffs which rise to such heights above sea level that generally it is not feasible to attempt landings by means other than helicopter or other suitable aircraft. Above the ice cliffs, the surface of continental ice rises steeply toward the interior at an initial rate of perhaps five feet in a hundred (Fig. 8), then levels off until the increase is so slight that it is hardly noticeable. This gradual rate of increase may continue until the polar plateau or high interior mountains are reached. It is important to note that the rise often occurs without a single visible change in type of ice topography. Hills, valleys, escarpments and the like are conspicuous by their absence. The radio altimeter of the U.S. Navy photo reconnaissance airplane found the continental ice here to have risen in just such a manner to an elevation of 7,700 feet at 70°49'S., 77°56'E., 105 miles inland from the Ingrid Christensen Coast. This represents an average rise of 1.38 feet per hundred and even less slope than one foot per hundred after the initial rapid rise. Such conditions create a dangerous situation for inland flights, since the ice surface may rise to meet any aircraft flying at less than 10,000 feet without the aircrew realizing this fact, unless the plane is fitted with a radio altimeter or similar instrument which records altitude above ice terrain.[7]

The floating edge of the continental ice is so narrow, its descent so steep and its crevasses so numerous that only relatively small portions of it, such as those illustrated in Figs. 2 and 3, can separate en masse as icebergs from any one place at any one time. Complete removal of the ice would not materially change the position of this coastline, although its configuration would probably be radically altered by such an event.

The surface of the continental ice here consists basically of hard, light pastel-blue tinted glacier ice (Keys 87-95) which causes the medium-gray photo tones in Fig. 1. Numerous shallow, irregularly shaped depressions are partially filled with whiter and lighter-toned, wind-blown firn and snow. These depressions are notable for their uniform orientation and for their longer sides, usually being perpendicular to the direction of the surface drainage and parallel to the general trend of the coast.

Although rock, rock dust, soil and other materials which might increase the local absorption of the sun's heat and its reradiation to the adjacent ice are not present, the photographs show that during recent summers, temperatures have been sufficiently high to permit moderate surface melting. If examined closely, Fig. 1 reveals thousands of tiny channels on the ice surface which form part of a vast summer drainage network. Moreover, many of the light-toned depressions are meltwater

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[7]The flight log for Task Group 68.2, Mission 9, shows that at 2345 hours, 21 January 1947, the aircrew of the flying boat concerned suddenly found themselves at an altitude of only 1,500 feet above the continental ice, although their pressure altimeter indicated an altitude of 11,300 feet above sea level. Since the elevation of the icecap at this point (72°35'S., 135°00'E.) was higher than the single engine performance capability of the twin engine aircraft, failure of only one engine would have resulted in a crash landing in the continental interior.

lakes covered by snow and firn. The dark tones in Fig. 1B represent surface drainage from one such lake to another. The dark tones in Fig. 1C are clouds and cloud shadows (Keys 263-267).

Long, parallel crevasses of the tension or downslope-tension types appear in great numbers. These are especially notable along the coastline where they are subjected to less pressure and widen because of increased tension in this area. In some cases, the crevasses are closed, partially filled with firn and snow, or bridged.

Sastrugi (Keys 96-117) are present but not conspicuous, a characteristic of north-facing continental glacier coastal areas in late summer.[8] The sastrugi, as well as the small drifts created by ragged edges of crevasse lips, indicate the prevailing wind direction to be generally downslope and toward the sea.

Ice-free land occurs at only two places along this coast, and in both instances, the occurrence is in the form of offshore skerries: Tvistein at 68°20'S., 78°21'E. and Småskjera at 68°25'S., 75°16'E. (Map 10, Figs. 2 and 3). Each of these consists of two small, steep, bare rock isles. These isles are about a quarter of a mile long at Tvistein and 300 and 600 feet long at Småskjera. Light-toned stains indicate that both groups may support small Adelie penguin rookeries. Aside from these factors, however, there is an essential difference in the appearance of the two pairs of islands. Småskjera appears to consist of massive, jointed rock, softly rounded by glaciation. Tvistein appears darker, with sharper, more

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[8]Airphotos taken during the midsummer 1946-1947 of areas which were rephotographed in late summer 1947-1948 illustrate the disappearance of sastrugi in certain coastal areas during the late summer months (Keys 193-194). Similarly, the Norwegian airphotos of this coast were made during midsummer (26 January) 1937, while the U.S. airphotos were made during late summer (1 March) ten years later.

rugged peaks, which may indicate a different manner of resistance to glacial erosion caused by a variance in the rock structure. While morainal material is not evident on the photographs, the author's experience with similar skerries permits him to presume the presence of scattered erratic material on these isles.

THE VESTFOLD HILLS COASTAL AREA

General description. The Antarctic coastline is insular, peninsular and almost entirely ice-free between 68°27'S., 78°12'E. and 68°46'S., 77°25'E.[9] This indentation of the continental glacier extends for 32 miles (28 air miles) along the coast with a maximum width of about 14 miles near its center. The area is limited by the Prydz continental ice coastal area on the northeast and east, by the Sörsdal Glacier on the southeast and by the Sörsdal Glacier Tongue on the south.

The Thorshavn (Polar Record, 1935, p. 126) was the first ship to reach the Vestfold Hills coastal area. It remained in the vicinity for about a quarter of one day, during part of which time its captain, Klarius Mikkelsen, led a party ashore for the purpose of establishing a small emergency depot, building a cairn, raising the Norwegian flag and having lunch. No scientists are known to have been among the seven crew members who rowed Captain Mikkelsen and his wife ashore, but some pictures were taken and a small collection of rocks was made about which nothing is known to have appeared in the literature.

The landing site is thought to be illustrated in Fig. 21 at left

[9] Since the area has not been affixed to the terrestrial grid, these locations, taken from Maps 9, 10 and 11, must be considered only tentative.

center, but the officials of the Norsk Polarinstitutt could not identify it from the airphotos furnished them by the writer. The rock here was thought to be sedimentary with strata of harder, darker rock two to three meters thick.

Lymburner and Sir Hubert Wilkins (1939, MS diary, 11 Jan.), both British subjects, went ashore four years later in the same general area to claim the land for the Commonwealth of Australia. On that same day, Lymburner, as pilot, and Lincoln Ellsworth (1939a, p. 1), leader and financier of the expedition, flew into the continental interior where the latter claimed some 80,000 square miles of continental ice-capped land for the United States. All first-hand knowledge of the Vestfold Hills coastal area stems from the landings of Mikkelsen and Wilkins, the Norwegian airphoto flights on 27 January 1937 (Christensen, 1938, p. 8)[10] and the American photo reconnaissance of 1 March 1947. No other landings or flights over the area are recorded in the polar journals.

Maps and Airphotos. Map 10, prepared from the Norwegian aerial photography, is reliable for reconnaissance purposes and locating areas of ice-free terrain, but it is entirely inadequate for the precise delineation of terrain configuration. It cannot be used for classifying landforms, even into such broad categories as islands and peninsulas. The validity of this statement is substantiated in the following text and airphoto illustrations. The cause for this inadequacy can be assigned to one or more of these factors: (1) some of the Norwegian airphotos may not have been of suitable quality or scale, (2) the oblique angle

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[10]Hansen (1946, p. 4) states that these flights took place on 26 January 1937. Neither author indicates which time zone was used for reckoning dates.

of the photography may have prevented analysis of the areas in defilade from the camera lens, (3) the presence of sea ice may have made the analysis of low-lying areas difficult, (4) the photogrammetrist who plotted the detail upon the compilation sheets did not have field experience in Antarctic terrain[11] or (5) the map was made strictly by photogrammetric plotting techniques without the use of photo interpretation methods for analysis of the plotted detail.[11]

Numerous lakes, ocean inlets and areas of ice-free land are either represented incorrectly or omitted. Areas of major error or omission are indicated on Map 13. Precise corrections cannot be made without replotting the entire map from the airphotos and navigational data of the 1947 photo reconnaissance missions. The employment of photogrammetrists and technical plotting equipment to replot these airphotos would cost several thousand dollars, although this expenditure would be but a fraction of the cost of a comparable ground survey. But even replotting and recompilation would not permit the results to conform to the terrestrial grid unless ground control points were first obtained. Therefore, because of the existence of Hansen's atlas, which is of sufficient accuracy for most reconnaissance purposes, it is not feasible to plot new aerial photography until geographic positions (longitude, latitude and elevation) for a few selected control points have been established. Until that time it will be more practical to make corrections on Hansen's maps. Accordingly, Map 13, an overprint of Map 10, has been prepared to illustrate the major changes in coastal delineation and the recommendations for new place names arising from these changes.

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[11]Personal communication from H. U. Sverdrup, Director of the Norsk Polarinstitutt, Jan. 1952.

The facts cited above make it mandatory that Maps 10 and 13 be used only as guides. It must be emphasized, however, that they are most useful guides, for they present information relative to the character of the area which is not available elsewhere in so usable a form. In addition, they can serve as temporary base maps upon which to plot further discoveries. Map 13 has been used for this purpose. Map 13 also serves as a location index for the aerial photographs which are used to illustrate this chapter.

There are no individual or paired airphotos which cover a sufficient amount of the Vestfold Hills coastal area to be useful for general reference or index purposes. Moreover, the aerial photography is mostly of the oblique type which does not lend itself easily to rectification and subsequent mosaicking. Nearly all of the area concerned, however, is represented in photographic form in one or more of the illustrations presented in this chapter and indexed on Map 13. This index should be consulted whenever the reader desires to view a particular portion of the area.

The Vestfold Hills are covered by a total of about 210 airphotos as follows:

TABLE 2. VESTFOLD HILLS: AIRPHOTO COVERAGE

Print Nos	Angle	Roll	Mission	Agent	Alt/T	F/L	Scale	Date
32-69/1	LAV&R	67	M26 AAW	Amer USNTF68	10000	6"	20000	1 Mar 47
1-5	OR	18	M26 AAW	Amer USNTF68	9800	12"	-----	1 Mar 47
30-71	OL	18	M26 AAW	Amer USNTF68	5900	12"	-----	1 Mar 47
72-82	OR	18	M26 AAW	Amer USNTF68	5900	12"	-----	1 Mar 47
83-113	OL	18	M26 AAW	Amer USNTF68	5900	12"	-----	1 Mar 47
680-703	Obl		[illegible]D	Norw Widerøe	6550	8¼"	-----	27 Jan 37

<u>Geographic delineation and place names.</u> The principal geographic features of this area which require improved delineation are the islands,

peninsulas, and "alleged" mainland areas[12] as well as the tarns, lakes, fiords, ocean inlets, and bays. The larger ones of these features and the more strategically situated smaller ones also require place names or other means of identification. Mere numbers on the map compiler's sheets may suffice for the smaller and less important features. Unless vertical stereo airphoto cover is available for any given point in this region, it is sometimes quite difficult to assess whether one is viewing a tarn, fiord or bay on one hand or an island, peninsula or a part of the mainland on the other. Other than isolated islands and open bays, there appear to be but very few exceptions to this. The difficulty is caused by the presence of sea ice in various stages of growth and decomposition in an area of very unusual topography and rugged relief.

Comprehensive analysis of the 1947 aerial photography, taken at a time when there was relatively little sea ice in the Vestfold region, has revealed that numerous areas, mapped as peninsulas from the 1937 photography, actually are islands. The reverse is also true. On Map 10, some peninsulas were delineated as islands or as undivided larger peninsulas. Bays are shown as fiords and fiords appear as lakes.[13]

Three distinct problems arise from these discoveries by use of the photogeographical method. The first is concerned with the problems of

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[12]Until the continental ice retreats or until mechanical, electronic or other sounding methods are carried out in this area, it will not be known for certain whether the land areas now projecting from the continental glacier are islands or peninsular portions of the continental mainland.

[13]For example, contrast Map 10 with Fig. 20. The island pictured here was one of those placed on the map as a peninsula. The error may have been caused by sea ice bearing snow drifts between the island and the peninsula at top left. Conversely, the peninsula at right on Fig. 11 is shown as an island on Map 10, while the channel shown on Fig. 11 does not exist on the map. The omission of this channel caused a fiord to be mapped as a lake.

cartographic representation. The second involves the renaming of these features, many of which have already received descriptive names with generic suffixes in Norwegian. The third problem deals with the reclassification of the landforms and the determination of their origins. This last problem will be treated separately.

Proceeding from northeast to southwest on Map 10, the following major changes in landform delineation and cartographic representation are in order. A number of these changes appear on Map 13:

1. Langnestrynet (Long Snout Peninsula), the northeast portion of Langneset (Long Peninsula), which lies between Trynevika (Snout Bay) and Trynefjorden (Snout Fiord), should be represented as an island, with Trynesundet (Snout Sound) separating it from the area indicated as mainland on the east and a newly discovered channel (Fig. 21) separating it from Langneset on the west.
2. Langnesfjorden (Long Peninsula Fiord) should be extended to include Breidvatnet (Broad Lake) which is an integral part of this body of water. The sea-ice-covered channel connecting these bodies of water is illustrated in Figs. 4 and 5 and is given in three-dimensional detail in Fig. 23.
3. The Breidvatnet sector of Langnesfjorden must be extended to the south. The exact limits of this extension are not determinable from the existing photography, but a portion of the area of extension is indicated in Fig. 5, in which the known parts of the Langnesfjorden system have been stippled for illustrative purposes.
4. The Breidvatnet sector of Langnesfjorden may also extend northward under the drift snow between the rock outcrops in this vicinity (Fig. 21).

5. Large areas of ice-covered water are visible in Figs. 4, 8 and 21, south of Trynsvika, east of Trynsfjorden and north of the Breidvatnet sector of Langnesfjorden. Until these bodies of water are subsequently established as connected or separate, Langneset must remain suspect as an insular area.

6. A hammerhead-shaped peninsula, nearly three miles in length, located on the south shore of Langnesfjorden must be remapped as an island (Fig. 20).

7. Langevatnet (Long Lake) is connected directly to the ocean by a channel at Mulvik (Figs. 11, 12, 13). Hence, this major body of water constitutes a fiord rather than a lake. Note should be made of the eastward continuation of the fiord valley with its bottom now above sea level and partly filled with a chain of lakes (Fig. 12).

8. The discovery of the fiord at Langevatnet divides Breidneset (Broad Peninsula) into two relatively narrow peninsulas or into a single peninsula with two long prongs.

9. Krokfjorden (Crooked Fiord)(Figs. 28, 29, 33) must be extended eastward between the Westfold Hills and Sörsdal Glacier to a point south of Krokvatnet (Crooked Lake) (Figs. 10, 29, 30, 31). No present water connection between Krokfjorden and Krokvatnet is visible on the aerial photographs, but this possibility cannot be ruled out until a field survey has been made or more suitable airphotos become available.

10. Krokvatnet is larger than indicated on Map 10. It possesses several sizable islands as well (Figs. 30, 31).

11. Krokfjorden is really not a fiord at all, its southern shoreline being a temporary ice wall. When the Sörsdal Glacier Tongue recedes, as it eventually must, the main portion of Krokfjorden will disappear and leave the Vestfold Hills projecting a dozen miles out to sea (Figs. 28, 29). Moreover, if better aerial photography, a ground survey or a glacial recession should show that the Krokfjorden and the Breidvatnet sector of Langnesfjorden are connected by a water channel, then the main portion of the Vestfold Hills area is insular.

12. Numerous islands, rocks, abandoned lakes and channels evident on the 1947 airphotos have not been recorded on Map 10.

In view of these changes in the configuration of the Vestfold Hills coastline, and in view of the Norwegian descriptive names and generics now in use, it is suggested that the following names which have been placed on Map 13 be established for some of the more significant portions of the Vestfold complex.[14]

1. Tryne Island for Langnestrynet.
2. Tryne Inlet for Trynefjorden.
3. Tryne Channel for the channel dividing Tryne Island from Langneset.
4. Tryne Strait for Trynesundet.
5. Langnes Channel for Langnesfjorden and Breidvatnet.
6. Ellis Fjord for Langevatnet.
7. Krok Inlet for Krokfjorden.

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[14]These names have been submitted by the writer to the U.S. Board on Geographical Names. The names were examined during February 1952 by the Board's Antarctic Committee, at which time they were tentatively approved.

Hinterland. At the Vestfold Hills, the continental ice hinterland is exactly as described for the Prydz continental ice coastal area, except for the line of contact of the continental glacier ice with the ice-free terrain. Here, it presents cliffed faces to bays, fiords and marginal lakes (Figs. 4, 8, 14, 21, 23); terminates in a marginal moraine and meltwater complex (Figs. 4, 5, 6, 7, 21, 23); or slopes or drifts to the ice-free rock (Figs. 7, 10).

Area and configuration. The first coastal rock outcrop opposite Nörsteholmen (Map 13) marks the separation of the ice-free Vestfold Hills coastal area from the continental ice-covered coast to the northeast. For three miles south of this initial outcrop, however, the continental ice fronts on Tyrnevika. Except for the presence of offshore rocks and islands, this portion of the continental glacier is in most respects similar to the continental ice coast to the northeast (Fig. 8). For the next 30 miles south, the coastline is both ice-free and deeply indented for a maximum depth of 14 miles (Map 13). In the rough triangle thus formed, the amount of exposed land, including lakes, is about 200 square miles.

The U.S. Hydrographic Office (1943, p. 236), the U. S. Board on Geographical Names (1947, p. 245) and the British Admiralty (1948, p. 306) all record the elevation of the Westfold hilltops as lying between 600 and 1,000 feet, but an analysis of the aerial photographs indicates the elevations to be more in agreement with those of Hansen's atlas (1946, Map 11). The 1947 airphotos show that the hilly terrain apparently does not exceed 425 feet in elevation. The higher hills are located in the central portion of the ice-free area and extend from this point southeastward toward the junction of the continental ice with the base of Sörsdal Glacier Tongue (Figs. 10, 17, 18). While the land on all sides of this hilly core is lower, it is still quite rugged (Figs. 12, 21). In fact, the land is nearly all in steep slope, except for former lake and channel beds where moraine has been deposited (Fig. 22) and small areas of bed rock near the seaward edges of the Vestfold Hills (Figs. 13, 29). The fact that low-lying areas exist between the higher hills and the continental ice hinterland is significant, for it indicates that when the ice recedes further, the Vestfold Hills may all become "Vestfold Islands."

The hills, when viewed from seaward (i.e., from the west), may appear as individual, cone-shaped peaks (Fig. 12, top left). When viewed from the north or south, however, their aligned arrangement at once becomes apparent.

Surface composition. The surface consists of the local bed rock, intrusives, morainal material, mantle rock and ice. As indicated previously by the apparent difference in resistance to glacial erosion (Figs. 2 and 3), there probably is more than one kind of rock in the region adjacent to the northeast. Although similar erosional differences may exist in the Vestfold region, except for the dike ridges paralleling Langnes Channel (Fig. 17), the picture here is essentially one of relatively equal resistance to glacial action. The basic rock components of the Vestfold Hills are difficult to determine from aerial photographs but appear definitely to be metamorphic in origin. Igneous rock is also present in the form of several series of dikes.

Aside from the ubiquitous dikes, the very presence of which is indicative of, although not proof of, metamorphism, evidence of metamorphic character occurs in the bed rock at the entrance to Ellis Fjord (Fig. 11) where three series of parallel lines are evident in the rock structure. The three series are also clearly visible in Fig. 13 where one of them, the series of black stripes running horizontally across the illustration, is quite obviously a series of dikes. Of the other two series of parallel lines, one is oriented from the upper left to the lower right of the picture. Its precise character has not been determined, although glacial grooving seems to be a possibility. The third series trends from top to bottom of the figure and appears to consist of lines of metamorphic foliation.

While to the casual observer the bed rock everywhere in the Vestfold Hills seems to reflect the same gray tones in the panchromatic emulsion, the more experienced eye has little difficulty in locating the subtle variations in tone which reveal changes in rock composition. Steep slopes which have a minimum of glacial overburden are generally the places where these lines of contact between different qualities of rock are best revealed. In Fig. 17 such lines of contact are visible, extending horizontally across the illustration in the middleground near where dikes seem to intersect on the hillsides at approximately right angles.

The intrusives, so conspicuous by their ubiquity, all appear to be similar in nature, largely because of their similar photo tones, yet relative differences in their resistance to erosion as compared to the resistance for the adjacent bed rock can be noted.[15] In most of the illustrations, the dikes seem to have about the same or a little greater resistance to erosion than the bed rock into which they have intruded. In some instances, however, the intrusives stand above the country rock to a marked degree (Figs. 17, 18), divide linear depressions into individual lake basins (Figs. 12, 16)

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[15]It is possible, of course, that the differences in resistance to erosion may occur in the adjacent bed rock rather than in the intrusives; the individual dikes seem to show the same relative resistance throughout their lengths.

or serve as spines for peninsulas (Figs. 11, 13), all of which indicate a greater ability to withstand the agents of erosion. The prominence of the dike-ridges in Fig. 17, which may run parallel to the former course of the glacier movement, may indicate that although the dikes not parallel to the direction of ice movement are more resistant than the surrounding rock to ordinary erosion, they have been planed level with the local bed rock by glacial action.

Occasional straight, narrow depressions in an area of rugged relief suggest the presence of some less resistant intrusives (Fig. 19). In these cases, the dark tones are absent, either because of a difference in the reflective quality of another variety of intrusive material or because the depressions are filled with moraine. It is significant that the floors of the linear depressions in Fig. 19, which run parallel to the black line separating the halves of the stereogram, vary in elevation from the adjacent topography. Although this could indicate the presence of a widened joint system, it does not appear to do so, since smaller dikes may be seen extending across these depressions.

Regardless of their relative resistance, the dikes are traceable for many miles, but frequently they disappear under deposits of ground moraine or bodies of water. The width of some of the dikes has been mentioned by Mikkelsen's party (Polar Record, 1935, No. 10, p. 126) as being two to three meters (six and a half to ten feet). Wilkins (1939, MS diary, 11 January) describes the spot at which he placed the Australian flag and claim as being located on a black dike, which was four inches wide at sea level, increasing to a width of four feet at the hill top. Fig. 15 illustrates the tremendous difference in width of the various dikes. Dikes so narrow that they can hardly be noted in the airphotos occur alongside a large one, which is conservatively estimated as being 120 feet wide.

Several systems of parallel dikes appear to be exposed in the area. The system containing the largest number of dikes is oriented in a north, northeast-south, southwest direction (Figs. 11, 13, 16, 18, 28). A lesser number of long dikes forms a second system which trends in a northwest-southeast direction, diagonally intersecting the first system at an angle of approximately 65 degrees (Fig. 10). Still a third system of dikes trends east-west. These dikes are fewer in number, but rather distinctive in size and resistance to erosion (Fig. 17), a condition which may have resulted from these dikes being aligned in the direction of glacier movement. In addition to these three systems, all of which can be seen in Fig. 17, other dikes occur, oriented in almost every conceivable direction (Fig. 10).

While most of the dikes cause the same photo tones on panchromatic film, their variations in resistance, orientation, thickness and manner of intersection seem to indicate that they were not generated simultaneously. The absence of numerous lateral displacements indicates that there has been no significant post-intrusive faulting. Post-intrusive faulting has occurred to a limited extent, however, as illustrated in Fig. 15. Photo-geologists experienced in the airphoto analysis of intrusive rocks would, no doubt, be able to add considerably to the geological knowledge of the area from these airphotos.

The composition of ground moraine is described in the section on surface features. Except for some of the finer material, the moraine here probably consists largely of igneous and the more resistant of the metamorphic rocks, since most of the sedimentary rocks, if any, and the brittle or less resistant metamorphic rocks would have been broken up or ground to bits during glacial transport.[16]

A mantle rock approaching the character of soil probably exists in a few favored localities of the area. Small depressions, abandoned tarns and minute, sheltered areas among the moraines and lake beds contain patches of tiny rock fragments, rock flour, remains of algae, guano or combinations of these. Thick deposits of penguin guano occupy certain of the more accessible portions of the outer islands and the seaward tips of the peninsulas. While these materials cannot be considered as soils by established standards, they provide a base for the growth of the present flora and minute fauna which must include algae and mosses as well as bacteria, mites and other forms of microscopic invertebrates. Under such conditions, it is quite possible that very sparse, scattered stands of grasses may exist, as claimed by Wilkins (1951, personal communications to the writer, 6 and 16 July). Soil forming processes are now operating. Lichens, which do not require soil or mantle rock, are not visible in the airphotos but grow on almost every known exposure of bed rock in Antarctica and, therefore,are presumed to be present here.

Only a few surfaces here are composed of ice. These are predominantly lakes and fiords which are frozen over for the greater part of the year. Snowdrift ice (Figs. 5, 7, 10, 16, 23), similar to the type found on slopes protected from the sun, wind or both in the Bunger Lakes area, occurs near the continental ice hinterland but is generally absent elsewhere. Seasonal snowdrifts, which may form in the absence of the sun during the long winter

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[16] The writer spent several days in a similar moraine-covered coastal area at 101°31'E. during which time only two erratics of sedimentary character were noticed. See Keys 341-343.

night, evidently disappear early in the summer as a result of the relatively intense heat radiated by the exposed rock. A number of small drifts are to be seen near the Sörsdal Glacier Tongue, however (Figs. 28, 29).

Surface features. Many kinds of landforms which are typical of the belts of accumulation of the Pleistocene glaciers in the northern hemisphere are absent in this region or occur only infrequently. No terminal, lateral, interlobate or medial moraines, outwash plains, kames, drumlins or eskers appear in the photographs of this area.[17] The surface shows very little evidence of glacial polishing, especially for an area so recently released from the ice, but then, the type of bed rock present may not lend itself to polishing.

Several distinctly glacial features, however, can be observed. The shapes of the hills show knoblike rounding (Fig. 19, among others). Ground moraine (Keys 207-218) is peculiarly light in some areas (Fig. 9) and particularly heavy in others (Fig. 22). Large boulders, probably glacial erratics, are omnipresent, but the ground moraine occurs predominantly as a fill in the depressions and channels. The airphoto image differentiation between the bed rock and the ground moraine, which approximate the same photo tone, is aided by a difference in texture and by the superabundance of dark-toned intrusives which invariably give the exposed bed rock a contrasting black-striped pattern.

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[17]Since ice-free land is thought to occupy far less than one per cent of the continent of Antarctica, landforms of any kind are rare. The character of much of the ice-free land that does exist, i.e., mountain peaks, dry valleys, cliffs, peninsulas and similar forms (Keys 169-244), does not lend itself to supporting the types of landforms typical of the belts of accumulation of the Pleistocene glaciers of the northern hemisphere. Such landforms will no doubt appear after glacial recession begins to uncover large portions of Antarctica.

Both the bed rock and the ground moraine here reflect the same general photo image tone on panchromatic film, but the ground moraine appears to have a smoother photo image texture (Key 212). The moraine is sometimes pitted with large, shallow, kettlelike depressions (Fig. 22). The upper layers of the ground material have been partly reworked by melt-water derived from the glacier, from trapped ice, from precipitation and from wind-blown snow and firn. The reworking by meltwater may account in part for the "flowing," "smooth" appearance of the morainal terrain as viewed on airphotos. In actuality, this variety of photo image represents terrain that is far from smooth. It is composed of a wide variety of sizes, shapes and colors of rock material and appears from the airphotos to be quite similar to the type terrain found at the helicopter landing field in the Bunger Lakes Region (Key 343).

Circular and oval-shaped depressions appear in the bed rock in one area (Fig. 9) in which a cover of moraine or mantle rock is conspicuous by its absence. These holes are apparently far too large to be glacier mills and do not have the shapes generally associated with these features, although the exact procedure by which glacier mills are excavated is not fully understood (Streiff-Becker, 1951a, p. 488; 1951b, p. 582; Hollingsworth, 1951, p. 490). Some of these bowl-shaped depressions contain lakes and others clearly show the presence of former shorelines. The precise origin of these depressions is not apparent to the writer.

Drainage. Perhaps no other single factor illustrates the recency of the emergence of the area from the continental ice better than the drainage. Pleistocene depositional landforms in North America and Europe are still obstructing "normal" drainage after 25,000 years of freedom from the continental ice. The drainage system here, however, more resembles certain portions of Canada in which glacial erosion is considerably greater than glacial deposition. Drainage is locally obstructed chiefly by erosional features and is largely internal. The length of a typical surface run-off stream is very short, merely extending downslope to the nearest basin which generally does not have an outlet. Some slopes drain directly into the ocean or into channels or fiords leading to the ocean, but this is not yet the rule.

Streams are few, short, seasonal and generally in extreme youth. While they are variable in width, they are usually quite shallow, with many projecting erratic boulders. Such streams do not constitute a bar to field parties in ordinary field clothing. In all probability, a significant percentage of the volume of these streams moves through the glacial gravels in the stream bed, causing the streams to appear as (dark-toned) wet streaks superimposed upon the photo image texture normal to the area (Fig. 12, bottom left).

The lakes and tarns are of two origins. Marginal lakes, which receive the meltwater of the continental ice, are located along the line of contact of the continental ice and the ice-free land (Figs. 4, 5, 21). Since a portion of the shoreline of these lakes is frequently formed by a face of the receding glacier, the shape, level and volume of these lakes are quite temporary in nature. In the Westfold area, many of them are connected with ocean inlets and thus do not exist as independent lakes. There are several important differences between the waters of the fiords and the lakes. These differences include the stability of the water level, the presence or absence of diluted (ocean) salt in the water, the presence or absence of marine plant and animal life and the presence or absence of such elements as tides and marine temperatures as factors in the solution and erosion of glacial ice, which frequently dams one side of these bodies of water.

Away from the glacier front, lakes are less numerous and usually result from the collection of drainage water from precipitation and the melting of wind-blown snow and firn that had found lodgment in the hills.[18] In the vast majority of instances there is abundant material available for use in aggrading lake basins. Basins fully aggraded or aggraded to a point where overflow will occur under the existing water economy, however, are infrequent. This situation is brought about by the lack of accumulation of precipitation and meltwater in an area where evaporation may balance or exceed precipitation. The lack of lake outlets causes a brackish water to develop which alters the character of the microscopic life in the lakes and the composition of the bottom deposits.

Occasionally, these lakes and tarns do have overflow outlets or subsurface outlets which drain through the moraine, rather than on its surface. The location of such lakes is important in terms of their potential use as a fresh water supply for field parties in an area where most water bodies are brackish and snow is not readily available.

Both the surface area and depth of the lakes and tarns vary considerably, depending upon the character of the basin, the size of the accumulation area and the presence or absence of distributary channels. While many

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[18] Though no accurate meteorological or climatic data are available for this local area, it seems reasonable to assume that no greater amount of precipitation occurs here than at other similar locations in this portion of the Antarctic. This would mean a maximum average of 10 inches per annum. During the course of the year, blizzards which may not be accompanied by precipitation (Keys 256-258) may move greater quantities of snow and firn into or out of an area than is accumulated as a result of the normal annual precipitation.

basins are controlled by the configuration of the bed rock, considerable amounts of unconsolidated glacial debris may hide the rock structure, provide means for subsurface drainage or create temporary local base levels.

Most of the lakes and tarns in the Vestfold Hills are not represented on Map 10. In some instances, this omission has occurred because the scale of the map is not sufficiently large to permit their inclusion. In other cases, the omission can be credited to poor quality airphotos or a lack of adequate photo analysis. While the lakes and tarns occur more frequently in the hilly areas near the center of the ice-free land, they are also found in the linear depression systems (Figs. 10, 16), in bowl-shaped depressions in the bed rock (Fig. 9), in over-deepened portions of fiord valleys (Fig. 12, background), and as remnant lakes at the bottom of former lakes or ocean channels (Fig. 22).

Changes in water level are evident in a number of the lakes and tarns. The lake in Fig. 22, as previously implied, is a remnant of a much larger salt water body which originally may have been an integral part of the fiord and ocean channel system. It occupies an over-deepened portion of the channel in which it lies and is approximately at sea level. The ground moraine which covers the rest of the channel floor is definitely above sea level. (Langnes Channel at the top left is an ocean inlet; the water at bottom left and bottom right are portions of the ocean.) The level of the lake has apparently receded through evaporation. Its present level may be controlled either by accumulation from drainage and loss by evaporation or perhaps by subsurface drainage between it and the nearby fiord through permeable glacial moraine. If this lake is a surface expression of the water table controlled by the fiord or if it is due to the recent breaking up of larger water bodies connected with the sea, its salt content may wholly or partly result from its present or former relationship with the ocean. Many of the brackish lakes and tarns in the area, however, are well above sea level and could not have been subject to such influences. Their salt content must be derived from the evaporation of lakewater which contained salts in solution from contact with the moraine, mantle rock and bed rock.

A series of former shorelines is clearly visible in Fig. 9, indicating that the lakes which occupy or once occupied these bowl-shaped depressions in bed rock have undergone a gradual lowering of surface level. The complete absence of lakes in the bottom of some of these depressions and the reduction of the lakes in others to tiny remnants of their former selves are attributed to the excess of evaporation over supply. Here, there can be little doubt, for the former shorelines clearly show that the previous extent of the water and the basins are of solid bed rock, which effectively prevent the escape of the accumulated water in any other form than as water vapor. Note the general absence of ground moraine here in contrast with the tremendous amounts appearing in Fig. 22 (Keys 212-214, 341, 343).

Shorelines. This subject has been treated previously in connection with cartographic representation and place names. It is mentioned here in terms of configuration, relative change in water level and marine influences.

Although further corrections may be required, Map 13 demonstrates the general configuration of the coast more adequately than could any word picture. The shoreline is everywhere irregular and in several places is severely indented by fiords. Islands and peninsulas are the rule rather than the exception. Most of the shoreline is steep or even precipitous. In the rare instances in which beaches do occur, they are generally pocket beaches connecting with former ocean channels (Fig. 24).

Bars, spits and similar formations are absent, partly because of the steep gradients offshore, partly because of a lack of suitable building materials and in large measure because of the action of the pack ice in eliminating or reducing waves and swell.

The character of the present shoreline has been considerably affected by glacial erosion and deposition and very likely by subsidence and emergence as well. The original landforms were eroded by the glacier and the area was depressed by its weight. When the portion of the continental glacier in this general vicinity decreased in thickness and finally receded from this specific area, landforms of glacial erosion and deposition were formed in the coastal zone and the land must have been left out of isostatic adjustment and perhaps out of elastic adjustment from the release of the great weight of the ice. During this period, most of the valleys and dry channels in the illustrations may have been below sea level, thus forming ocean inlets and causing the Vestfold Hills area to be divided into small islands and insular groups similar to those which now lie off the tip of the southernmost peninsula near Sörsdal Glacier Tongue (Fig. 26). Strand-lines, wave cut cliffs (Figs. 11, 27) and previous channel deposits (Fig. 22) demonstrate the course of the emergence of the coast as the glacier continued to recede and the earth's crust began to respond to the glacial unloading.

Wengerd (1951, p. 616) concludes that in the Arctic such strandlines ". . . . the result of episodic but regular stillstands of the sea between relatively rapid positive plastic readjustments in delayed response to ice unloading." From the summaries of changes in sea level by Daly (1925) and Flint (1947, Ch. 19), it is inferred that major changes in the level of the oceans which resulted from the disappearance of the Pleistocene glaciers in the northern hemisphere must have occurred before the ice receded from the Westfold Hills. If such is the case, the strandlines do present evidence that this area has risen recently because of glacial unloading rather than a change in the level of the ocean.[19] If the emergence of the Westfold Hills took place while the sea level was still rising from the water released by the Pleistocene glaciers, the evidence is even more convincing, since the local land would have to be rising more rapidly than the sea to produce strandlines and similar raised shore forms.

This upward isostatic and/or elastic readjustment, returning this portion of the earth's crust to a position more nearly equivalent to its relative position preceding glaciation, has already resulted in the combination of some of the former insular elements of the Westfold Hills into larger units, some of which may be attached to the continental mainland as peninsulas.[20] If upward adjustment continues, the entrances to Tryne Inlet, Langnes Channel and the newly discovered Ellis Fjord, which was portrayed as Langevatnet on Map 10, will be sealed, thus forming new large lakes which may shrink from an excess of evaporation over supply until they, too, are brought into adjustment with the local water economy and perhaps resemble the area in Fig. 22.

As the glacier recedes, it may continue to reveal more and more water

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[19]This evidence cannot be said to be absolute proof, since it is possible that an isostatic movement of a separate origin may have caused the uplift.

[20]It must be noted that either this isostatic readjustment occurs with greater celerity than implied by Daly (1925, 1934) and Flint (1947) or that the recession of the glacier from the Westfold Hills is of relatively long standing.

bodies which constitute marginal extensions of Tryne Inlet, Langnes Channel and Krok Inlet. If this development should continue until the interior portions of Langnes Channel become connected with Tryne Inlet, Krok Inlet or both, a substantial portion or all of the Westfold Hills will have to be redrawn on the map as the "Vestfold Islands." However, if isostatic or elastic readjustments in this local area take place more rapidly than glacial recession (perhaps caused by greater surface ablation than terminal wastage), the Vestfold Hills will become sufficiently elevated to raise all valleys above sea level. The islands and peninsulas will then disappear in favor of a rugged terrain which would be a part of the mainland of the Antarctic continent.

Marine influences on the shoreline are less than might be expected. Although wave-cut and storm-cut areas do occur, the presence of fast ice over the sea for most of the year and the constant presence of pack ice offshore prevents much of the erosion by swell and wave that would otherwise occur. Tidal action is not barred by the presence of floating ice, but the tidal range in the Vestfold Hills coastal areas is not very great. No prominent sea ice tidal cracks or other evidence of high tide occurs in the airphotos. This is consistent with what is known about Antarctic tides. But then tide, of itself, has little effect upon the steep shoreline. Perhaps the greatest marine factor affecting the shoreline is the presence of sea ice which expands against it with great pressure in the winter and bumps against it in the summer.

Offshore. The U. S. Hydrographic Office (1943, p. 236) reports a west setting current to have been observed in this sector. While information from one aerial photo sortie cannot be considered as proof, the airphotos for 1 March 1947 clearly show that surface winds over the sea and surface currents were moving to the south and southwest or generally parallel to the coastline.[21] Fig. 26 shows the surface current bending brash around islands. Figs. 10, 21, 24 and 25 reveal that the winds have similarly pushed all the lake and fiord ice out of bays exposed to the south and into those facing north.

Aside from the islands within its fiords (Figs. 5, 8, 20, 21), the seaward side of the Vestfold Hills coastal area is ringed by half a dozen islands up to two miles in length and by several hundred small islands. Small rocks abound on all sides from Trynevika to Krok Inlet, but the water does not appear to be particularly shallow. Navigation would evidently be impeded by the danger of submerged pinnacles. All islands are located close inshore, the distance separating the outermost islands from the peninsulas being not more than three miles. Some of the islands are visible in the backgrounds of Figs. 4, 5, and 8, but better views of them are offered in the background of Fig. 9, in the foreground of Fig. 21 and especially in Figs. 26 and 34. Fig. 14 provides a three-dimensional, vertical view of Nörsteholmen, the northernmost island group of the Vestfold Hills complex.

The greatest floating ice activity is noted at Nörsteholmen and along the shores of Trynevika (Figs. 8, 14, 21). The icebergs and ice floes jammed among the tiny islands create a confusing, ever-changing pattern in which it is difficult to separate ice masses from land masses without stereograms. In Fig. 14, a typical floating ice phenomenon is

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[21] This current parallel to the coast is a west setting current in the sense of one which sets westward around the continent.

again noted, the bergy-bits appearing to float on a higher plane than the icebergs (Kays 233, 254).

In middle or late Antarctic summer, the continental lead which separates the moving pack ice from the shore bound fast ice, advances landward until the Vestfold Hills coastal area is reached (Fig. 26). At this time there is no difficulty in navigating within the coastal area, save for the precautionary measures which must be adopted for areas with icebergs and submerged peaks. The approach to the area, however, is still through the pack ice, the length, thickness, compactness, state of disintegration and distribution of which is established partly by other than local conditions. The pack ice, here as elsewhere, probably varies considerably from year to year.

Flora and Fauna. No flora was observed by any of Mikkelsen's party (Polar Record, 1935, No. 10, p. 126), but then no members of his party are known to have been trained in science, interested in botany or especially interested in searching for flora. Wilkins (1951, personal communication to the author), who had dealt with flora on previous Antarctic expeditions, notes that he found algae, lichens, mosses, and 30 to 40 tufts of grass. Both parties observed animal life, particularly in the Adelie penguin rookeries. Aerial photography does not normally record the presence of vegetation so small and so widely scattered, nor does it often picture the animal life by direct image. Airphoto interpretation, however, can indicate the presence and types of plant and animal life not directly visible on airphotos by analysis of the photo images of objects or conditions known to relate to their presence.

From previous field experience in the Antarctic, it has been determined that the presence of tarns in ice-free areas generally indicates a relative abundance of minute organisms, both plant and animal. Numerous species of algae are usually present. Few large areas of ice-free land in Antarctica are known to be totally without life.[22] Perkins (1945, p. 283) contends that the greatest single factor limiting the numbers and varieties of plants and their distribution in the Antarctic is the absence of water in an available form. Although he has apparently overlooked the fundamental importance of a suitable base from which to grow, it is significant that his investigations show that the importance of water in usable form is of the same order as the importance of sunlight. He reports that whenever there is sufficient water in the rock, even in miniature caves, lichens are apt to be found growing there.

Siple (1938) found a direct correlation between peaks which supported bird rookeries and peaks which supported a relatively abundant vegetation. The wealth of vegetation seemed to be apart from the bacteria and plant life supported directly by the guano, for the clean portions of the rock supported superior amounts of vegetation as well.

Therefore, in the absence of any indications to the contrary, and because the airphotos demonstrate the Vestfold Hills to be ice-free, large in extent, inclusive of lakes, tarns, streams and salt and fresh water, and host to penguin rookeries, it seems reasonable to assume that algae, lichens, mosses, bacteria, mites and other forms of minute plant and animal life exist here. Even so, most of the plant and animal life in the area, both in terms of strength of numbers and variety of species, live in the ocean offshore and in the fiords and inlets in the Vestfold Hills.

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[22] The exposed peaks of the Raymond Fosdick Mountains, however, were examined and found lacking in vegetation. According to Perkins (1945, p. 283) this lack may be due to the chemical composition of the very dark volcanic rock.

Although it is not difficult to prove beyond a reasonable doubt by means of associative photo interpretation keys (Keys 271-275) and correlated field work that flora and fauna exist in the area, it probably will never be possible to determine the precise species of all the plants and animals by this method. Associative keys for a few of them have been developed, but indicator keys for most of the minute species appear to be improbable of formulation.

The penguin rookeries of the Westfold Hills coastal area are visible in the illustrations (Figs. 14, 24, 25, 26, 27) as splotches of guano (light tone) against the debris and bed rock (darker tone). The rookeries of visible size are almost entirely confined to the offshore islands and to the seaward portions of the peninsulas. This suggests that the fiords leading to the interior usually are not ice-free at the time the penguins arrive at their rookeries in early summer. At that time, the ocean surrounding the islands is probably covered by fast ice which extends for several miles out to sea. While most rookeries are near the sea on relatively level ground, steepness of slope, unless a sheer precipice is involved, is no bar to the Adelie penguin. Levick (1914, p. 98, Fig. 70) shows a rookery atop Cape Adare, a thousand-foot, one-hour climb for short penguin legs. Normally, however, the rookeries are located at the outermost extensions of the land in the manner indicated by the distribution of the guano deposits visible in the airphotos of this area.

The rookeries appear to be largely uninhabited at this time (1 March '47), since the guano (light tones) is plainly visible and not covered by masses of penguins (dark tones). A month or two earlier, the occupied rookeries might have looked very dark with light-toned edges (Key 274).

From field experience, it seems reasonable to assume that rookeries of other birds exist in the area as well. Since the other Antarctic birds fly, their rookeries are usually on steep slopes and in nooks and crevices in the rocks. No great amount of guano accumulates, however, and associative keys for the presence of such nesting places have not been established. This region may play host to such birds as the cape pigeon, Wilson's storm petrel and the snow petrel.

Adelie penguin rookeries are, probably without exception, accompanied by nesting skuas who place their "skuaries" directly alongside or even within the rookeries and prey on the Adelie eggs, the chicks, and the sick or starvation-weakened adults. In a similar fashion, leopard seals lurk off the ocean entrances to the rookeries to feed upon the Adelies as they enter the water to bathe and search for food.

Thus, while not a single animal is visible on these airphotos, the presence of sizable deposits of penguin guano provides adequate evidence of the further presence of bacteria, bird parasites, mites, skuas and sea leopards. These animals form a normal faunal association in Antarctica which is based on the presence of an Adelie penguin colony. Moreover, the appearance of the land makes it reasonable to predict the presence of certain other birds which nest on the Antarctic coast, but indicator keys to substantiate this fact do not yet exist.

Human occupance. No airphoto (Keys 285-343) or other evidence exists which indicates that humans have ever lived in the Vestfold Hills coastal area. Even primitive peoples usually disrupt natural patterns in some way, but no clearly visible evidence of a cultural pattern superimposed over the natural conditions previously described exists. Moreover, only an experiment could tell whether a primitive, eskimo-type or a small "civilized" European type colony could survive and prosper in this locality, since no primitive peoples have had the opportunity of going there and no "civilized" peoples have had sufficient desire. While the area is definitely not one of hospitality, small groups of people might exist there indefinitely if provided proper guidance.

The Westfold Hills coastal area might be suitable as a temporary base for Antarctic exploration, or as a permanent scientific station. It appears to be accessible to modern ships for a short period of time almost every summer (Map 4). It provides many sheltered areas for mooring or even wintering ships. It is located in an area which has been landed on twice but never explored. It offers field research problems of interest to scientists from many disciplines. Field studies can be performed during either summer or winter seasons on the glacier ice, sea ice, land, lakes and ocean. Finally, this area contains one of the few land termini of the Antarctic continental glacier.

On the other hand, one must record the problems of trafficability over the morainal surface (Key 343), the lack of a suitable airstrip in summer and the problem of obtaining fresh water. With foresight, good planning and the use of helicopters, these difficulties might be overcome.

THE SØRSDAL GLACIER TONGUE

General description. From 68°46'S., 77°25'E. to 68°52'S., 77°42'E. the coastline first trends south, then southeast and finally southwest (Map 13). The de facto, ice-cliff shoreline here is over 11 miles (8.7 air miles) long although the Sørsdal Glacier Tongue which forms it is only about 8.5 miles wide and 10 miles long. The exact interior boundary of the glacier tongue has not been determined, but the floating ice mass is limited on the north by the Vestfold Hills, on the east by its parent glacier and on the south and west by the Indian Ocean.

Previous descriptions have been both brief and inaccurate. The explorers have paid little attention to this ice tongue, which to them was just one of many glacier tongues in the area. Among the authoritative compilation sources, the U. S. Hydrographic Office (1943, p. 236) allows it four sentences, two of which are in error while the other two might apply to almost any Antarctic glacier discharging into the ocean. The British Admiralty (1948, p. 306) merely mentions that a large, rough glacier reaches the sea here. The U. S. Board on Geographical Names (1947, p. 234) has but a single descriptive sentence which seems to have been inferred from Hansen's atlas (1946, Map 10).

<u>Maps and airphotos</u>. Maps 10 and 13 cover the Sörsdal Glacier Tongue with the same degrees of accuracy previously mentioned for the Vestfold Hills. As was the case with the continental ice hinterland which backs the Vestfold Hills, the glacier which backs the Sörsdal Glacier Tongue can not be represented with any degree of accuracy. Its whiteness, the absence of distinguishing features, cloud cover and its distance from the oblique camera make plotting from airphotos difficult.

The Sörsdal Glacier Tongue is covered by a total of 38 oblique and three vertical airphotos as follows:

TABLE 3. SÖRSDAL GLACIER TONGUE: AIRPHOTO COVERAGE

Print Nos	Angle	Roll	Mission	Agent	Alt/T	F/L	Scale	Date
32-34/1	V	67	M26 AAW	Amer USNTF68	10000	6"	20000	1 Mar 47
29-42/1	R	67	M26 AAW	Amer USNTF68	10000	6"	------	1 Mar 47
6-8	OR	18	M26 AAW	Amer USNTF68	9800	12"	------	1 Mar 47
27-29	OR	18	M26 AAW	Amer USNTF68	10000	12"	------	1 Mar 47
114-117	OL	18	M26 AAW	Amer USNTF68	5900	12"	------	1 Mar 47
118-123	OL	18	M26 AAW	Amer USNTF68	7900	12"	------	1 Mar 47
677-685	Ohl		D	Norw Widerøe	6550	8¼"	------	26 Jan 37

<u>Geographic delineation and place names</u>. In all known literature in which this coastal feature is described and named, it has been termed erroneously "Sörsdal Glacier." A brief reference to the airphotos, however, is all that is required to show it to be a true ice tongue, extending seaward as a floating mass for approximately 10 miles. In fact, so perfect is the structure of this ice tongue, it can be considered a classic example, and accordingly it has been placed in Chapter V as Key 35.

Although the front (Figs. 34, 36) and both sides (Figs. 29, 32, 33) of the ice tongue changed shape during the 10 years which elapsed between the two aerial photo reconnaissance missions, the basic shape and size of the Sörsdal Glacier Tongue remains similar in all essential aspects. In 1947, the tongue was not as long as it had been in 1937, according to Map 10. This does not prove glacial shrinkage, however, since the difference is relatively slight and might be accounted for by the irregular calving of icebergs.

Other changes include the exposure of additional rock surfaces. For example, a marginal peak which projected from an angular bend on the north side of the ice tongue in 1937 (Map 10) has now become sufficiently exposed to be redrawn on the map as an island (Fig. 33). The best indication of glacial recession in the area is the exposure of five new peaks through surface wastage which represent similar islands still covered by the ice tongue. These are located near the narrow waist of Krok Inlet (Fig. 33). Crevassed surface areas (Figs. 32, 33) which were not indicated on Map 10 might profitably be inserted on new, larger-scale maps of the area, since the positions of these areas are less likely to vary than the shape of the ice tongue itself.

The only major change in place names recommended here is the substitution of the term "Sörsdal Glacier Tongue" for this feature which until now has been known officially as Sørsdal Glacier (U. S. Board on Geographical Names, Sp. Pub. 86, 1947, p. 234). The term "Sörsdal Glacier" should then be applied to the relatively unknown channel glacier which drains the hinterland to feed this glacier tongue.[23]

Hinterland. In 1947, the hinterland (Figs. 28, 29, 30, 33, 35) was largely obscured by cloud formations at the time of the photography, and little can be reported concerning its nature. It would appear from the small portion which is exposed that it is very similar to the hinterland previously described, except for the probable presence of a subglacial depression in the bed rock which has caused a channel glacier to form, thus permitting more rapid ice drainage from the interior at this point.

Area and configuration. While the precise division line between the Sörsdal Glacier Tongue and the Sörsdal Glacier cannot be established because of cloud cover on the aerial photography, the area of the tongue can be said to approximate 50 square miles. Suitable photogrammetric plotting equipment was not readily available to the writer, but standard, improvised height-finding methods indicate the height of the ice cliff at the front of this glacier ice tongue to be not less than 96 feet, and possibly as much as 150 feet. Fig. 34 (scale 1/20,000) shows the glacier tongue towering over the adjacent islets.

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[23]The names "Sörsdal Glacier" and "Sörsdal Glacier Tongue" for these features were approved tentatively by the U. S. Board on Geographical Names in February 1952. According to the general policy established by The Antarctic Committee of this Board, when a glacier and the tongue derived from it bear the same name, the tongue is named a glacier tongue. If the tongue and the glacier which supplies it bear different names, the tongue is named an ice tongue.

Unlike the continental ice, the surface of the glacier tongue does not rise rapidly from the de facto shoreline. At first glance it appears to be level and flat but on closer examination gentle undulations are visible as well as a gradual increase in elevation toward the interior (Figs. 31-35). While as a rule the tongue is higher toward its center and toward its base, this does not apply throughout its extent. Local areas of relatively high or low elevations can be seen by closely examining the ice cliff in Fig. 32. Fig. 30 shows that initially elevations in the hinterland increase in much the same manner as those of the continental ice hinterland to the north and the south.

Surface composition. The surface consists of glacier ice with occasional snowdrifts and depressed areas filled with firn and snow (Keys 87-96). The accumulation of firn and snow in other than protected depressions and crevasse fillings is probably prevented by the complete exposure of the tongue to erosive winds from all directions, whereas only easterly winds can carry drift to the tongue.

Surface features. No bed rock or moraine surfaces are exposed on the glacier tongue, except for the few small islands and peaks previously mentioned which are adjacent to Krok Inlet and form a part of the Vestfold complex. Therefore, only ice surface features are considered here. For the Sörsdal Glacier Tongue these include sastrugi, snowdrifts, crevasses and hinge line depressions. The face of the vertical ice cliff is described in the section pertaining to shorelines.

Sastrugi (Keys 96-117) are present but in a lesser number and a more modified form than those of the hinterland previously described. The surface of the glacier tongue is so cut by crevasses that the formation of sastrugi is hindered considerably (Fig. 34). Even where crevassed areas have been somewhat covered over by drift, the sastrugi are not particularly well developed (Figs. 35, 35a). Their orientation indicates that they may have been formed by winds blowing from the continental interior toward the southwest. Small snowdrifts caused by the ragged lips of crevasses projecting into the airflow are also present. The formation of long drifts is prevented by the intensively crevassed areas.

In several parts of the ice tongue, groups of short, linear ridges with associated depressions seem to cut across the transverse crevasse system. The ridges resemble right angle drifts (Keys 160-162) in (1) their spatial relationship to the crevasse system and (2) the manner in which they reflect as streaks of brilliant white (Fig. 31) or dark gray (Fig. 32) according to their orientation with the sun in respect to the observer. They appear to differ from right angle crevasses in that they (1) occur in linear zones parallel to the direction of glacial movement, (2) are of sufficient age to resemble the appearance of glacier ice and to be crevassed in a manner similar to the local glacier ice, (3) frequently contain meltwater, and (4) do not have access holes to deep crevasses.

Complex crevassing (Keys 138-168) occurs almost everywhere. Several systems of longitudinal and transverse crevasses are distinctly recognizable, but vertical photography of this ice tongue and its parent glacier may be required before their precise derivations can definitely be established. Many crevasses present are typical of those that must have been formed during the period the ice flowed down the Sörsdal Glacier before entering the Sörsdal Glacier Tongue.

Others are typical of those resulting from tension andthe release of pressure which results when the ice from a confined glacier begins to spread out in a floating mass upon the sea. Although the entire glacier is crevassed, bands of open, distorted crevasses, alternating with smoother, drifted-over areas, extend the length of the ice tongue.

While the crevasses are deep, wide, intersecting and occur frequently, this ice tongue does not possess the chaotically rough surface ascribed to it by the U.S. Hydrographic Office (1943, p. 236) and the British Admiralty (1948, p. 306), especially when compared with the other ice surfaces in the area (Fig. 47) or in the Antarctic in general (Keys 36-44). This is not meant to imply that the surface of the Sörsdal Glacier Tongue is recommended for ice trafficability (Plate 1).

Hinge line depressions, not prominent in Figs. 28-35, are present nevertheless. Key 35 illustrates them well. Here they exist in the form of drifted over depressions which have blotted out the crevasses. The depressions are parallel to the ice tongue front.

There are no surface moraines of any kind present.

Drainage. Small quantities of meltwater or frozen meltwater (Keys 177-191) are visible on many portions of the ice tongue. Figs. 32, 33 and 35 illustrate a large meltwater lake near the southwest portion of the ice tongue, chains of meltwater ponds in the slight depressions between the crevassed zones, and numerous meltwater pools in the hollows associated with the linear ridges described under surface features, above. Other dark areas on the surface are caused by cloud shadows rather than damp or wet ice surfaces.

Meltwater stream patterns similar to those on the hinterland continental ice (Figs. 1, 6) do not exist on this glacier tongue. A few meltwater streams lead into the large meltwater lake and the ponds. Streams generated in the heavily crevassed areas are short-lived. The remaining meltwater streams are discussed under radiation, below.

While in 1947 the summer temperatures were not sufficiently warm to thaw the entire surface of the large meltwater lake on Sörsdal Glacier Tongue, a quantity of fresh thaw water was apparently added to the lake. It is not possible to state from the aerial photography whether additions were made to the other meltwater pools this year or whether their contents represent the accumulations of past seasons exclusively.

Radiation (Keys 169-176) from the rock area of the Vestfold Hills adjacent to the Sörsdal Glacier Tongue has produced a substantial amount of melting. The radiation from the area as a whole has created a sloped, rather than cliffed, surface on this edge of the ice tongue over which a series of meltwater streams drain into the upper reaches of Krok Inlet (Fig. 31). Likewise, radiation melting has caused the widening of Krok Inlet (Figs. 28, 29). In addition, radiation from individual rocks or islands has produced radiation moats on the Sörsdal shore of Krok Inlet (Fig. 33).

The major form of melting and drainage in the area in terms of volume is hidden from direct view and can only be estimated from associative factors. Marine contact or subaqueous melting is caused by the presence of ocean water in contact with the bottom and the lower side walls of the ice tongue. This contact continues for the entire year, rather than for just a brief summer season. The ocean is most likely a little warmer than the ice tongue which causes the ice crystals in contact with the marine waters to melt and "drain" into the ocean by solution. This process is not seasonal but may continue throughout the year. While the melting itself cannot be observed from the airphoto, the conditions under which it may occur can be assessed and its after effects, such as the lowering of the surface level, may be noted and measured, if comparative airphotos are available.

The portions of the Sörsdal Glacier Tongue surface not covered by fresh drift snow present surface patterns characteristic of ablation areas. Like marine contact melting, the process of ablation is impossible to see, but its effects are visible. Ablation is in great measure responsible for the presence of the five additional peaks which now protrude through the Sörsdal Glacier Tongue.

Measurement of solid drainage, i.e., the calving of icebergs, requires the use of comparative photography, since the rate of glacial movement and the average length of the ice tongue must first be computed.

<u>Shorelines</u>. On all sides of the Sörsdal Glacier Tongue, save for some of the portions immediately adjacent to the east where it adjoins its parent glacier and on the north where it meets the Westfold Hills (Fig. 31), the shoreline consists of vertical cliffs (Figs. 32-35a). These cliffs generally reach elevations from 100 to 150 feet above sea level, except for occasional low places such as the small bay on the southwestern tip of the tongue (Fig. 35a), some low points on the southern ice wall (Fig. 32), and the northern limit which has been exposed to the radiation from the Westfold Hills (Fig. 31). In addition to its height above sea level, the density of the glacial ice in relation to the density of water and the absence of any indication that the ice tongue is not moving with the tide make it certain that the portion of the sea cliffs below sea level are greater than the exposed portion.

In spite of the clarity of the Antarctic waters and the lack of a rippled surface at the time of the 1947 photography, the underwater portion of the cliff could not be photographed because of the angle of the sun in relation to the positions of the camera and the ice cliff and because of the presence of frazil ice crystals on the surface of the water. The apparent continuation of the ice cliff beneath the surface of the water in some of the illustrations (Figs. 35, 35a) is merely a reflection of the upper portion (Key 255).

Several interesting features may be noted concerning the cliffs which front the Sörsdal Glacier Tongue (Figs. 35, 35a). First, there is the difference in appearance between the cliff faces on the north side (Fig. 35) and on the south side (Fig. 35a). This difference in appearance is caused by the type of cliff face which remains after the calving of icebergs and subsequent avalanche erosion. Icebergs generally calve at the hinge line depressions (Keys 35, 66-70) but in one case, this is perpendicular to the principal direction of crevassing and in the other, it is not. The differences between cliffs of this type and the barrier face of shelf ice are established by comparison of these figures with Key 52. Similarly, the differences between the cliffs of ice tongues and those of piedmont glaciers can be noted by comparing these illustrations to Keys 31 and 32.

A white line occurring along the contact between the ice cliff, water and air may represent an icefoot, a wave-cut nip or a tidal mark on the ice cliff. If it were the last named, it would indicate that the body of ice concerned is not floating freely with the tide. The white line in Fig. 35 does not represent such an instance because it is in the water, not on the ice cliff and because it does not extend for the length of the cliff. Although there is some evidence of wave-cut erosion, which occurs on both stranded and free-floating ice masses, this line most likely represents a thin accumulation of brash ice along the edge of the tongue.

The de facto shoreline of the ice tongue constantly suffers changes in level and location caused by the forward movement of the uneven surface of the ice tongue, the marine contact melting, minor avalanches and the calving of icebergs. Changes in level here, then, have no direct relationship to isostatic movements or changes in sea level unless these movements affect the quality of the ice supply and the speed with which it is delivered.

A major change will occur in the frontal sector of the ice tongue when one or more icebergs are severed at the widely cracked floating fissure clearly visible in Fig. 35.

Offshore. Islands offshore the Sörsdal Glacier Tongue belong either to the Vestfold complex on the north or to the Rauer Islands on the south and are considered in the sections devoted to those regions.

Surface currents and surface winds are similar to those described for the area previously considered. A continental lead develops between the ice tongue and the drifting pack ice in the summer.

In Fig. 35 the smooth, oily character of the sea indicates the growth of frazil crystals, the first stage in the formation of thin black (transparent) sea ice. Normally this thin ice will form and break up several times before the final winter coat of fast ice takes firm hold, locking in the fledgling icebergs for another season. The tongue, itself, will continue to push forward, however, causing cracks to occur in the sea ice.

Flora and fauna. No animal or plant life (Keys 268-284) is evident or likely to exist on the Sörsdal Glacier Tongue. Except for bottom vegetation, limited because of the great depth of the water, the marine life off the ice tongue must resemble that off the remainder of the Ingrid Christensen Coast.

Human occupance. There is no record of airphoto evidence (Keys 285-343) of humans having landed upon the Sörsdal Glacier Tongue or of its surface ever having been explored. Surface landings or surface explorations by any means would be considered dangerous, but the most feasible means of approach by a small party of explorers or scientists would be by helicopter, if available, or by foot from the interior portion of the Vestfold or Rauer coastal areas. It is unlikely that sufficient motivation to accomplish this feat will occur for some time.

THE WEST INGRID CHRISTENSEN COAST

In the preceding pages the morphology of thePrydz continental ice coastal area, the Vestfold Hills coastal area and the Sörsdal Glacier Tongue, which comprise the eastern portion of the study area, has been briefly inventoried and analyzed from aerial photographs. Reconnaissance photogeography of the West Ingrid Christensen Coast (Maps 13, 14) reveals that it consists of elements of the morphological types encountered in the area previously described. Therefore, since detailed analysis of each individual ice formation or landform along the remainder of the Ingrid Christensen Coast would be repetitious, this area of typically integrated Antarctic coastal ice formations and landforms will be treated as a unit.

General description. The coast from 68°52'S., 77°42'E. to 69°48'S., 73°11'E. consists of alternating areas of ice-free insular and pseudo-peninsular groups, continental ice-covered coasts and both small and large ice tongues backed by glacial streams of corresponding volumes and rates of advance. Proceeding from the northeast to the southwest, using Maps 13 and 14 as guides, the principal morphological areas along the West

Ingrid Christensen Coast are defined as:

Rauer insular coastal area
68°52'S., 77°42'E. to 69°01'S., 77°27'E.
15 miles by coast, 12.4 miles by air line
Figs. 39-45, Map 13

Ranvik Ice Tongue coastal area
69°01'S., 77°27'E. to 69°16'S., 76°54'E.
32 miles by coast, 21.1 miles by air line
Figs. 44-50, Map 13

Svenner insular coastal area
69°16'S., 76°54'E. to 69°28'S., 75°53'E.
41 miles by coast, 29.2 miles by air line
Figs. 36-38, 51-59, Map 13

Larsemann insular coastal area
69°28'S., 75°53'E. to 69°37'S., 75°20'E.
30 miles by coast, 15.6 miles by air line
Figs. 57-73, Map 14

Publication Glacier Tongues
69°37'S., 75°20'E. to 69°48'S., 73°58'E.
50 miles by coast, 35.4 miles by air line
Figs. 66, 67, 72-90, Map 14

Sandefjord insular coastal area
69°49'S., 73°58'E. to 69°48'S., 73°11'E.
23 miles by coast, 18.6 miles by air line
Figs. 87-95, Map 14

Two offshore island groups are:

Svenner Islands
69°06'S., 76°25'E.
12 to 14 miles offshore
Figs. 36, 52, Map 13

Bölingen Islands
69°33'S., 75°10'E.
0 to 8 miles offshore
Figs. 38, 58-59, 64-73, Map 14

The region is bounded by the Sörsdal Glacier Tongue on the northeast and the Amery Shelf Ice which juts out from the Lars Christensen Coast on the southwest.

These areas were discovered by Mikkelsen (<u>Polar Record</u>, 1935, No. 10, pp. 126-129) during a cruise along these 191 miles of coastline which occurred from 2000 hours to 1100 hours on the night and morning of 20-21 February 1951. No landings were made. On 2 January 1939, Ellsworth (1939a, p. 3) sighted the Rauer Islands. The next day he landed briefly on another insular group which, from his description and that of Wilkins (1939, MS diary, 3 Jan.), may have been the Svenner Islands. On 6 January Wilkins (1939, MS diary, 6 Jan.) records brief landings made upon islands, presumably the Rauers. Ellsworth (1939a) generally agrees but places the date one day later. In all, Ellsworth (1939b) records seven islands to have been visited and 50 pounds of rock samples to have been gathered.[24] In 1937, the Norwegians made photo flights in the area. In 1947, the Americans carried out aerial photo reconnaissance of the coast and the hinterland. No landings on islands have occurred other than those just previously described, and no landings of any description are recorded for the pseudo-peninsula or mainland area.

The known, primary source references to the geography of this area include:

TABLE 4. WEST INGRID CHRISTENSEN COAST: PRIMARY SOURCES

Authority	Date	Quantity
Polar Record	(1935)	1/3 page text (from Mikkelsen).
Christensen	(1938)	Two sentences of text.
Christensen	(1939a)	No text, one aerial photo.
Christensen	(1939b)	1/5 page text.
Ellsworth	(1939a)	1/2 page text, one photo.
Ellsworth	(1939b)	1/8 page text, four photos.
Hansen	(1946)	No text, four aerial photos. Area mapped from aerial photos without ground control at 1/250,000 scale.

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[24]Wilkins divided the geological specimens into two representative collections, giving one to Lincoln Ellsworth and the other to Sir Douglas Mawson. The former collection is missing and the latter collection has never been reported upon in the professional literature.

When duplication of information is omitted, the total amount of descriptive material from published original sources (Table 4) which applies specifically to the geography of the 191 miles of coastline under consideration amounts to less than one page of printed text. Moreover, only a small portion of this text is sufficiently precise to be useful, the remainder being somewhat vague and in some instances incorrect. Published maps and photos are more helpful. The entire 191 miles of coastline have been mapped by airphotos, but without the use of ground control, at the scale of 1/250,000 (Maps 10, 11). Five airphotos and five surface photos have been published.

Maps and airphotos. Maps 10 and 11 cover the area concerned. They are reliable for reconnaissance purposes and in locating areas of ice-free terrain but entirely inadequate for precise delineation of the coastline or terrain configuration. Maps 13 and 14 are reproductions of Maps 10 and 11 overprinted with information produced in this study. If Maps 13 and 14 are folded in half horizontally and then joined laterally, a map of West Ingrid Christensen Coast results.

More than 1,780 airphotos have been made of this coast, though only five are known to have been made generally available through publication. The United States Navy aerial photography amounts to 1,641 9" x 9" trimetrogon exposures. The Norwegians have taken more than 140 7" x 7" obliques. The breakdown follows:

TABLE 5. WEST INGRID CHRISTENSEN COAST: AIRPHOTO COVERAGE

Print Nos	Angle	Roll	Mission	Agent	Alt/T	F/L	Scale	Date
26-69/1	LAV&R	65	M25 AAW	Amer USNTF68	9100	6"	18200	27 Feb 47
70-144/2	LAV&R	65	M25 AAW	Amer USNTF68	6000	6"	12000	27 Feb 47
145-169/3	LAV&R	65	M25 AAW	Amer USNTF68	3100	6"	6200	27 Feb 47
170-194/3	LAV&R	65	M25 AAW	Amer USNTF68	2900	6"	5800	27 Feb 47
133-160/2	LAV&R	66	M26 AAW	Amer USNTF68	7300	6"	14600	1 Mar 47
161-192/2	LAV&R	66	M26 AAW	Amer USNTF68	9500	6"	19000	1 Mar 47
1-25/1	LAV&R	67	M26 AAW	Amer USNTF68	10000	6"	20000	1 Mar 47
81-160/2	LAV&R	67	M26 AAW	Amer USNTF68	10000	6"	20000	1 Mar 47
30-112/2	LAV&R	69	M26 AAW	Amer USNTF68	8000	6"	16000	1 Mar 47
113-227/3	LAV&R	69	M26 AAW	Amer USNTF68	9700	6"	19400	1 Mar 47
9-26	OR	18	M26 AAW	Amer USNTF68	9800	12"	-----	1 Mar 47
124-151	OR	18	M26 AAW	Amer USNTF68	10000	12"	-----	1 Mar 47
521-680	Obl			D Norw Widerøe	6550	8½"	-----	26 Jan 37

Except for left oblique, vertical and right oblique rolls numbered 65, which were exposed in the interior, and the sixth and tenth listings above which bisect the coastline, all other photography generally parallels the coast. Some photographs include only sea ice or "featureless" icecap, but these are necessary for photo control and for ascertaining the presence or absence of small islands or significant surface features in the areas concerned. Clouds prohibited photographing some of the immediate hinterland.

Geographic delineation and place names. The insular and pseudo-peninsular groups of the West Ingrid Christensen Coast are in need of more accurate delineation. In some instances, the old names will continue to make sense when applied to the correctly delineated landforms, but in others, new names or at least new generics must be utilized. Since the area is so large in relation to the extremely numerous minor changes, only some of the more significant changes are considered here. Commencing with the Rauer Islands and proceeding from the northeast to the southwest (Maps 10, 11), the following principal changes in landform delineation or cartographic representation are in order. The more significant of these changes have been made on Maps 13 and 14:

1. Filla (Rag Island) and Hopöy (Shoal Island), the two chief islands of the Rauer Group and the two largest insular masses along the entire Ingrid Christensen Coast, must each be redrawn and separated into more than a half-dozen individual islands and many small skerries and rocks (Figs. 39-43).
2. Ranviktangen (Ranvik Tongue) of the Rauer insular coast must be separated from the adjacent rock outcrops on the ice coast. It then must be further divided into one principal island and several islets (Fig. 44).
3. The ice-free land areas inshore from Filla-osen (Rag Strait), previously designated as uncertain, may now be shown as islands, except for the second group from the southern end, which must continue to be indicated as a possible peninsula (Fig. 44).
4. The Rauer Islands may now be redrawn to show the presence of more than 125 islands and hundreds of rocks. Individually these changes are not significant, but collectively they are important in terms of navigation as well as in terms of establishing their spatial orientation and map pattern which in turn may aid in establishing the classification and origin of these features (Figs. 39-45).
5. Ranvikbreen (Ranvik Glacier) and two similar, unnamed areas nearby should be indicated as ice tongues backed by small glaciers (Figs. 45-50).
6. An indication of the presence of the small ice tongue at Hovden is quite in order (Fig. 36). The cliffed ice edge here is not indicated on Hansen's map (Map 10).

7. Larsemannfjella (Lars-boy mountains) are definitely insufficient in mass or elevation to be termed mountains. Pseudo-peninsular in their de facto character, it is almost certain that a further recession of the ice will reveal many, if not all, of these hills to be insular rather than continental (Figs. 58-63).

8. In the Larsemannfjella, Storneskloa (Large Claw Peninsula) is insular rather than peninsular and should be mapped as an island connected to Stornes (Large Cape) by a combination remnant and snowdrift glacier (Fig. 63).

9. Bölingen and Söstrene Islands appear to possess no qualities which require that they be considered as separate and distinct from each other or from the insular portions of Larsemannfjella. The major difference between these three island groups seems to be the relationship of their individual sites to varying kinds of sea ice which surround them. Although sufficient data are not yet available to be absolutely certain, the Larsemannfjella apparently become free of sea ice for a portion of almost every summer, while the sea ice surrounding the Bölingen Islands breaks up and goes out to sea less often and the Söstrene Islands are trapped in a combination of extremely heavy sea and land ice between two ice tongues. When it is considered that all of these differences are of but a temporary nature, it would seem as if the arbitrary division into three groups has no valid basis in fact (Figs. 38, 58-73).

10. Vågöy of the Bölingen group appears to be slightly distorted as it is rendered on Map 11. A string of islets adjacent to it are lacking on the map (Figs. 64, 68).

11. The Indre Bölingen (Inner Hørd) Islands also appear somewhat distorted in their presentation on Map 11, but they are faithfully represented in detail, except for Skorøy which consists of two islands rather than one (Figs. 66-67).

12. The Söstrene (Sister) Islands are indicated on Map 11 as two major islands, Vesle Syster (Little Sister) and Store Syster (Big Sister) together with three small rocks. The airphotos, however, show that one of these rocks is the exposed portion of an ice-covered island longer than Store Syster. At least two other ice-covered islands larger than Vesle Syster are in the group (Figs. 72, 73, Map 14).

13. The outstanding ice feature of the entire Ingrid Christensen Coast, according to Maps 9, 10 and 11, is a huge shelf ice which occupies the coastline from 73°55'E. to 75°20'E. and projects 22 miles into the sea. Map 11 gives no indication that this area consists of anything other than the flat, "featureless" ice plain typical of shelf ice structures. Hansen's text which accompanies his maps confirms this impression by indicating the boundary symbol used is that of shelf ice.[25] However, no shelf

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[25] Hansen (1946, p. 7): Kystlinjen er tegnet med en enkelt linje hvor dens forløp anses forholdvis konstant, og med en dobbelt linje med tverrstreker for utflytende barriere." This has been translated: "The coastline is drawn with a single line where its course is regarded as fairly permanent, and with two lines joined by crosslines for shelf ice." It may be possible that utflytende barriere can be translated more broadly than shelf ice although that is Hansen's approved translation. It then becomes necessary to determine whether the term barriere is the equivalent of the English term barrier, meaning shelf ice, or the American term barrier, meaning the cliffed edge of the shelf ice. In any case, either the statement is in error or the Norwegians did not distinguish between shelf ice and ice tongue.

ice is actually present on the Ingrid Christensen Coast, even though the standard compilation sources (U. S. Hydrographic Office, 1943, p. 237 and British Admiralty, 1948, p. 306) both so state. A large mass of floating, terrestrially formed ice does exist off the coast at this point, but only a glance at the illustrations (Figs. 66, 67, 72-90) is needed to determine that this ice is the product of the floating ice tongues of five glaciers. A brief inspection of the keys for shelf ice (Keys 47-65) and ice tongues (Keys 35-46) readily confirms this opinion. The ice here stands in startling contrast in appearance and function to the genuine shelf ice fronting Lars Christensen Land which it almost touches at the entrance to Sandefjord Bay. The character of this vast ice tongue complex should be truly represented on the map (Figs. 72-90). Accordingly, its 1947 appearance has been sketched in on Map 14.

14. The shape of the ice tongue complex changed markedly during the ten years intervening between the two photo reconnaissance sorties (cf. Maps 11, 14). The 1947 ice tongue stretched 20 miles further out to sea than the 1937 ice mass as indicated by its mapped boundaries. The ice tongue from the principal supplying glacier forms a curved spine for the ice tongue complex and in 1947, it averaged some 12 miles in width. The specific width at any one place is difficult to determine, since the sides of this tongue consist of its own massed icebergs and similar large fragments of the adjoining ice tongues (Figs. 72-90).

15. One major, three medium and one minor glaciers (Map 14), none

of which are indicated on Map 11, supply the five ice tongues that comprise the ice tongue complex (Figs. 72-75, 79, 83-84, 94).

16. Sandefjordbukta (Sandefjord Bay) also radically changed its shape during the ten years from 1937 to 1947. However, a small portion of its southern coast is fringed with islands, is partly ice-free and did not change its shape. The remainder of Sandefjord Bay is a de facto affair of an ephemeral nature created by the dynamic boundaries of the shelf ice, glacier ice and ice tongues in which it is formed. Its only (ice-covered) land boundary will form a cape rather than a bay upon eventual recession of the ice. Because the bay is of such a dynamic and ephemeral character, constantly undergoing changes in its position, shape, orientation and size, such facts should be represented on the maps and a suitable symbolization applied to its boundaries (Figs. 72-90).

17. Mount Caroline Mikkelsen must be recharted to a position directly on the coastline. There is even some evidence in the photos which indicates that this peak could be an island, but this has not been proved.

In view of these changes in the configuration of the West Ingrid Christensen Coast and in view of the Norwegian descriptive place names and generics now in use, the following names are proposed[26] and have been

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[26]These names have been submitted by the writer to the U.S. Board on Geographical Names. The names were examined during February 1952 by the Board's Antarctic Committee, at which time they were tentatively approved.

placed on Maps 13 and 14:

1. Filla Island for the newer, smaller-sized Filla (Map 13, Figs. 39, 40).
2. Hop Island for the newer, smaller-sized Hopöy (Map 13, Fig. 42).
3. Ranvik Island for the principal island which formed the Ranviktangen, (Map 13, Fig. 44).
4. Browns Glacier Tongue for the unnamed ice tongue adjacent on the south to the base of the former Ranviktangen (Map 13, Fig. 44).
5. Browns Glacier for the glacier which supplies Browns Glacier Tongue (Map 13).
6. Chaos Glacier Tongue for the unnamed ice tongue between Browns Ice Tongue and Ranvikbrekka (Map 13, Fig. 47).
7. Chaos Glacier for the Glacier which supplies Chaos Glacier Tongue (Map 13).
8. Ranvik Ice Tongue for Ranvikbreen (Map 13, Figs. 48-50, 55).
9. Hovde Ice Tongue for the unnamed ice tongue at Hovden (Map 13, Fig. 36).
10. Flatnes Ice Tongue for Flatnes (Flat Peninsula) (Map 13, Fig. 36).
11. Dålk Glacier for an unnamed glacier ending in a Fjord in Dålköybukta (Map 14, Figs. 38, 56).
12. Larsemann Hills for those portions of the Larsemannfjella which are peninsular or pseudo-peninsular (Map 14, Figs. 58, 60-61). (Approved by U. S. Board on Geographical Names in its Special Publication 86.)
13. Timid Sister, Hidden Sister and Shy Sister for three unnamed islands in the Söstrene group which lie adjacent to the eastern-

most ice tongue of the ice tongue complex (Map 14, Figs. 72, 73).

14. Debutante for the long, slim island in the Söstrene group south of Store Syster which is just beginning to "come out" from under its ice cover (Map 14, Figs. 72, 73).

15. Publication Glacier Tongues for the ice tongue complex formed by five glaciers discharging into the sea between the Bölingen Islands and Sandefjord Ice Bay (Map 14, Figs. 72-86).

16. Polarårboken Glacier for the easternmost of these five glaciers, the tongue of which passes close aboard the Söstrene Islands (Map 14, Figs. 72, 73).

17. Polar Record Glacier for the principal glacier of these five and the second one from the east which passes between the Söstrene Islands and Ausknatten, supplying the main tongue in the ice tongue complex (Map 14, Figs. 73-75).

18. Polarforschung Glacier for the middle of these glaciers which passes west of Meknattane and around Vestknatten (Map 14, Figs. 79, 83).

19. Il Polo Glacier for the fourth and least active of these five glaciers. The glacier is not as greatly crevassed as its neighbors (Map 14, Figs. 79a, 84).

20. Polar Times Glacier for the fifth and westernmost of these five glaciers, reaching Sandefjord Ice Bay and forming the western boundary of the Publication Glacier Tongues at Tvillingfjell (Map 14, Fig. 84).

21-25. Polarårboken Glacier Tongue, Polar Record Glacier Tongue, Polarforschung Glacier Tongue, Il Polo Glacier Tongue and Polar

Times Glacier Tongue respectively for the ice tongues stemming from the five glaciers listed above (Map 14, Figs. 72-84).

26. Sandefjord Ice Bay for Sandefjordbukta (Map 14, Figs. 88-92).

27. Caroline Mikkelsen Peak for Caroline Mikkelsen Fjell (Map 14, Fig. 95). (Approved by the U. S. Board on Geographical Names in its Special Publication No. 86.)

The following names are used in referring to specific island groups but have not been suggested for use as formal place names:

1. Hop Island group for Hop Island and the small islands about it (Map 10, Fig. 42).
2. Filla Island group for Filla Island and the small islands about it (Map 10, Figs. 39, 40).
3. Ranvik Island group for Ranvik Island and the small islands about it (Map 10, Fig. 44).
4. East Island group for the islands in the Rauer Islands which lie adjacent to the continental coast (Map 10, Fig. 44).

Hinterland. Along the West Ingrid Christensen Coast the hinterland appears to be similar to that of its eastern counterpart. Here, however, there is better aerial photography available with which to illustrate its principal features. The interior, to a depth of at least 200 miles, is comprised of a smooth "featureless" ice plain of the type illustrated in the foreground and middleground of Fig. 55. The icecap here is essentially level, but has a constant, although almost imperceptible, rise in elevation toward the interior. An ice elevation of 7,700 feet was measured by radio altimeter from a photo reconnaissance aircraft 105 miles inland at 70°49'S., 77°56'E. on 27 February 1947.

Inland from its initial rise near the coast, the ice presents a sastrugi-covered surface so constant in appearance that it becomes difficult to fuse the airphotos in stereo vision. Fusion is difficult because the sastrugi, which form the only visible surface features, look so similar to one another that an arduous effort is required to find and match two photo images of the same individual sastrugi. Crevasses are generally absent in this particular area. Meltwater streams, puddles and ponds are seldom in evidence here. Few, if any, of the coastal glaciers penetrate inland this far, for most of them end within a few miles of the coastline (Fig. 56).

As it nears the coast, the downward slope of the continental ice surface suddenly increases its previous rate of descent some four or more times. The release of pressure resulting from the lower end of the ice being supported in water without marginal confinement permits a series of long tension crevasses to develop in the ice flowing downslope (Fig. 57). Valleys or depressions in the bed rock surface underneath the ice, oriented in the general direction of glacier movement, may give rise to the presence of coastal channel glaciers (Figs. 54, 56, 84). The surfaces of these glaciers are generally thoroughly crevassed and may or may not be slightly depressed below the general level of the ice in the adjacent area. Occasional nunataks are met with as the coast comes within sight (Fig. 87). Glacial recession has uncovered numerous fringing rocks at the coastline. In addition to the crevasses and nunataks, meltwater features are present on the continental ice of the coastal zone. Depressions which have held meltwater streams or ponds in the past are generally covered with snow and appear as very light gray splotches on the airphotos (Fig. 56). Active meltwater ponds and streams appear dark gray and at a distance may easily be mistaken for rock, clouds or cloud shadows.[27]

Fig. 56 furnishes a good impression of the character of the hinterland surface, while Fig. 57 shows the character of the continental ice in more rapid descent as the coastline is approached. Fig. 58 illustrates the boundary between these two morphological zones. Downslope tension crevasses are also visible in the cloud shadows of Fig. 61.

Area and configuration. The West Ingrid Christensen Coast extends for 191 miles along the Indian Ocean. Airphoto coverage is available for the entire length of this coastline and for parts of the interior to depths of from 150 to 200 miles. Thus, the portion of the Ingrid Christensen Coast under consideration exceeds 30,000 square miles, or more than three times the size of the state of Maryland. Although some of the hinterland area is hidden by clouds, enough is visible to state that, insofar as the glacier surface is concerned, the great bulk (if not all) of the area behind the coastal zone may be considered as a morphological unit with a simple surface structure. This has been described under the subsection dealing with the hinterland above. However, there is considerable variation in the morphology of the coastal zone, and accordingly, it has been given more detailed attention in this study.

The approximate extent of area and the relief of the ice tongues and ice-free lands, including the islands, peninsulas and peaks, along the West Ingrid Christensen Coast are:

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[27] Meltwater features, rock, clouds and cloud shadows all appear on Fig. 73 where their relative differences in appearance may be studied.

TABLE 6. WEST INGRID CHRISTENSEN COAST: AREAS AND RELIEF

Place	Square Miles of Land	Ice Tongue	Maximum Relief[28]
Rauer insular coastal area	29	0	500 feet
Ranvik Ice Tongue coastal area	0	75	200 feet
Ranvikbrekka	0	0	1,300 feet
Svenner insular coastal area	6	21	410 feet
Larsemann insular coastal area	20	0	490 feet
Bolingen Islands	6	0	275 feet
Publication Glacier Tongues	2.5	737	640 feet
Sandefjord insular coastal area	2.5	0	770 feet
West Ingrid Christensen Coast	66	833	1,300 feet
As contrasted with:			
Vestfold Hills coastal area	200	0	425 feet
Sörsdal Glacier Tongue	0	50	200 feet

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[28]Maximum relief figures are based upon the plottings by Bernhard Luncke. Hansen (1946, p. 7-8) admits that these elevations are probably in error because of the lack of ground control. Hansen indicates the error may be as great as eight per cent. Like Hansen, this author has no ground control data. Furthermore, he lacks the plotting machinery of Luncke, which is not warranted for a reconnaissance study of this kind. Nevertheless, he is of the opinion that most elevations could be reduced by ten per cent and some by as much as 25 per cent. There are, however, no facts available to support or contest this opinion. Moreover, a change of ten per cent in the elevations of the ice-free terrain would not materially affect the conclusions of this study.

These figures show the collective ice-free lands of the West Ingrid Christensen Coast to be barely one-third of the ice-free area at Vestfold Hills. They also demonstrate the vastness of the Publication Glacier Tongues which exceed the area of the Sörsdal Glacier Tongue by some 15 times. The aggregate area of the smaller ice tongues along the Ranvik and Svenner Coasts amounts to about twice the area of the Sörsdal Glacier Tongue.

The Rauer Islands are for the most part lower in elevation than the Vestfold Hills, but a single peak on the southern shore of the Rauer insular coastal area (Fig. 40 and a partial close-up on Fig. 44) accounts for the higher relief accorded the Rauer area. The Ranvik Ice Tongue coastal area has the typical low relief of flat ice tongues, except for the roughness of Chaos Glacier Tongue (Fig. 47) and the steepness of what must be presumed to be ice-covered land at Ranvikbrekka (Fig. 45) between the Chaos Glacier Tongue and the Ranvik Ice Tongue. Ranvikbrekka rises some 1,300 feet in the first three-quarters of a mile, at a rate of one foot in elevation for every three feet inland. The steepness of this slope is matched in this area only by the ice falls of the Polar Record Glacier.

While the Svenner insular coastal area is shown as having a maximum elevation of over 400 feet, the average relief of the ice-free surfaces fringing this coast is not greater than 300 feet. The Svenner Islands range from 30 to 260 feet in elevation. The average height of all islands off this portion of the coast, excluding rocks, approximates 135 feet.

The Larsemann Hills have several peaks which rise to about 490 feet and one peak on Stornes may exceed 500 feet. The Larsemann and Bolingen Islands do not exceed 275 feet in elevation but Vesle Syster, one of the Søstrene Islands, rises to more than 400 feet above sea level.

None of the small nunataks and islands within the Publication Glacier Tongues complex or the Sandefjord insular coastal area reaches more than 575 feet in elevation, except for one of the Mekmattane, which is credited with an altitude of 640 feet (Fig. 83) and Caroline Mikkelsen Peak (Fig. 95). The last-named peak is about 750 feet in elevation and is the highest ice-free land in the region, Although it hardly has the stature of a mountain, it is nearly always termed as such in the literature.

By far the highest elevations belong to the continental ice which rises rapidly at first and then more gradually to an elevation of 7,700 feet within the immediate hinterland of the coastal zone concerned. One may surmise that this rise continues at a constantly reducing rate until the elevation of the polar plateau at approximately 10,000 feet above sea level is reached. The profile of the icecap here closely resembles the flattened dome form thought to be characteristic of continental glaciers. In some cases, the sharp rises in elevation at the coast appear to be controlled by the underlying topography rather than by the plasticity of glacier ice. Nowhere is this more evident than at Ranvikbrekka (Map 13) already cited, and at the Brattekjoesen on the Polar Record Glacier (Map 14) where the ice descends more than 1,500 feet in less than a mile.

The many ice-free islands and fringing rock shorelines of the West Ingrid Christensen Coast are still dwarfed by the continental ice from which they are emerging. While these ice-free areas are conspicuous by their very presence in a land where ice cover is ubiquitous, the coast is really dominated by the continental glacier. In order to maintain the proper perspective during the evaluation of this coast, it is necessary to keep this fact in mind, for the greater portion of the text and illustrative materials presented here are devoted to the ice-free areas, ice tongues and coastal glaciers. This was made necessary by the more complex surface morphology of these forms and the greater significance of the coastal areas.

<u>Surface composition</u>. The two principal surface materials of the West Ingrid Christensen Coast are ice-free bed rock and glacier ice. Associated with the bed rock are small quantities of morainic materials. Since the ice-free land is primarily composed of small bed rock islands and peninsulas, the surfaces of which are almost entirely in slope, the places in which moraine may accumulate above the surface of the sea are few in number and small in size. Individual boulders and small deposits

of moraine are plentiful, but in the main, the surface rock of the area is bed rock. Soil, as such, is nonexistent here, but some areas possess small penguin rookeries, the guano of which, in association with fine glacial debris, comprises the closest approach to soil in this area.

Dikes, which played an important part in the character of the Vestfold bed rock, are present here, but to a markedly lesser degree. The student need only compare Fig. 10, which illustrates the intrusive activity in the Vestfold Hills, with Figs. 39, 63, 64, 65 and 67, which show the dikes and probable intrusives in the area under consideration, to note the difference in the quantity of dikes present.

Although dikes are largely absent from the area at hand, it seems reasonable to state that at least a portion of the bed rock, if not most of it, is metamorphic. The islands toward shore in the middleground of Fig. 40 contain vertical banding of the sort that is common in gneissic rocks.

Strictly speaking, major structural lines in the rock may be considered as surface features. They are treated here not only because they extend into the rock structure and are related to its formation, but also because they are one of the best indicators of surface materials. Lines in bed rock indicative of morphological structure are caused by such factors as the presence of bedding planes, joints, faults, mineral banding, schistocity, strandlines or intrusives. These lines are sometimes rendered visible to the airphoto interpreter when outlined by crevice-lodged snow, when highlighted by sun reflection or darkened by shadow, and when outlined by difference in photo tone or by three dimensional vision.

These lines in the rock structure are not always visible in airphotos, but they are apparent in Figs. 36, 39, 40, 42a, 44, 51, 59, 60, 63, 64, 65, 67, 68 and 95. Most of these lines are not parallel to the general direction of glacier movement in this area, a fact which would seem to eliminate glacial grooving as a primary cause. There are a few notable exceptions to this, particularly in the case of Caroline Mikkelsen Peak, Klungöyane and the adjacent islands (Fig. 95) and at Hopöysteinane in the Rauer Islands (Fig. 42a). Most of the lines, however, appear to trend generally parallel to the coast in a northeast--southwest orientation (Figs. 40, 58, 60, 64, 65, 68). In several areas, more than a single set of lines has been observed (Fig. 51). In the majority of such cases, it is quite probable that at least one of these series of lines represents lines of foliation, indicating the presence of metamorphic rock.

Along the Prydz continental ice coastal area, Småskjera (Fig. 2) and Tvistein (Fig. 3), the only two areas of exposed rock in more than 92 miles, lie within a few miles of each other and are obviously of different composition. Similar variety is thought to exist in the Vestfold Hills and again along the West Ingrid Christensen Coast.

In all of these regions, however, there is evidence that rock of a metamorphic character predominates.[29]

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[29]In some areas, the true nature of the bed rock is very difficult to determine even from field analysis. Dr. Earl Apfel, Chairman of the Department of Geology at Syracuse University, would not state the nature of the bed rock at Bunger's Lakes, 600 miles to the east, after spending several days there in the field with this author in 1948. The rock was so complex that he preferred to make thin sections and laboratory analysis before making a positive statement concerning its metamorphic character. Drs. Mayuga and Chisnell, geologists attached to the Headquarters, U. S. Air Force, as well as William Fischer and members of his arctic photogeological staff at the U.S. Geological Survey examined the airphotos of

The basic ice component of the West Ingrid Christensen Coast area is glacier ice. For the most part, this is covered by layers of firn and snow in the hinterland (Fig. 55). During its rapid descent from the hinterland to the sea, however, the glacier ice is swept clean of loose firn and snow, except for small amounts which are lodged in the crevasses or the surface depressions (Figs. 56, 57). Along the coastal areas, the drift snow has lodged in the rough portions of the local glaciers and has filled in many of the crevassed areas on the ice tongues (Figs. 44, 49, 77, 78).

Surface features. The landforms most frequently associated with Pleistocene continental glaciation in the northern hemisphere are not found along the West Ingrid Christensen Coast. The ice-free rock reflects the recent presence of the continental glacier more through its rounded contours than from glacial polish or large deposits of moraine. The glacially excavated channels so evident in the Vestfold Hills coastal area in the form of long lakes, chains of lakes or dry valleys are not nearly so conspicuous in this area south of the Sörsdal Glacier Tongue. The illustrations of the Rauer and Larsemann insular coastal areas, however, may well lead one to believe that it is only a matter of time until continued ice recession and isostatic adjustment to glacial unloading bring such channels above sea level.

Surface features associated with continental glacier ice, however, are not lacking on the West Ingrid Christensen Coast. Conversely, the coast is dominated by the overwhelming presence of the continental glacier

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this area after this chapter was written, but were unable to make positive statements concerning the origin of the local rock which would contradict the opinions held here.

itself and characterized by the presence of many coastal channel glaciers and ice tongues.

Map 13 shows the ocean to be penetrated here by Browns (Fig. 44) and Chaos (Fig. 47) Glacier Tongues as well as by Ranvik (Figs. 48-50), Hovde (Fig. 36) and Flatnes (Fig. 36) Ice Tongues, each of which is backed up by a relatively short coastal glacier.

Map 14 illustrates the Dålk (Figs. 38, 60) and Hargreaves (Figs. 87, 93, 94) Glaciers to be without ice tongues. The Polar Record Glacier Tongue (Figs. 74, 75), supported by the floating extensions of the Polarårboken (Figs. 72, 73), the Polarforschung (Figs. 79, 83), the Il Polo (Figs. 79, 84) and the Polar Times (Fig. 84) Glaciers, forms the Publication Glacier Tongues complex, the main tongue of which extended 42 miles to sea in 1947 (Figs. 85-86, 88-90).

Nearly all of the glaciers of the area have a common pattern but vary considerably in size. From their appearance, it would seem that each one occupies a subglacial rock depression which acts as a funnel for draining the adjacent fields of glacier ice. In most cases the ice surface of these glaciers forms a steep incline or an ice falls just before reaching the sea, becoming intensively crevassed as it does so. Il Polo and Hargreaves Glaciers are not so crevassed and are therefore exceptions to this rule.

The ice tongues fall into several categories. They may be entirely lacking as in the case of Dålk and Hargreaves Glaciers. They may be similar to Sörsdal Glacier Tongue in surface and barrier characteristics, but not in length, as in the cases of Browns Glacier Tongue and Ranvik, Hovde and Flatnes Ice Tongues. They may possess a fantastically rough surface, as in the case of Chaos Glacier Tongue. The tongues of five of the glaciers, Polarårboken, Polar Record, Polarforschung, Il Polo and

Polar Times Glaciers, form an associated complex. The surface features of these tongues are considered elsewhere in this section and in the section on drainage.

The Publication Glacier Tongues deserve special mention. The Polar Record Glacier sends forth a tongue of ice which in 1937 was mapped as extending 22 miles out to sea (Map 11). By 1947, this distance had increased to approximately 42 miles (Map 14). Near its base, this tongue is joined by tongues from the four glaciers mentioned in the latter part of the previous paragraph, all of which merge into a multi-spined mass of ice tongues afloat with masses of icebergs trapped between the spines, frozen in a matrix of heavily drifted sea ice. This ice complex in no way resembles shelf ice, and yet every document known to the author which mentions the presence of ice on both sides of the Sandefjord Ice Bay terms this mass as such. Conversely, there is no mention of the presence of an ice tongue here, to say nothing about such a vast ice tongue complex.

Ice tongues are structurally different from shelf ice. The former normally possess a much smaller fraction of firn ice derived from the accumulation of snow and loose firn over a period of many years. The surface of the ice tongue is therefore less regular and the mass considerably more dense than the corresponding surface and density of shelf ice, all other factors being equal. The icebergs which form from these masses reflect the character of their parent ice mass. Icebergs from tongues are likely to ride lower in the water than shelf icebergs and also to have a more rounded, crevassed surface and irregular outline rather than a tabular shape.

The Polar Record Glacier Tongue of the Publication Glacier Tongues complex advanced seaward with an average annual net gain of at least two miles during the decade between 1937 and 1947. Concurrently, the Amery Shelf Ice (Map 11, Figs. 85-93, 99-101), which forms the opposite shore of Sandefjord Ice Bay, also advanced seaward at an undetermined, but slower, rate. A cursory glance at the 1937 and 1947 positions of these ice masses as printed and sketched on Map 14, demonstrates that soon the ice tongue and the shelf ice must meet. As a matter of fact, the meeting has without doubt occurred prior to the writing of this chapter, which was prepared during the season of 1951-52 but based on airphotos of the season 1946-47. When the two ice masses met, pressure from the shelf ice exerted upon the tongue may have caused a huge iceberg, perhaps 30 miles in length, to calve from the Polar Record Glacier Tongue and float out to sea. It would be unlikely that a major segment of the shelf ice would be broken off at the same time because of the orientation of the pressures in relation to the structure of each at the time of the meeting of the two ice masses.

The Publication Glacier Tongues and the Amery Shelf Ice off the Lars Christensen Coast, both dynamic ice masses, have previously been cited as forming the east and the west coasts of Sandefjord Ice Bay (Map 14), which also merits special consideration here. The other limits to the bay are the Baker Three Glacier (Map 15) on the southwest and the Sandefjord insular coastal area (Map 14) on the southeast. The latter is covered by continental glacier ice in recession, exposing fringing ice-free islands and peninsulas and as such is the only relatively stable coast of the Sandefjord Ice Bay. The bay is dependent upon the shelf ice, the floating ice tongue complex and the glacier. The movements of these three ice masses determine the size of the bay, the width of its entrance and even its very existence.

Changes brought about by ice movement of these components continually alter the character of Sandefjord Ice Bay. For example, the entrance to the bay in 1937 was 12.5 miles wide, whereas 10 years later the same entrance had been reduced to a small fraction of one mile in width. The functioning of this pincers movement is evident in the shear cracks of the year-old sea ice covering the waters of the bay (Figs. 93, 95) and in the icebergs trapped by the narrow bottleneck entrance (Figs. 86, 89, 90).

Ice bays of this sort, with a relatively constant presence but an essentially ephemeral character, occur elsewhere in the Antarctic, as for example the Bay of Whales in the Ross Shelf Ice (Keys 56-65). In that case, the sides of the bay are formed by two segments of the Ross Shelf Ice which are split by Roosevelt Island. The effect of the independently moving shelf ice segments which continually change the appearance of this famous bay has been described many times in the professional literature. In spite of the fact that the character of the Sandefjord Ice Bay changes with more than six times the celerity of its famous Ross Sea counterpart, no references to its ephemeral character are noted in the descriptions of the area.

Icebergs form along all parts of the Ingrid Christensen Coast, except at the Vestfold Hills. The Publication Glacier Tongues are veritable iceberg factories, producing these floating ice masses in large numbers, in addition to their ability to accomplish short term net gains in their own length approximating 10,000 feet per annum. Since icebergs generally float away upon calving, not a great deal can be discovered concerning the icebergs which form in a particular area unless the investigator is on the site when the calving takes place. Here, however, many of the icebergs are trapped between the spines of the various ice tongues comprising the complex or in Sandefjord Ice Bay (Map 14) where they may be examined in situ after their formation. Fig. 80, a vertical stereogram of the area in the middle background of Fig. 79, is a particularly good example of icebergs which have formed as a result of the impact of the Polarforschung and the Polar Record Glacier Tongues. If met at sea, these icebergs would undoubtedly be classified as tabular by all but the most discriminating eyes. While their shapes are indeed tabular, their contents are of glacier ice rather than the large percentage of compressed firn ice associated with the classical concept of tabular icebergs of shelf ice origin.

Some mention of the size of these icebergs is of interest. The iceberg in the center of the stereogram Fig. 80 is 0.42 miles in length, while the one on its right from which it has just recently separated (wholly visible in Fig. 79) is 4.59 miles long. These by no means represent the spread of sizes, for many icebergs are substantially smaller than the former or larger than the latter. A conception of the size and distribution of the icebergs here may be gained from examination of Figs. 79 and 86. Fig. 90 is interesting in that it demonstrates how a large section of ice tongue may break off and effectively prevent smaller icebergs from drifting out to sea by blocking the bottleneck entrance to the bay. A block in this position would also prevent the sea ice from escaping were the sea ice to break up under marine and wind influences. Because of this fact, it may be estimated that the large iceberg has not been blocking the bay entrance for more than a year, since the ice within the bay does not appear to be more than a year old. The evidence for this is the lack of pressure ridges in association with the shear cracks in the sea ice produced by the pincers movement of the bay's independently moving sides (Key 63).

Among the lesser surface features, crevasses, hinge lines, floating fissures, reentrant rifts, drift and sastrugi merit comment. Crevasses (Keys 138-168) first come into prominence at the beginning of the steep slopes which mark the coastal zone. Here they emerge by reason of wind loss of the surface snow cover, the widening of pre-existing cemented crevasses and the opening of new ones from the effects of tension (Fig. 57). In some instances, the long tension crevasses which are generally parallel to the contours of the slope are interrupted by shorter crevasses caused by obstructions in the underlying rock topography (Fig. 57). Similar short crevasses perpendicular to the glacier edge occur where the glacier meets the sea near a fringing rock, rock shoal or other obstruction (Figs. 43, 51). Sometimes this may occur near the edge of an ice tongue, causing crevasses similar to those appearing on Fig. 49. Small basins at the coast, acting as ice accumulators, create both normally and transversely oriented tension crevasses in their short runs to the sea (Fig. 54). In some cases, crevasses and seracs develop which cannot be covered by drift before the ice in which they are formed calves off the main mass or ice tongue and goes out to sea. Moreover, the main system of crevasses and seracs may be aligned with the prevailing wind direction, as at Chaos Glacier Tongue (Fig. 47), rather than perpendicular to it, as at Ranvik Ice Tongue (Fig. 49). In the former instance, the energy of the wind is harnessed to keep the seracs and crevasses free of drift snow, while in the latter case, loose firn and snow drift into the crevasses and a considerably different ice structure results (contrast Figs. 47 and 49). Since ice tongues frequently have several differently oriented groups of crevasses, it is common here to find some belts of crevasses kept free of drift by the very same winds that cover the adjacent crevasses with drift (Fig. 44).

Crevasses which form and widen during the descent to sea level normally become inactive when the ice mass in which they are situated becomes afloat. If these crevasses are not aligned with the wind, they will fill or bridge and drift over until completely lost from view, provided they are not calved off in icebergs before that stage is reached. Such a series is to be seen in the airphotos of the Polar Record Glacier Tongue taken near its base, midsection and calving end (Figs. 76, 77, 78, 86). Note, however, that even after the crevasses have been covered, the airphoto can be used to trace them and determine their orientation, width and frequency. The faint lines which permit this airphoto interpretation are not visible to the surface observer. It may also be noted that the crevasses are not always completely covered, even under favorable circumstances. The larger seracs in the center of the rolls between the hinge line depressions may remain uncovered after all traces of the other crevasses have vanished (Fig. 81).

Hinge line depressions (Keys 66-70) occur on all ice tongues (Keys 35-40) of the area and are remarkably well developed on the Publication Glacier Tongues. Figs. 76, 77, 78 and 86 show the development of the hinge lines from a point near the base of an ice tongue to the extremity of the same tongue. Their steep sides are created at their point of origin where they act as the hinge or axis upon which the tongue rises and falls with the tide. Once the ice mass has pushed sufficiently far into the sea to permit tidal leverage to crack a new hinge, the old one becomes inactive. This is the stage shown in Fig. 76. The steep sides and extreme depth of the hinge line depressions become less pronounced as drift begins to modify their shape (Fig. 77). At the extremity of the ice tongue the hinge lines frequently, but not always, act as zones of weakness and predetermine the size and shape of the icebergs which form (Fig. 78).

In Fig. 85, it is possible to see that these hinge line depressions are sometimes of a compound nature. That is, the hinge lines may be oriented in several directions (Key 67), rather than in simple lines parallel to each other and to the ice tongue front and perpendicular to the direction of the ice movement (Key 66). The precise reason for this has not been established, although the writer believes it to be caused by the shape of the line at which the tongue becomes waterborne, as well as by bottom obstructions in this area. On the Polar Record Glacier Tongue there exists in the conventional position a major series of hinge lines to which are connected several series of short hinge line depressions oriented at oblique angles. A similar pattern of hinge line depressions occurs on the Amery Shelf Ice (Fig. 89).

Floating fissures (Keys 49, 151-154) and reentrant rifts (Keys 155-158) both occur in the Publication Glacier Tongues. The origin of the floating fissures (Figs. 72-75, 78) here must lie in good measure within the complex stresses and strains established by the collision of the five ice tongues, rather than in the simple tension near the edge of floating ice masses which normally accounts for their presence. Some of the reentrant rifts (Figs. 79, 83, 84) are created by pressure at the junctions of the various ice tongues, while others owe their origin to the presence of nunataks at the foot of glaciers (Maknattane, Fig. 83) or of islands which split the ice tongues (Vestknatten, Fig. 83).

Hinge line depressions, floating fissures and reentrant rifts all occur on the Amery Shelf Ice on such a grand scale that they can be seen in the distant backgrounds of Figs. 87 and 91-93, although the nearest ones are 12 miles away and the farthest ones nearly reach the horizon.

Drift is evident almost everywhere. Only some of the steeper coastal slopes of the continental glacier have been swept clear of drift and even here it is found lodged in the crevasses and in the depressions (Fig. 56). On the ice tongues it has partially (Fig. 44) or almost wholly (Figs. 48-50) obliterated the original crevasse and serac structure, depending upon the orientation of this structure to the prevailing winds. Figs. 81 and 82 demonstrate the effect of drift in camouflaging the Sandefjord Ice Bay and Bolingen Island sides of the Publication Glacier Tongues. In the latter case, it is especially difficult to tell where the ice tongues end and the drift-covered sea ice begins, in spite of the rapid rate at which the ice tongues are moving. Drift also covers icebergs within the tongue complex (Fig. 79c) and provides natural ramps for the floating fissures therein (Fig. 74). Right-angle drifts can be seen developing at holes in the crevasse lids in Fig. 57. A drift-ice glacier creates a temporary tombolo at Stormesklon (Fig. 63). In fact, drift seems ubiquitous, its varied effects being found on the airphoto illustrations of all of the West Ingrid Christensen Coast.

Sastrugi (Keys 96-117) have been previously cited as being best developed in the hinterland (Fig. 55), then fading out and disappearing (perhaps for lack of snow) on the steeper coastal slopes of the continental glacier. Where the drift snow and firn again accumulate on the ice tongues, sastrugi also occur, although their formation is sometimes hampered by the presence of rough ice, seracs and crevasses. Where the drift has succeeded in obliterating this roughness, the sastrugi have formed with greater regularity. Figs. 84, 93 and 94, however, show the absence of well-formed sastrugi in some coastal zones even where snow cover is present. Figs. 77 and 78 show two delicate patterns of relatively small sastrugi which exist on the snow cover hiding the crevasses near the extremity of the Polar Record Glacier Tongue.

No surglacial deposits of moraine are visible anywhere within the West Ingrid Christensen Coast area. Banded icebergs, however, appear trapped in the sea ice of Sandefjord Ice Bay off Tvillingfjell (Fig. 84), which indicates the presence of englacial material somewhere in the area. It lies within the realm of possibility that these particular icebergs are products of the Amery Shelf Ice or even that they drifted into Sandefjord Ice Bay from somewhere else, but their appearance as a group, the blocked mouth of the bay and the fact that shelf icebergs are not usually banded, all indicate the formation of the icebergs from some part of the southern coast of the Sandefjord Ice Bay.

Drainage. In the ice-free regions of the West Ingrid Christensen Coast, the terrain generally consists of bed rock sloping down to tide water. No permanent streams are known to exist here. Tarns (Keys 212-213) are present, however, in the few areas where sufficiently large collecting basins exist on the rock surface. Perched tarns occur in the Rauer Islands (Figs. 40, 42), Larsemann Hills (Figs. 60, 62, 63), Larsemann Islands (Fig. 61) and the Bolingen Islands (Figs. 64, 65).

Ice drainage occurs by ablation, subaqueous solution and the calving of icebergs. Ablation is probably active throughout the area but is difficult to discern from photo analysis, even if ablation pits are created on the surface. Subaqueous solution of the portions of the ice tongues and glaciers in direct contact with the relatively warmer marine waters is also difficult to determine from aerial photos. However, the amount of ice surface exposed to ablation and (to a lesser degree of accuracy) the amount of surface exposed to marine melting can be determined by airphoto analysis. If climatic and oceanographical data exist in sufficient detail, they can be applied to these surface areas to provide an estimate of ice wastage through ablation and subaqueous drainage. Unfortunately, this data does not yet exist for the West Ingrid Christensen Coast.

Solid drainage, the calving of icebergs (Keys 23-24, 35, 54, 71, 74-77), cannot be determined from a single set of aerial photographs. Comparative cover is required, with the degree of accuracy depending upon the number of comparative airphoto missions and their time relationships. In the case at hand, there are only three airphoto missions, two of them within 48 hours of each other and the other one ten years previous. While these missions have permitted an estimate of the net annual gain over a period of ten years, they have been either too close together or too far apart to determine the exact rate of solid drainage. It can be stated with accuracy, however, that (1) solid drainage is more rapid at the Publication Glacier Tongues than anywhere else along the Ingrid Christensen Coast and that (2) solid drainage undoubtedly accounts for more ice wastage in the Publication Glacier Tongues area than either ablation or subaqueous melting.

A considerable amount of airphoto evidence exists concerning surface thaw and runoff (Keys 169-214). Sizable meltwater lakes are visible at the base of the Publication Glacier Tongues, particularly near the base of the Polar Record Glacier Tongue, at the Polarårboken Glacier Tongue and the area between these tongues (Figs. 72-75, 79). The hinge line depressions of the Publication Glacier Tongues also contain meltwater (Figs. 75, 76). Ponds and puddles of meltwater are visible on the Ranvik Ice Tongue (Figs. 48, 49). Meltwater lakes also occur midway on Dålk Glacier (Fig. 56). Large meltwater streams are lacking, however, and even small ones of any length are scarce. Apparently most meltwater drains directly into the ocean, into local meltwater lakes, ponds and puddles or disappears into the crevasses. The iceforms of the area preclude large drainage basins.

Radiation (Keys 169-176, 193-214) is far less effective here than in the neighborhood of the Vestfold Hills where 200 square miles of ice-free dark rock absorb and reradiate sufficient heat to affect the surrounding ice. The best evidence of the occurrence of radiation along the West Ingrid Christensen Coast is at Caroline Mikkelsen Peak (Fig. 95) and at the adjacent peaks where radiation from the dark rock in an area of slow moving ice has permitted the formation of radiation moats (Keys 173-176) and meltwater ponds. Another local evidence of radiation melting occurs at Flatnes Ice Tongue (Fig. 36), but in general, the phenomenon is lacking here because of the small size, insularity and scattered distribution of the ice-free land masses.

Shorelines. If from this study the reader has gained the impression that the shoreline of the West Ingrid Christensen Coast is extremely more complicated than that of the East Ingrid Christensen Coast, he must remember that in the analysis of the latter, individual "pure" type areas were examined as a feasible method of becoming acquainted with them. The approach to the area at hand has been one of dealing with a more typical, multi-element Antarctic coast. Actually, in all of the West

Ingrid Christensen Coast area there are only two kinds of ice terrain which were not examined in detail in the eastern areas. These are the kinds of ice found in the Baker Three Glacier, which borders its southern extremity and which will be considered in the section on the Ingrid Christensen Coast Extended, and the Amery Shelf Ice, which forms the west boundary of Sandefjord Ice Bay and, therefore, is actually outside the study area of this thesis.

Islands lying offshore, some of which are connected to the mainland by glacier ice, occur in the Rauer (Figs. 39-44), Svenner (Figs. 36, 51-54), Larsemann (Figs. 38, 58-73) and Sandefjord (Figs. 92-93, 95) coastal areas. The de facto shorelines here consist of an admixture of ice-free rock peninsulas and bluffs intermingled with low ice cliffs. When sea ice conditions permit a close approach to the shore, relatively easy access to the continent may be gained by the simple expedient of avoiding the ice cliffs and climbing to the continental ice surface over the rock fringe.

Browns and Chaos Glacier Tongues, Ranvik, Hovde and Flatnes Ice Tongues and the Dålk and Hargreaves Glaciers present vertical ice cliff shorelines similar to the one previously described for the Sörsdal Glacier Tongue. While the Publication Glacier Tongues are similar to the Sörsdal Glacier Tongue in many ways, there are some significant differences. The primary one is the greater instability of the shoreline of the former, which apparently advances and retrogresses (by calving) at a far more rapid rate. The accessibility of the shoreline also differs between the two areas. At the Sörsdal Glacier Tongue all sea faces are vertical ice cliffs, while the edges of the Publication Glacier Tongues facing Sandefjord Ice Bay are so infested with partly or wholly calved icebergs all compounded by drift, that it is difficult to tell just where the true edges of these ice tongues lie. A large portion of the east side of the Publication Glacier Tongues is bounded by old sea ice and drift. Here it is possible for one to descend from the ice tongue to the drifted sea ice, to the heavy floe sea ice, to the one-season sea ice and finally to open water without meeting any cliffs. Strips of photos indicating such a course are presented as Fig. 82abc.

The precise location of the real shoreline of the West Ingrid Christensen Coast as opposed to its de facto shoreline is difficult to determine (Keys 231-232, 237-241). Except for peninsulas and fiords, it probably exists somewhere between the 100- and 200-meter formlines on Maps 10 and 11. As yet, there is no concrete evidence to prove that any one of the pseudo-peninsulas uncovered by the recession of the continental glacier is definitely a part of the Antarctic mainland. On the other hand, there is no convincing proof that certain of the higher portions of the Rauer and Larsemann insular coastal areas are not parts of the mainland.

In any event, the question as to the real significance of the present true coastline may properly arise, since the loss of a sufficient amount of ice to reveal it might result in an important local isostatic change such as that which now must be occurring in the Vestfold Hills, for which ample evidence has been shown previously. If all this should occur, the fringing rocks and pseudo-peninsulas which now fall suspect of being of insular character would become a definite part of the mainland. Indeed, it is possible that eventually the isostatic changes might be of sufficient magnitude to include all the Rauer, Larsemann and Bölingen Islands as a part of the Antarctic mainland.

Offshore. There are no essential differences in the offshore conditions here compared to those previously ascribed to the several areas of the East Ingrid Christensen Coast. The Svenner Islands, a group of about a dozen islands and rocks (Fig. 52) exist some 12 miles north of Hovde Ice Tongue on the Svenner insular coastal area. Unfortunately, the aerial photography available is not of sufficient quality to count these islands accurately, much less to perform a photogeographical analysis of them.

Flora and fauna. Precisely the same type of life exists here as previously reported for the Vestfold and Sörsdal areas. The amount of life on the Ingrid Christensen Coast which is related to the presence of Adelie penguin rookeries (Keys 272-274), however, decreases to the southwest from the Vestfold Hills. The largest rookeries and the largest number of rookeries are on the islands off the Vestfold Hills. While several prominent colonies occur in the Rauer Islands (Figs. 39, 41), these grow fewer, smaller and farther apart toward Sandefjord Ice Bay.[30] The general absence of rookeries in the southwestern area may be ascribed to the fact that the annual departure of the sea ice from around these islands and peninsulas is either very uncertain or occurs very late in the season. One must also consider that there is relatively little ice-free land suitable for Adelie rookeries in the southwestern areas.

Human occupance. No airphoto evidence (Keys 285-343) or other records exist of humans ever having landed on any part of the West Ingrid Christensen Coast, although Ellsworth and Wilkins (1939, MS diary, 3 Jan.)

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[30]The Svenner Islands must be excepted from this statement, since the scale and oblique angle at which they appear in this photography make photo analysis of this detailed nature impossible.

landed briefly one evening on the Svenner Islands 12 miles offshore and on the Rauer Islands. Mikkelsen and Christensen have sailed past the area.

INGRID CHRISTENSEN COAST EXTENDED: BAKER THREE COASTAL AREA

One of the rewards of original research is the occasional occurrence of a bonus in the form of a significant discovery of a totally unexpected nature. Such an occurrence was brought about by the photogeographical analysis of the Ingrid Christensen Coast, when a hitherto unknown coast was discovered.

According to all existing maps and literature, the Lars and Ingrid Christensen Coasts join at Sandefjord Bay (Map 11). This was a reasonable statement from shipboard analysis, since the de facto coasts of these two lands do join at this point. But Sandefjord Bay is formed in ice and is more correctly termed Sandefjord Ice Bay (Map 14).

Aerial photographs (Figs. 96-101) clearly show that the true coastline of the Ingrid Christensen Coast does not meet the coastline behind the Amery Shelf Ice near this point, but instead, continues in a southwest direction for a distance not yet exactly determined, but certainly for more than 65 miles (Map 15).

This extension possesses a character quite apart from either that of Lars or Ingrid Christensen Coast. The designation "Baker Three coastal area," after the name of the first aircraft to visit and to photograph this area (27 February and 1 March 1947), is suggested, to permit the area to be distinguished from the former Christensen Coasts. The names given to the individual landforms and ice structures thereon, (Map 15, Figs. 96-101), honor the members of the two aircrews who endangered their lives to obtain this photography, which is the only record of the area.[31, 32] While the Baker Three coastal area did not constitute a part of the original problem, the determination of its presence is of such moment that it must be treated here, if only in an abridged manner.

The Baker Three coastal area is a southwestward continuation of the true Antarctic coast from the point at which the de facto Christensen Coasts join at Sandefjord Ice Bay. There is no water along the coast, unless it be underneath or permeating the glacier ice which borders it. The coast has not been explored previously; its existence has never been recorded.

Only the northeastern portion of the Baker Three coastal area is visible on Map 11. Except for this extremity, neither it nor the area in which it lies appears on any of the maps in Hansen's Atlas (1946), which is devoted to the mapping of this portion of the Antarctic coastline. For this reason, the coast and its immediate hinterland have been sketched on Map 15. The area is also covered by the following aerial photographs:

TABLE 7. BAKER THREE COASTAL AREA: AIRPHOTO COVERAGE

Print Nos	Angle	Roll	Mission	Agent	Alt/T	F/L	Scale	Date
155-206/2	L&VAR	67	M25 AAW	Amer USNTF68	10000	6"	20000	1 Mar 47
1-5/1	L&VAR	68	M26 AAW	Amer USNTF68	9600	6"	19200	1 Mar 47
1-69/1	L&VAR	65	M25 AAW	Amer USNTF68	9100	6"	18200	27 Feb 47

The delineation of the Baker Three coastal area is well displayed

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31 Three aircrewmen lost their lives in crashes induced by the Antarctic "white day" phenomenon while photographing the Antarctic coastline during this 1946-1947 season.

32 These names have been submitted by the writer to the U. S. Board on Geographical Names. The names were examined during February 1952 by the Board's Antarctic Committee, at which time they were tentatively approved.

in Fig. 96, on which the coastline is visible as a series of ice-covered and ice-free bluffs trending directly away from the observer. To its left (northwest) the Baker Three Glacier collects the contents of the ice pouring over the coast from the hinterland, forming a sort of a solid shore current which flows toward Sandefjord Ice Bay in the background. This glacial ice stream separates the Baker Three coastal area from the Amery Shelf Ice (Map 15), visible in the upper right of Fig. 96 and in the backgrounds of Figs. 99 through 101. To the right (southeast) of these bluffs lies the continental glacier.

Proceeding southwestward from Sandefjord Ice Bay (Map 15), the coastal bluffs are at first rather indistinct under the ice-covered coast. Soon, however, the Statler Hills (Figs. 96, 99) appear as a group of about a dozen ice-free peaks protruding from a single ice-covered rock mass and from here on the coastal outline is quite definite. Between the Statler Hills and the McKaskle Hills lies the Rogers Glacier (Figs. 96, 99), the first of several sizable glaciers to emerge from this coast. It is interrupted by the Maris (Fig. 99) and the Whisnant (Figs. 96, 99) Nunataks, which at some future date may possess functions similar to Meknattane and Vestknatten of the Polarforschung Glacier (Fig. 83) in splitting the floating ice tongues of these glaciers and causing reentrant rifts to form.

McKaskle Hills (Figs. 96, 100) and Mistichelli Hills (Figs. 96, 100) are the principal ice-free sections of the coastal bluffs between Rogers and Stevenson Glaciers. The latter (Figs. 96, 101) is the second largest glacier to discharge from this coast into the Baker Three ice stream. Near the mouth of Stevenson Glacier the ice apparently cascades over coastal bluffs, producing the Peterson Ice Falls (Figs. 96, 101).

Brunstetter Rocks (Fig. 96) and Thil Island (Figs. 95, 98) separate Stevenson Glacier from Jennings Promontory (Figs. 96, 96a, 97), an asymmetrical ridge which presents its steep side to the coast. Jennings Lake (Figs. 96, 96a, 97) borders Jennings Promontory at the coast.

Kreitzer Glacier (Fig. 97), a third large glacier discharging from the hinterland, lies adjacent to the Jennings Promontory. Continuing southwestward are the Reinbolt Hills (Fig. 97). At this point Gillock Island (Fig. 97), by far the largest known island along the entire area covered by this study, appears offshore between the Baker Three Glacier and the Amery Shelf Ice. Spayd outlier (Fig. 97) lies offshore near the southern end of Gillock Island and Preston Point is at its northern extremity. Five separate mountain ranges are visible on the distant horizon above Gillock Island and beyond the Amery Shelf Ice (Fig. 97).

The hinterland of the Baker Three coastal area seems to be similar to that of the West Ingrid Christensen Coast in all pertinent respects.

The aerial photography is not of sufficiently good quality to permit identification of the character of the ice-free bed rock. Definite distorted lines in the rock structure appear on Jennings Promontory above Jennings Lake (Fig. 96a), a fact which suggests the possibility of a continuation of the metamorphic rocks of the Ingrid Christensen Coast.

Many glacier surface features here differ from their counterparts along the Ingrid Christensen Coast. For instance, here occur the only surglacial medial moraines (Keys 202-206) encountered in the entire area under consideration (Figs. 96-98, 100-101).

Meltwater features (Keys 177-191) are particularly prominent. Numerous streams, streamlets, lakes and ponds appear on the surface of the Baker Three Glacier. Such features are clearly visible on every photograph of the area (Figs. 96-101). Moreover, all of the meltwater features appear to be active. The lakes are thawed or show signs of thaw. The nearly level ice surface of the Baker Three Glacier is honeycombed with tiny meltwater streams, some of which have deep channels (Key 177). Here also, for the first time in the study area, a large, continuous meltwater stream is found (Fig. 96). Numerous surficial meltwater streams descend to Baker Three Glacier from the continental ice, particularly where the latter comes under the influence of radiation from nearby ice-free rock masses (Figs. 96-99).

The entire Baker Three coastal area is icebound by the Baker Three Glacier, an unusual kind of an ice stream which, though apparently not heavily crevassed itself, drains the crevassed glaciers from the continent, includes surglacial moraines and separates the continent from the Amery Shelf Ice. Like the latter, the Baker Three Glacier moves toward the Sandefjord Ice Bay, but unlike the shelf ice, it possesses an obviously different ice structure as evidenced by its flat surface, meltwater (Keys 177-192), surface moraines, and its lack of hinge lines, floating fissures, reentrant rifts and other signs of floating ice masses. Many, although not all, of these differences are indicative of the fact that the Amery Shelf Ice is afloat while the Baker Three Glacier may be grounded on shelving coastline or moraine.

There is some evidence which indicates that the Baker Three Glacier may be partially afloat or at least permeated by marine waters. One such bit of evidence is that the glacier does not appear to be more than 400 feet above sea level, which is probably the upper limit of elevation for floating ice.[33] Another bit of evidence lies in the markings which appear

[33] No valid reports are known to exist of floating ice in which the general elevation of the upper ice surfaces is, 400 feet or more above the sea. The Norwegian-British-Swedish Expedition of 1949-1952 is expected to bring back more definite information concerning this subject, however.

in Jennings Lake (Figs. 96, 97). Viewed in third dimension (Fig. 96a), what first appears to be an innocent-looking meltwater lake shows the distinctive markings around its shoreline and the shorelines of its islands which are most frequently associated with tidal cracks and marine ice foot.

While it is possible that tide water reaches the area of Jennings Lake via passage under the shelf ice, it would not be prudent to classify Baker Three Glacier as a floating glacier on this evidence alone, especially in view of the total lack of other evidence as previously demonstrated. It is well within the realm of possibility that the markings on Jennings Lake are caused by differential thaw, which is controlled either by varying water depths or radiation from the adjacent ice masses (Keys 180-192).

Except for the presence of islands, the offshore conditions here are totally unlike the open water conditions of the Ingrid Christensen Coast. This factor alone is of sufficient merit to require the establishment of a separate name for this coastal area and for its treatment as an entity.

Flora and fauna conditions here are unknown, but the presence of ice-free rock at this elevation suggests the presence of several species of Antarctic lichens and perhaps some mosses. In some, but not all instances, minute insects are associated with this type of flora in Antarctica. Their presence here, though, is a matter for speculation. Normally, land this close to the coastal area could be expected to house rookeries of such birds as Cape Pigeons, Snowy Petrels and Wilson's Petrels, but with so many more favorable sites available nearer the ocean feeding grounds, it is doubtful whether the ice-free terrain of the Baker

Three coastal area is inhabited by bird life. There are no evidences of the presence of penguins or seals. The closest that humans are known to have approached the area is a distance of about two miles, and this was from above, by photo reconnaissance aircraft.

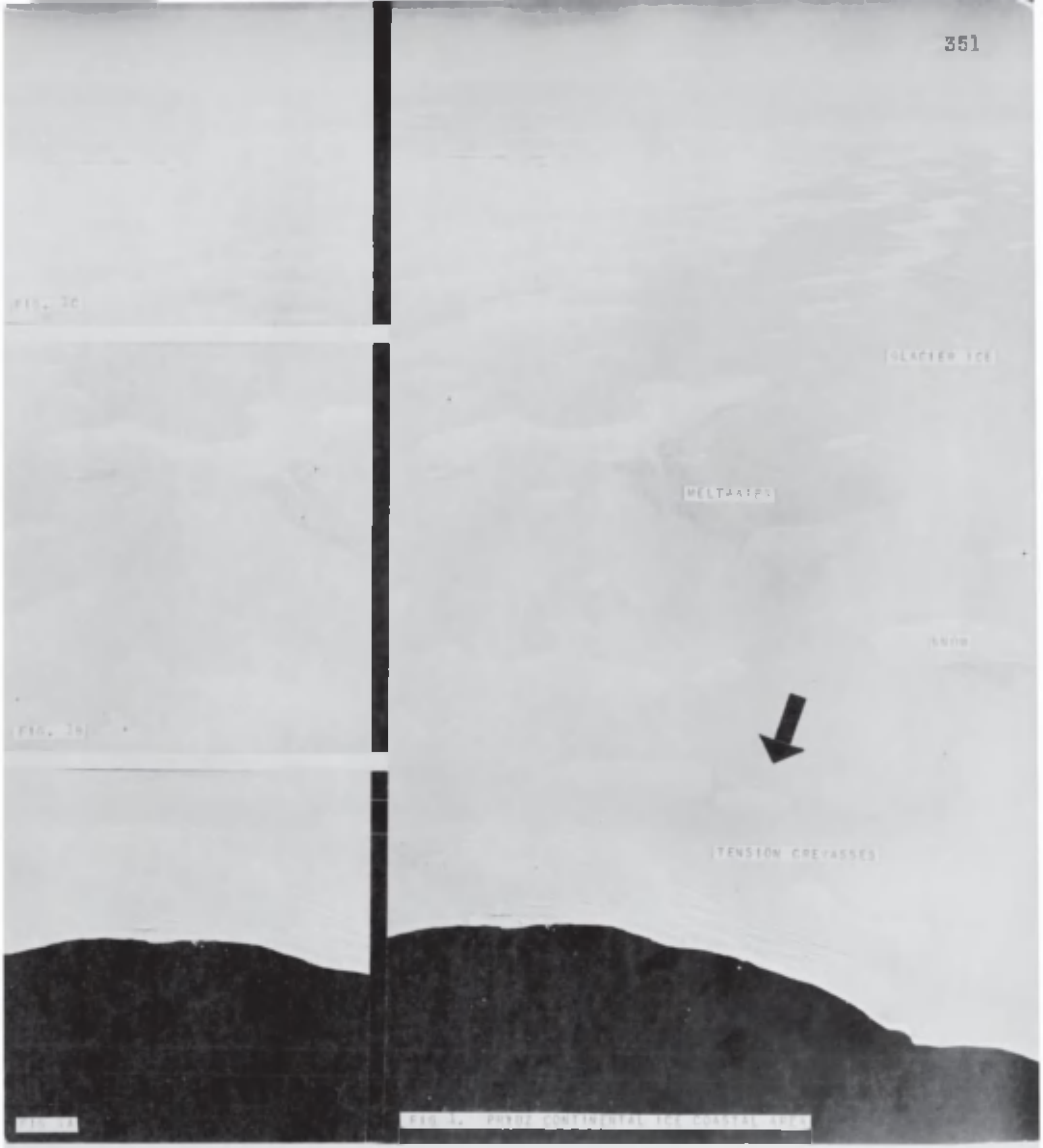


FIG 1. PRYDZ CONTINENTAL ICE COASTAL AREA

FIG 2.


SURFACE DRAINAGE
CONTINENTAL ICE

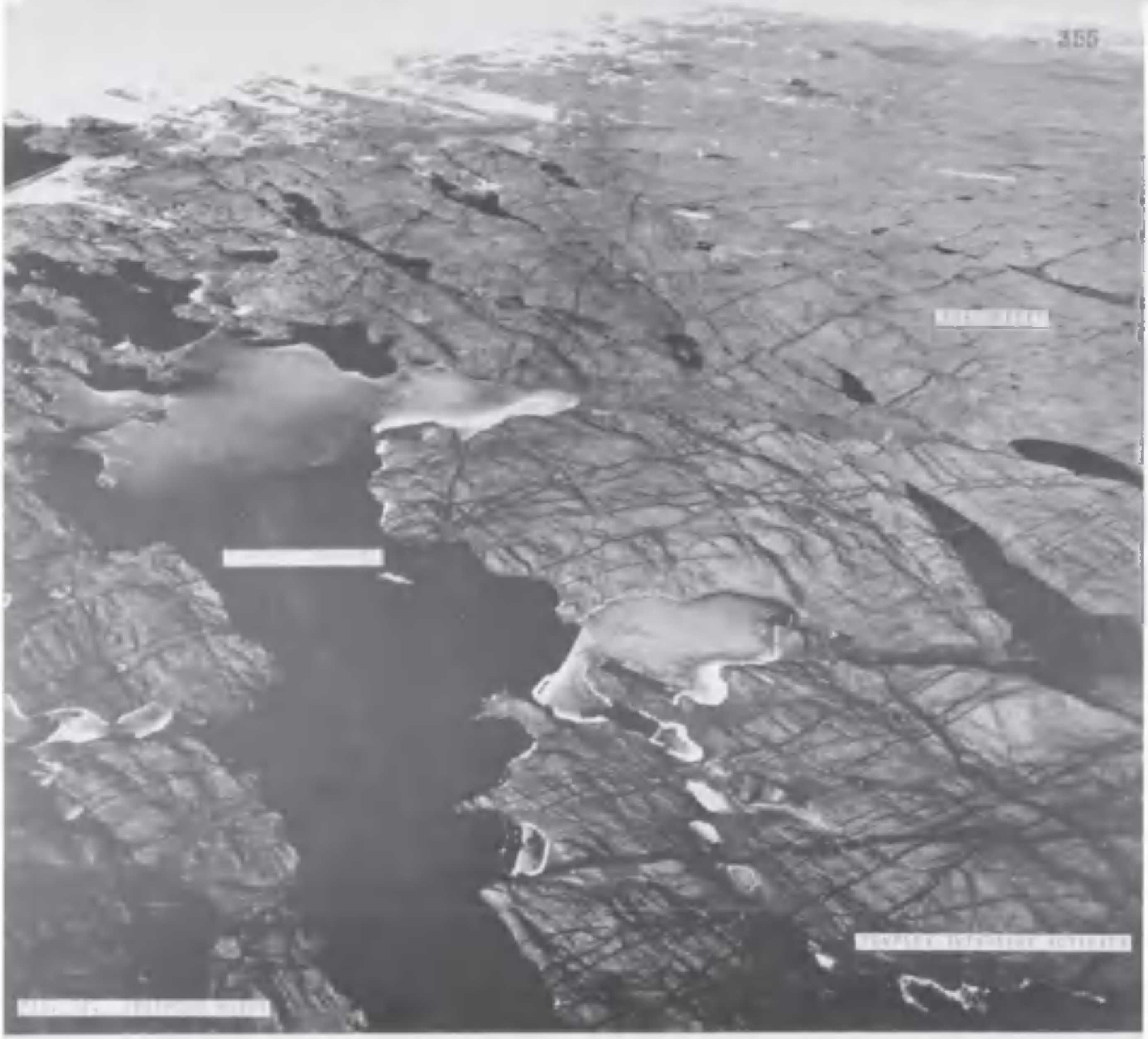

LANGNES (STIPPLED)
MELTWATER STREAM


CONTINENTAL ICE HINTERLAND
MELTWATER AND MORAINE


MELTWATER STREAMS
POND
DRIFT
LAKE

FIG. [illegible] VESTFOLD HILLS

FIG. [illegible] VESTFOLD HILLS



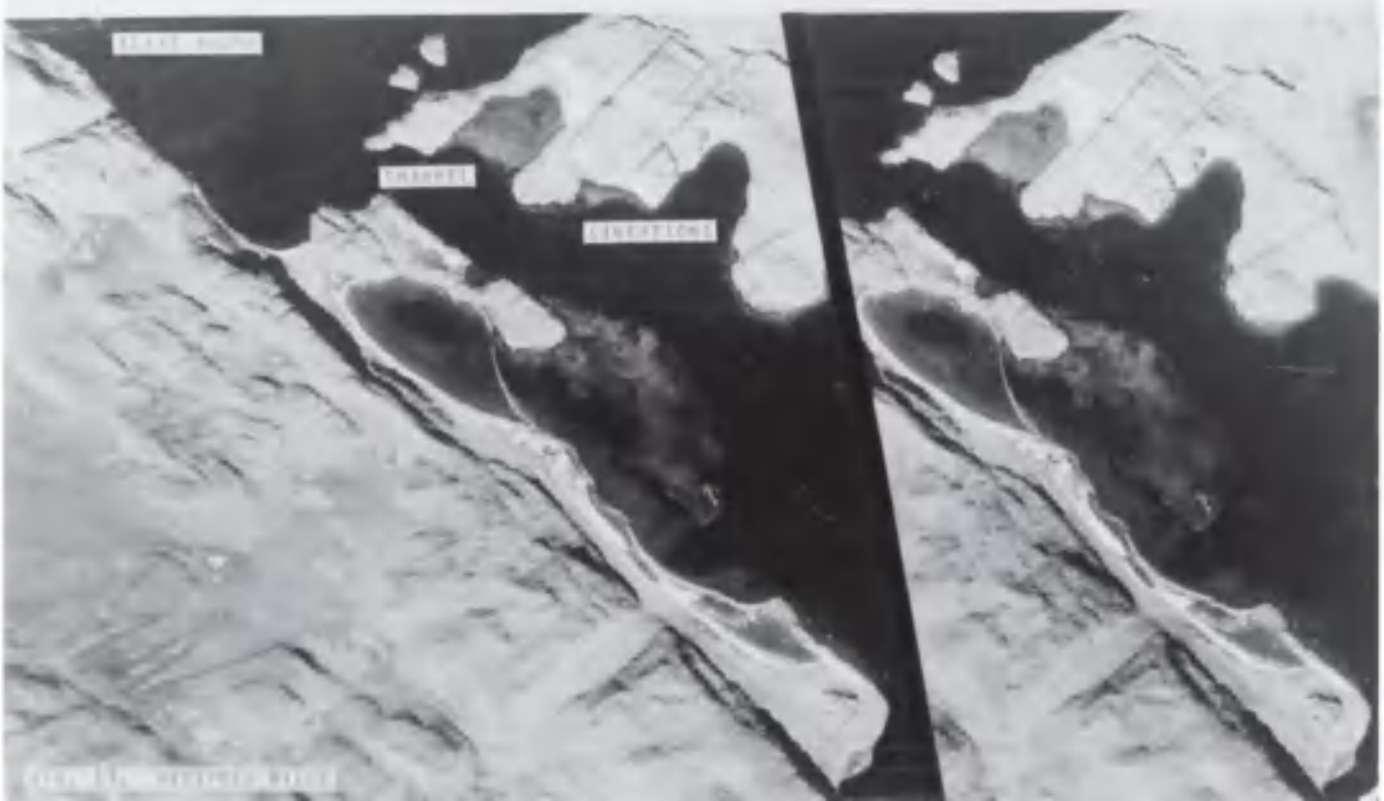
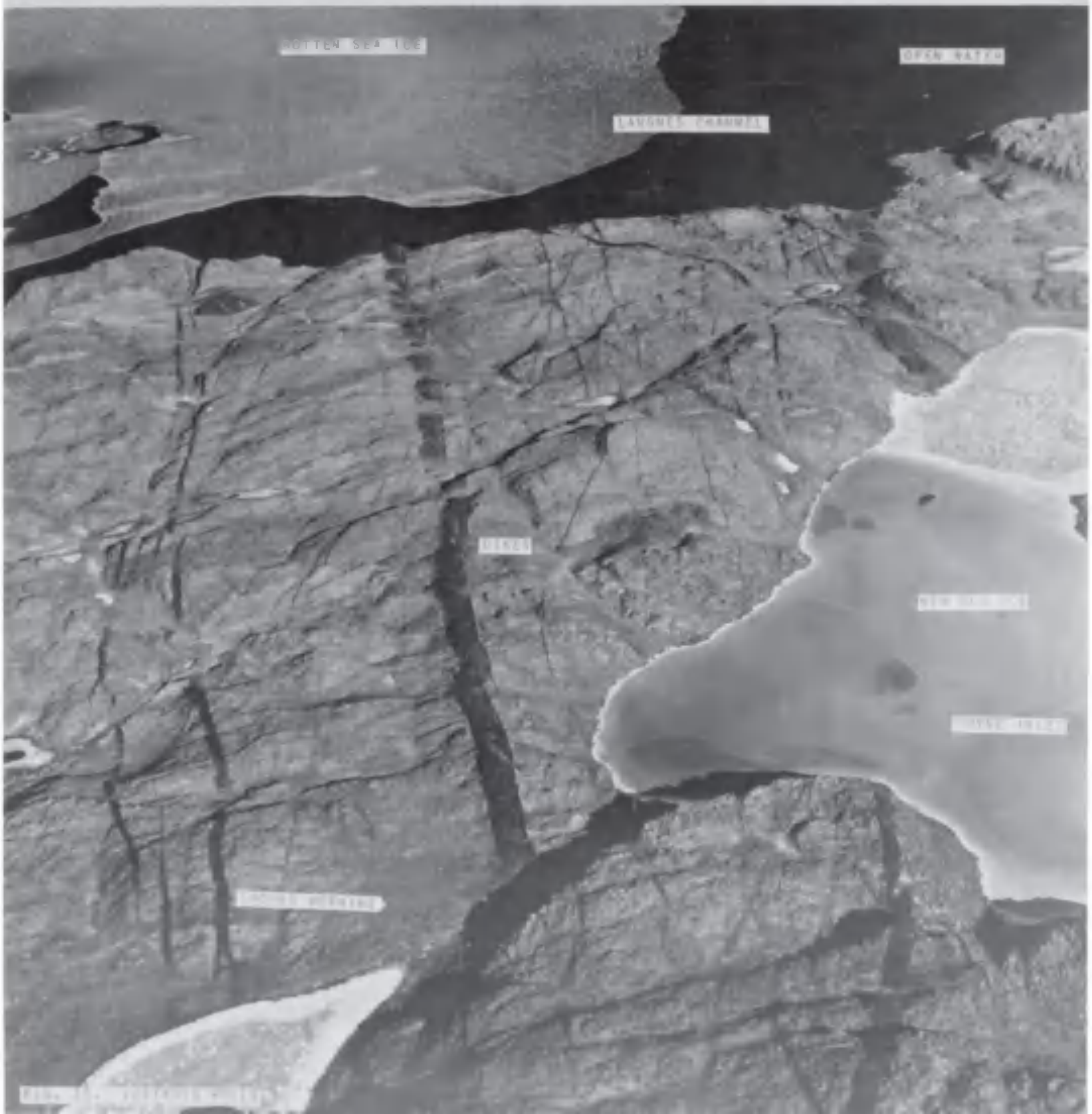
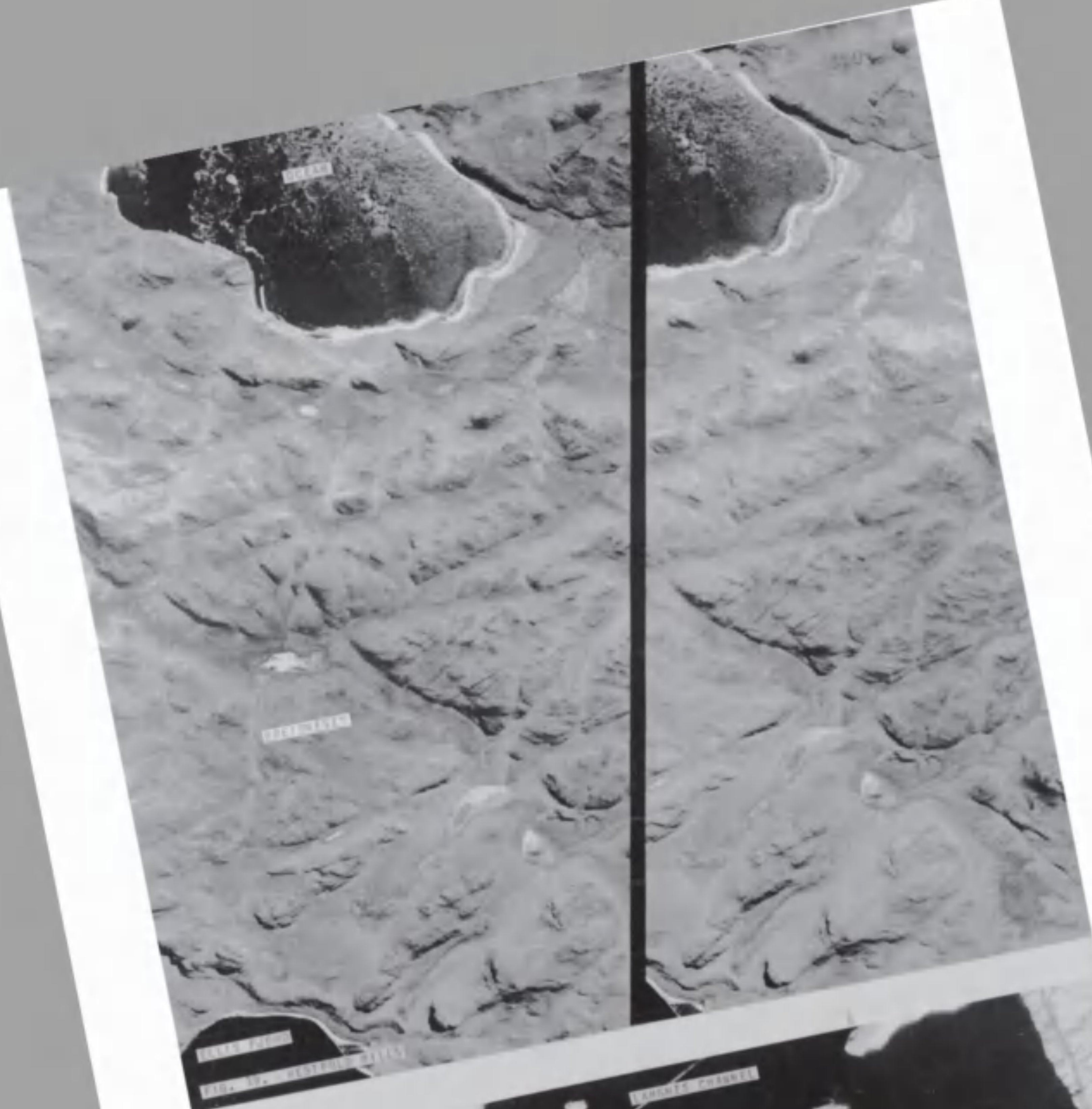


FIG. 11. VESTFOLD HILLS

FIG. 13. VESTFOLD HILLS

FIG. 34. VESTFOLD HILLS




OCEAN

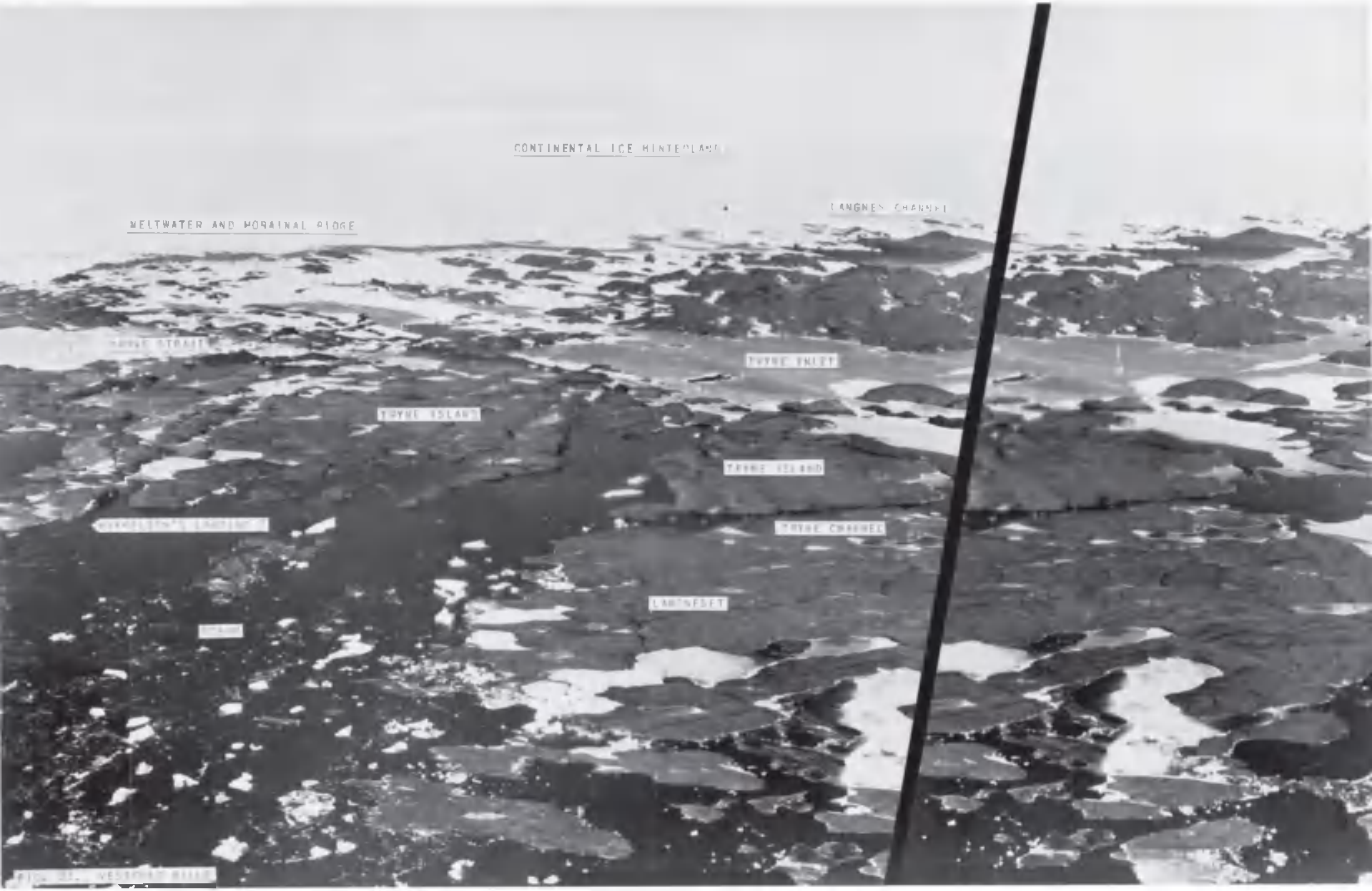


FIG. 31. VESTFOLD HILLS

FIG. 32. VESTFOLD HILLS

FIG. 33. VESTFOLD HILLS

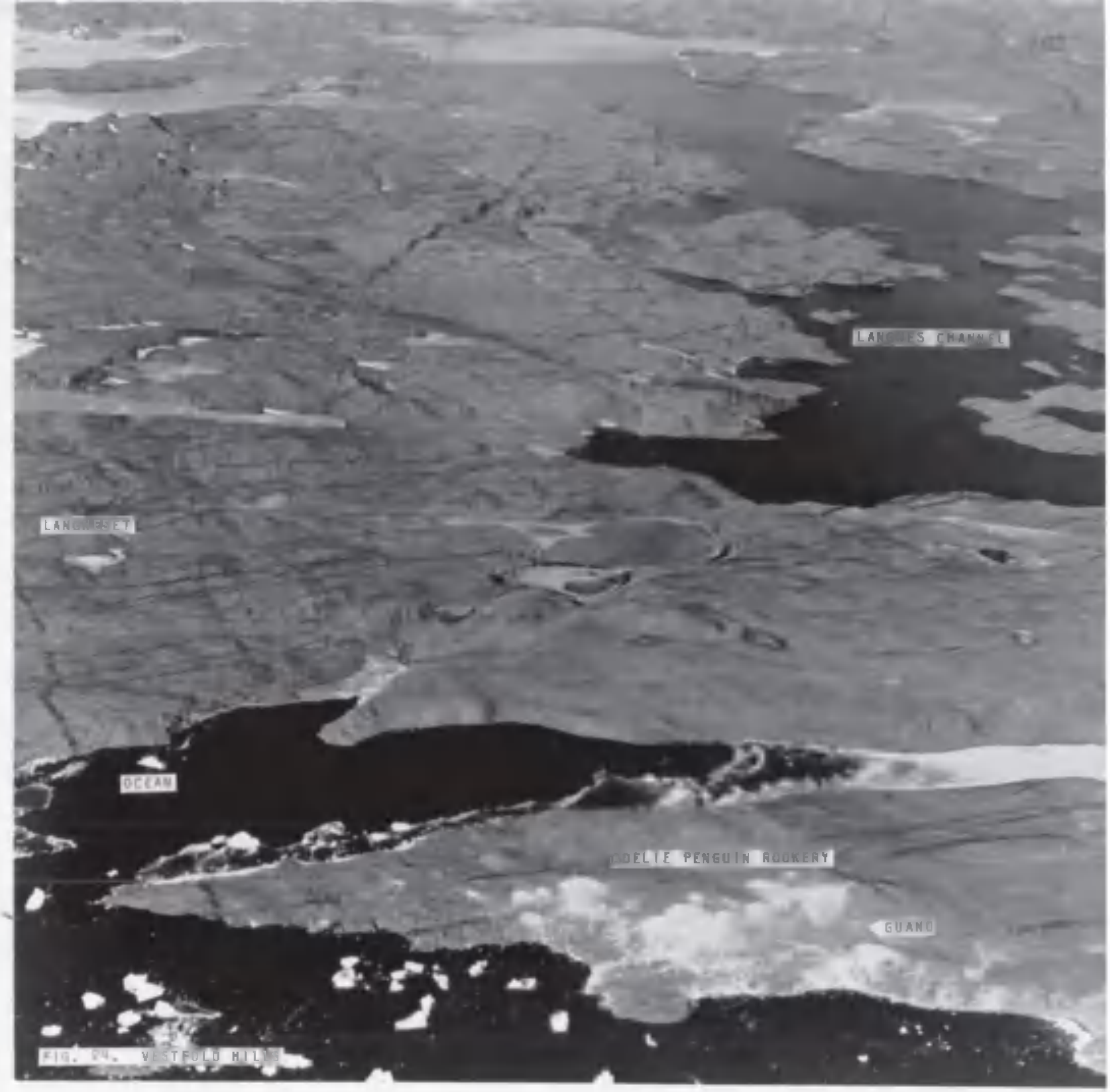


FIG. 24. VESTFOLD HILLS

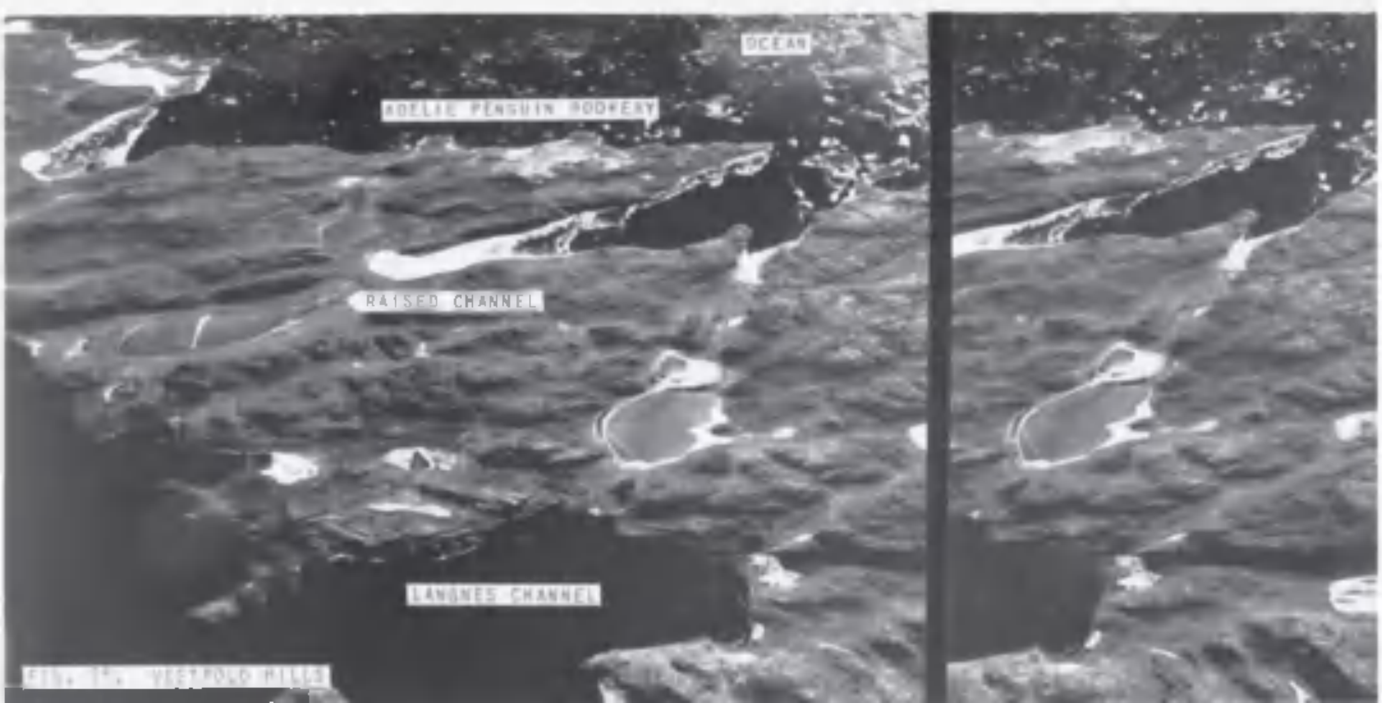


FIG. [illegible]. VESTFOLD HILLS

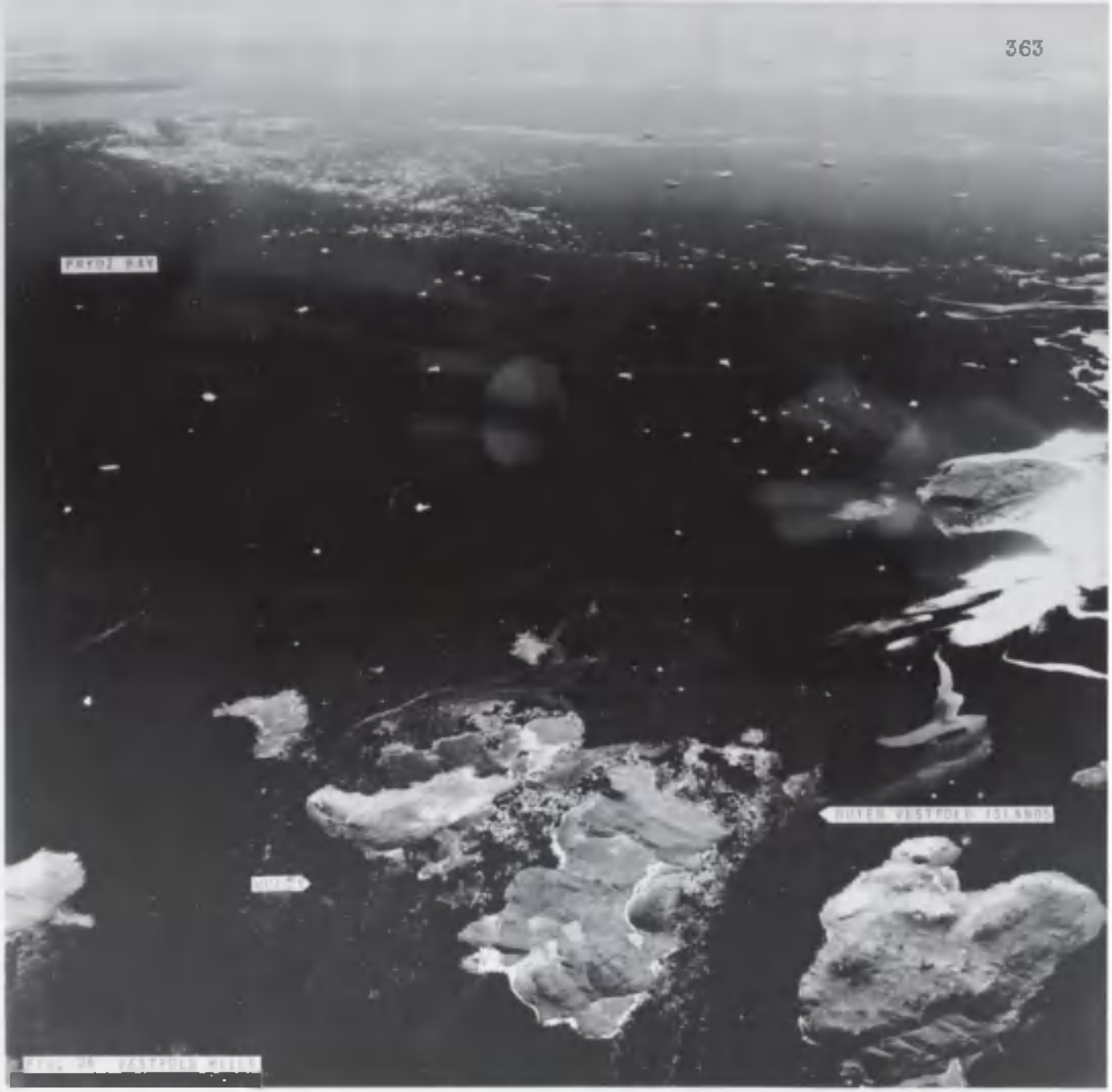


FIG. 26. VESTFOLD HILLS

FIG. 27. VESTFOLD HILLS

FIG. [illegible]. VESTFOLD HILLS, SØRSDAL GLACIER TONGUE

FIG. [illegible]. VESTFOLD HILLS, SØRSDAL GLACIER TONGUE

FIG. 30. VESTFOLD HILLS, SØRSDAL GLACIER TONGUE

FIG. 31. VESTFOLD HILLS, SØRSDAL GLACIER TONGUE

FIG. 32. SØRSDAL GLACIER TONGUE

FIG. 33. SØRSDAL GLACIER TONGUE

FIG. 34. SØRSDAL GLACIER TONGUE

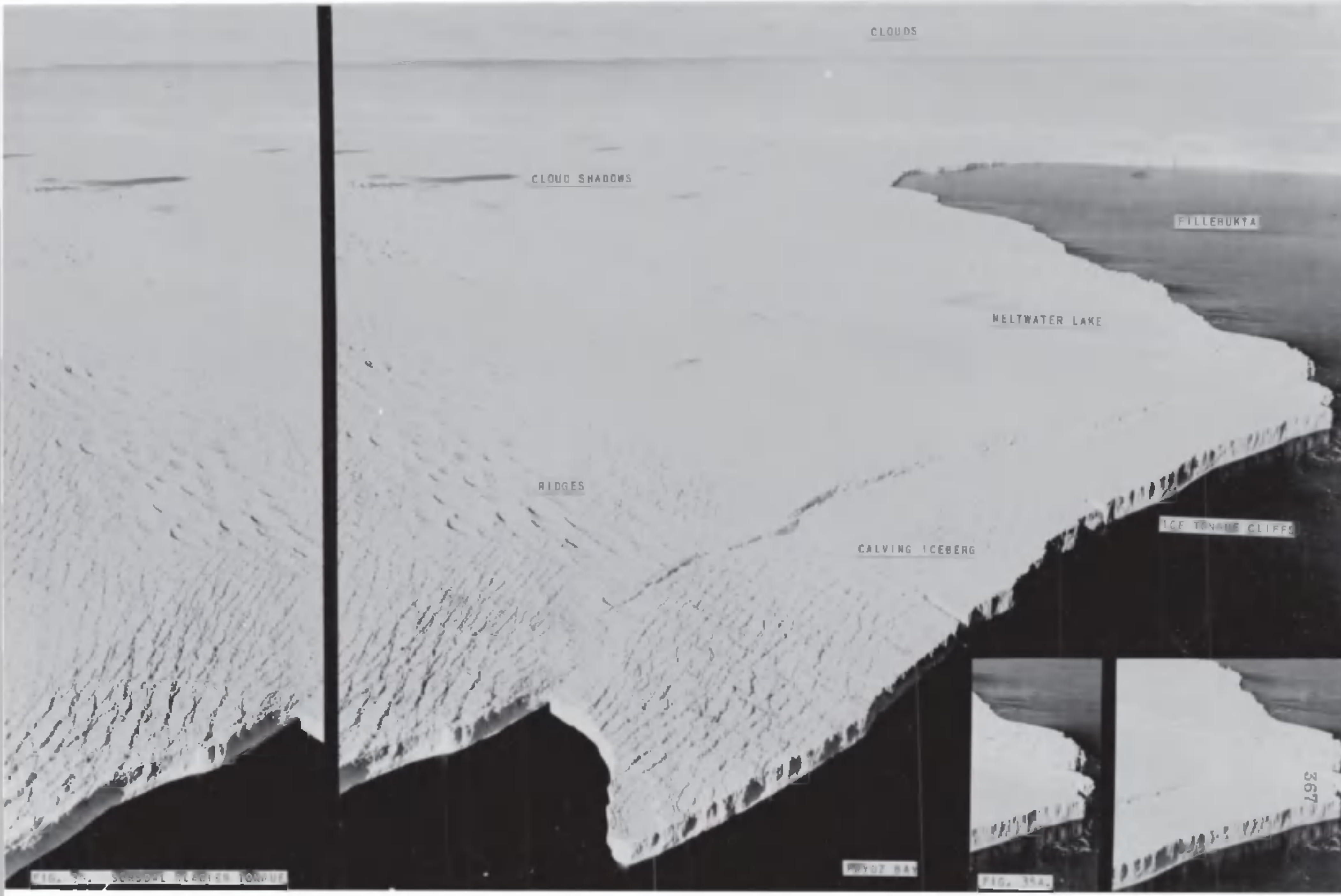


FIG. 35. SORSDAL GLACIER TONGUE

FIG. 35A.

FIG. 36. WEST INGRID CHRISTENSEN COAST, LOOKING NORTHEAST

FIG. 37. WEST INGRID CHRISTENSEN COAST, LOOKING SOUTHEAST

FIG. 38. WEST INGRID CHRISTENSEN COAST, LOOKING SOUTHWEST

FIG. 39. RAUER ISLANDS

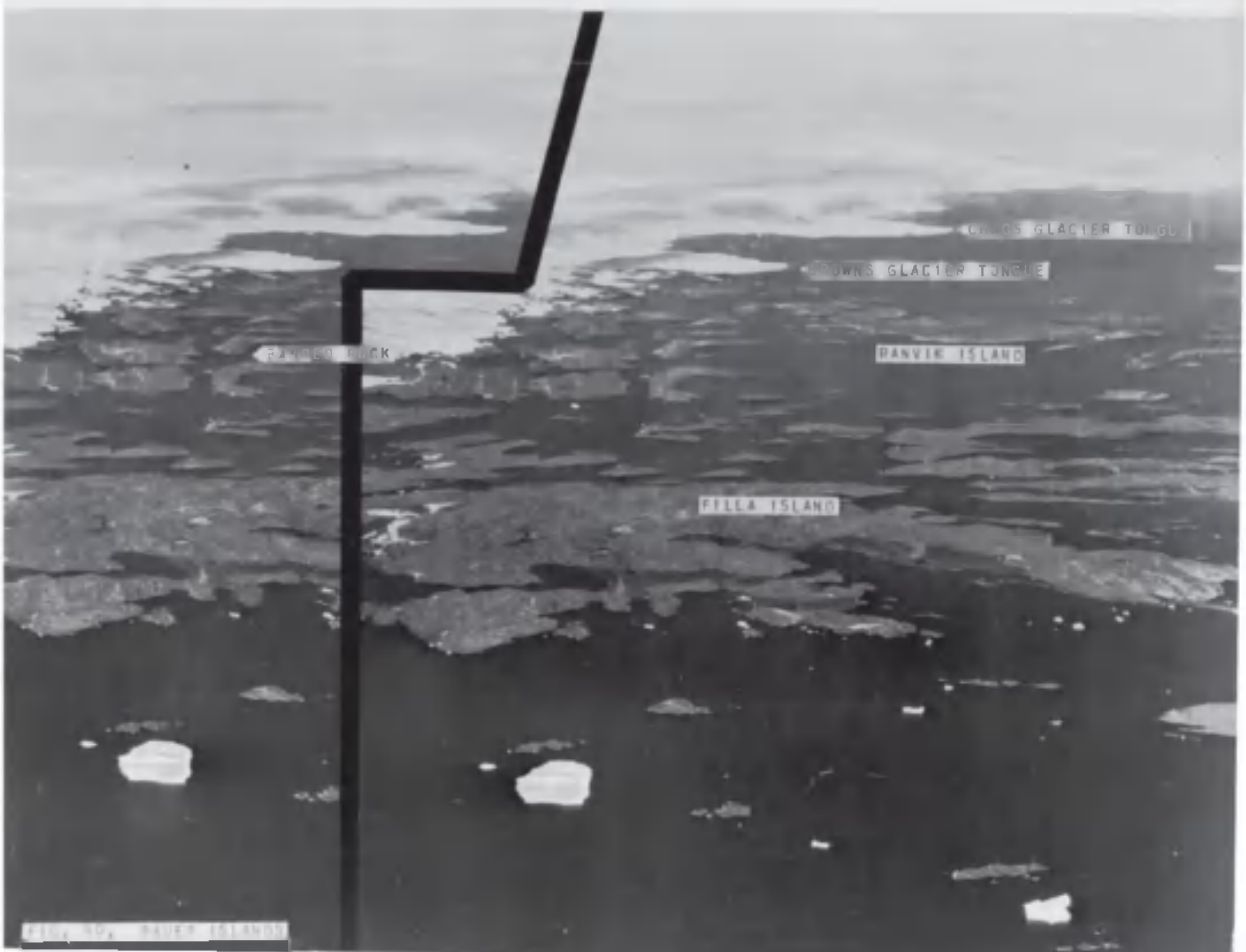


FIG. 40. RAUER ISLANDS

FIG. 41. RAUER ISLANDS

FIG. 42. RAUER ISLANDS


CLOUDS
CONTINENTAL GLACIER


DRIFTED OVER CREVASSES

FIG. [illegible]. RANVIK ICE TONGUE COASTAL AREA

FIG. 45. RANVIK ICE TONGUE COASTAL AREA

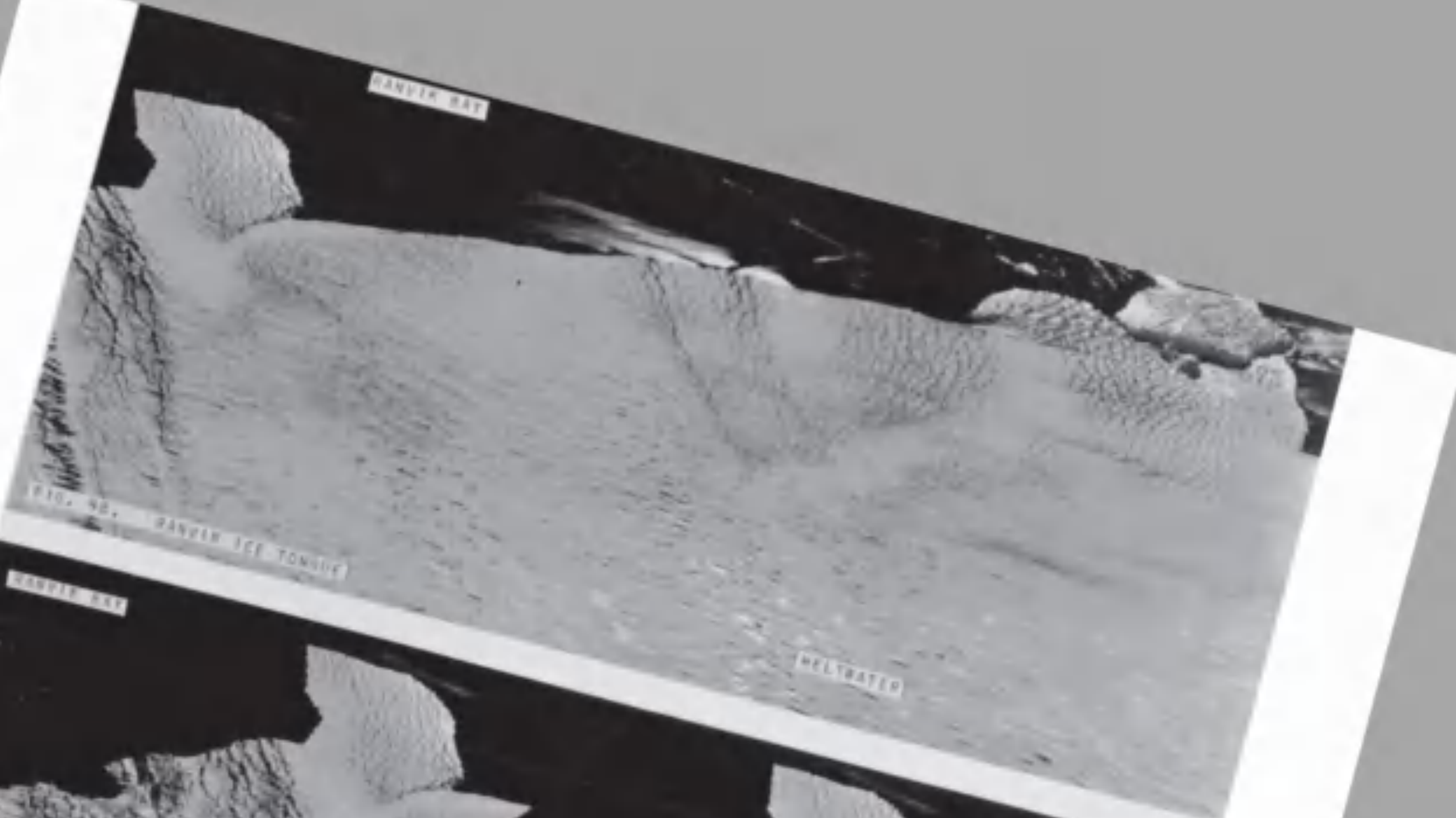


FIG. 48. RANVIK ICE TONGUE

FIG. 49. RANVIK ICE TONGUE

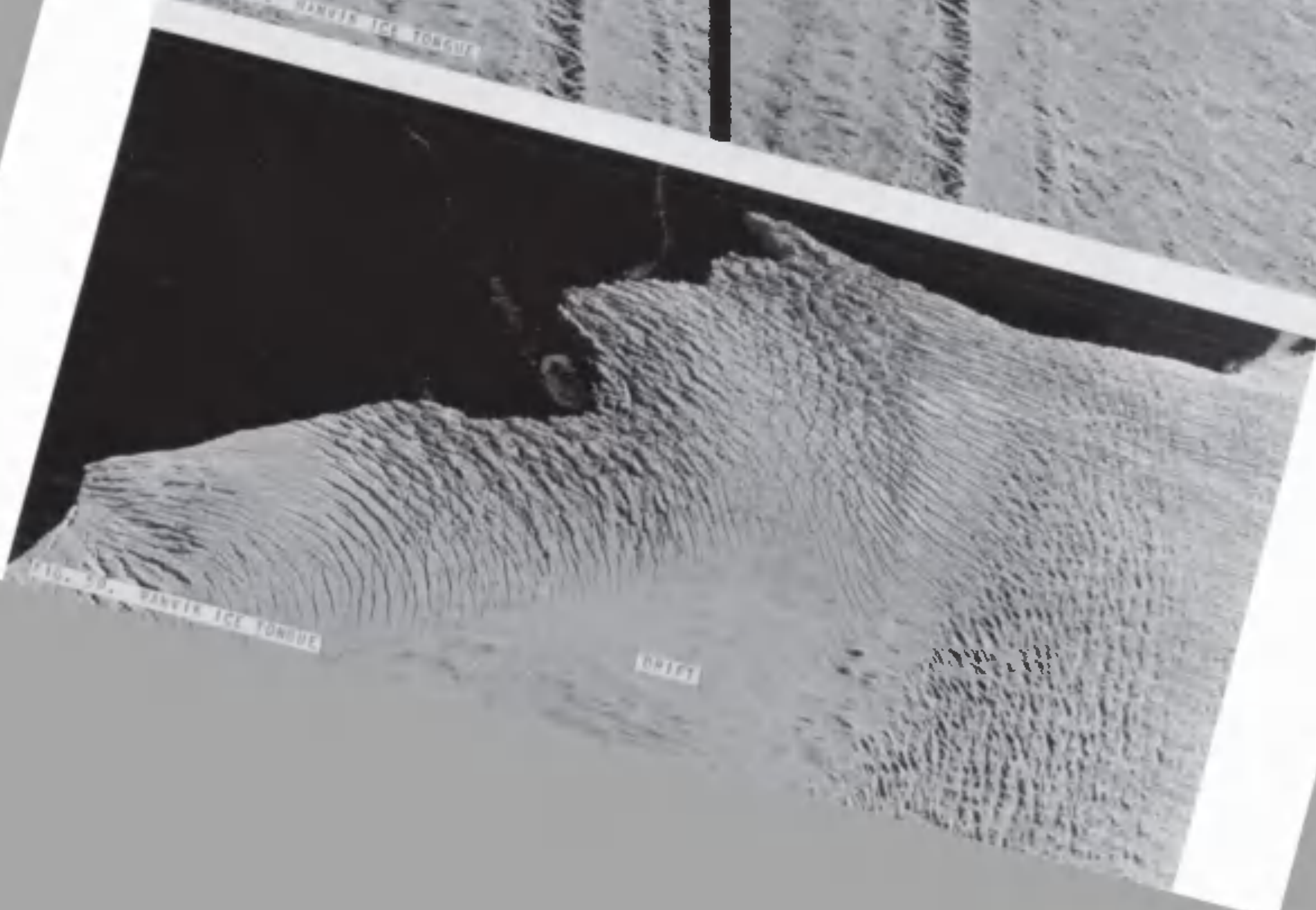


FIG. 50. RANVIK ICE TONGUE

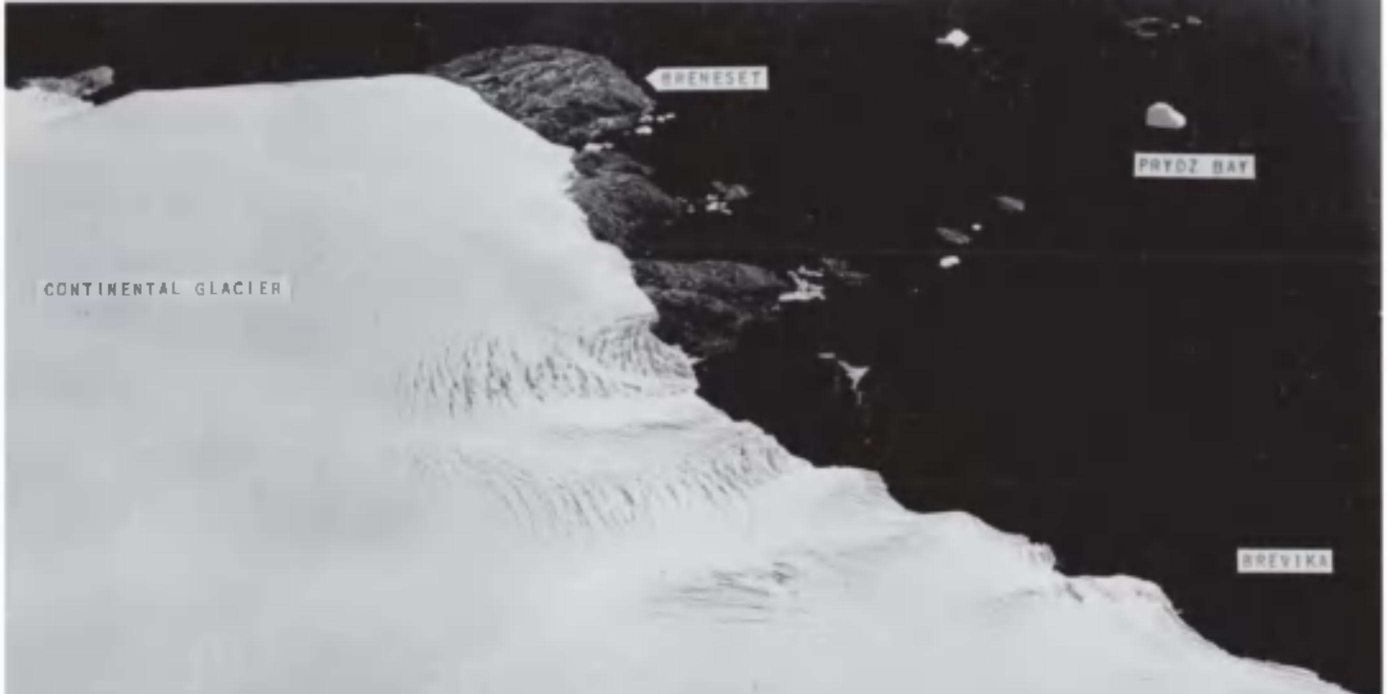


FIG. 51. SVENNER INSULAR COASTAL AREA


FIG. 52. SVENNER ISLANDS

FIG. 53. SVENNER INSULAR COASTAL AREA

FIG. 54. SVENNER INSULAR COASTAL AREA

FIG. 55. HINTERLAND, RANVIK GLACIER AND RANVIK ICE TONGUE

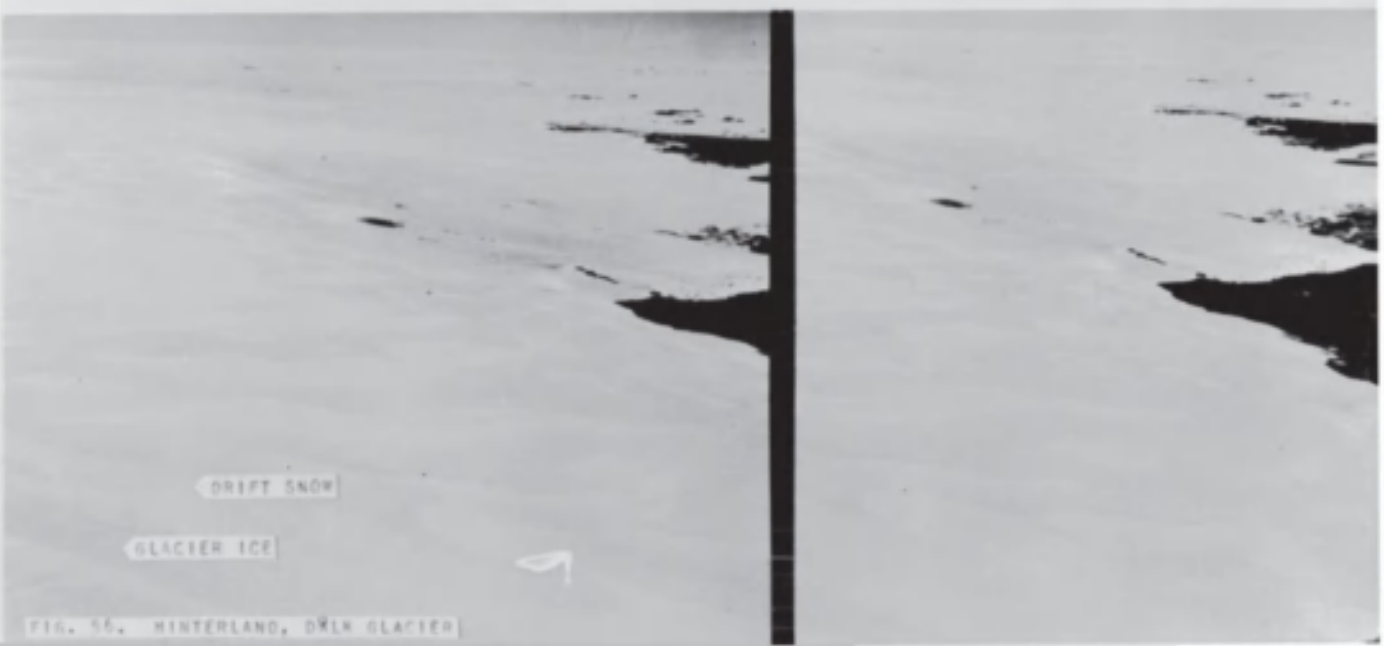


FIG. 56. HINTERLAND, DÅLK GLACIER

FIG. 57. HINTERLAND

FIG. 58. LARSEMANN INSULAR COASTAL AREA

FIG. 59. LARSEMANN INSULAR COASTAL AREA

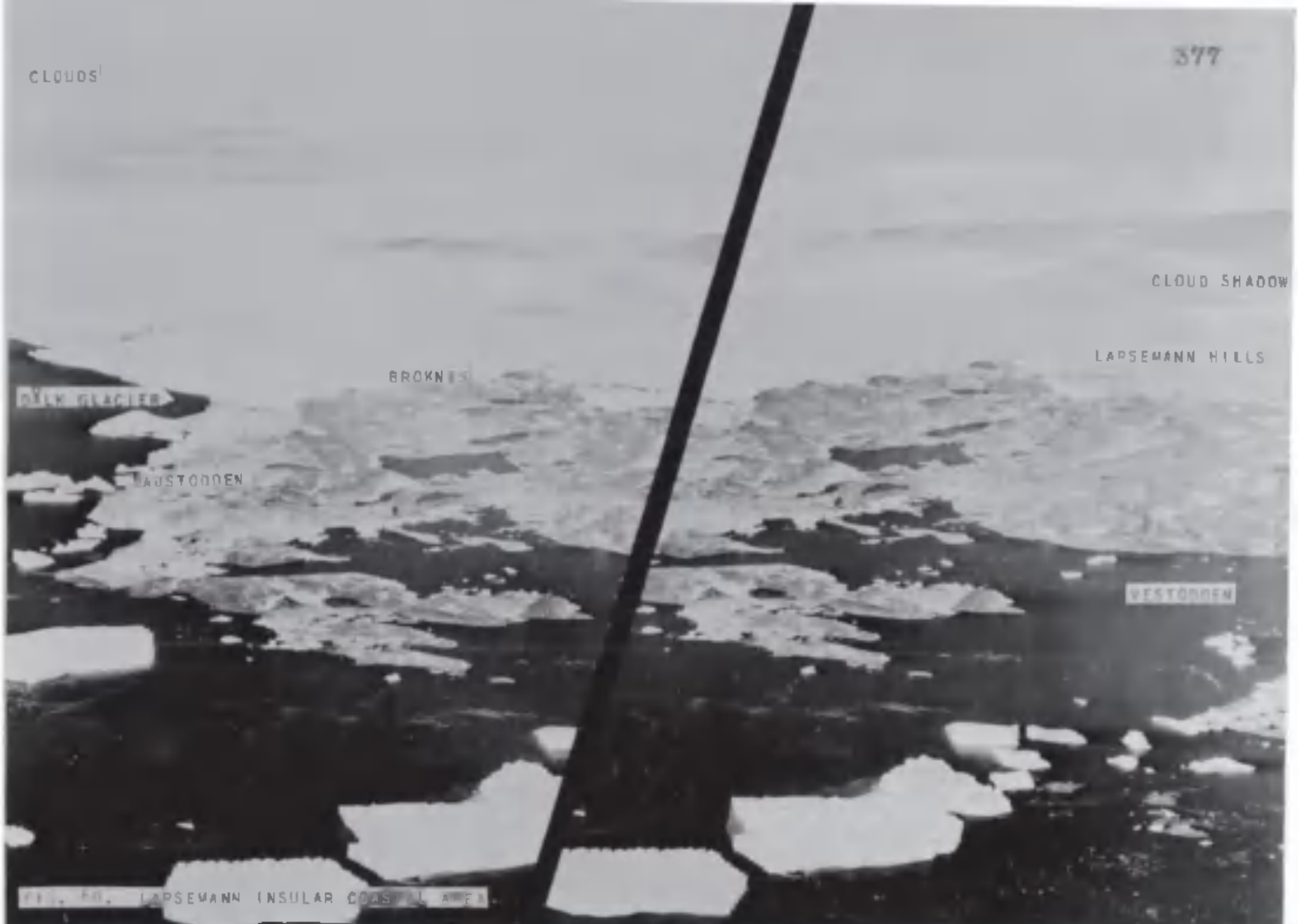
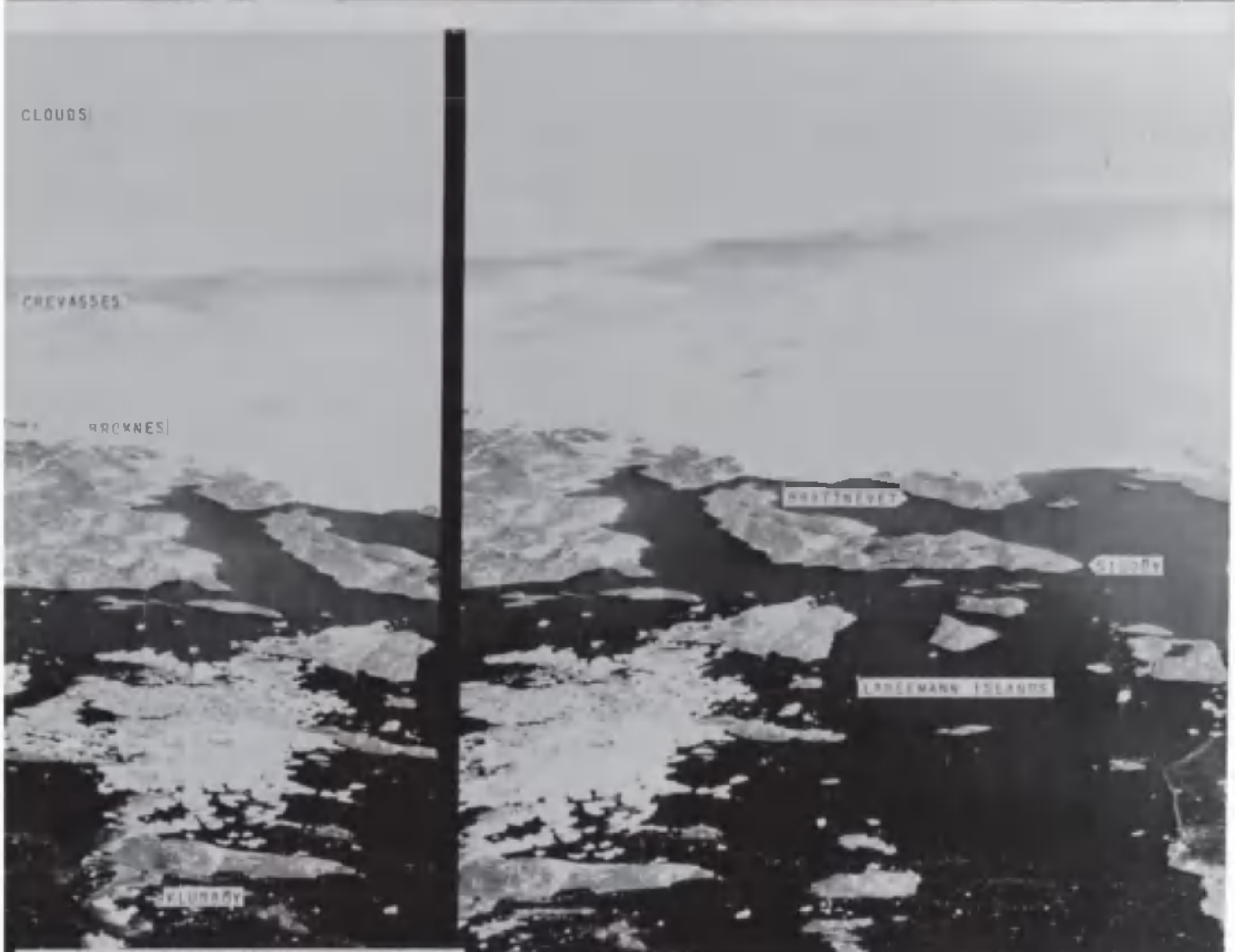
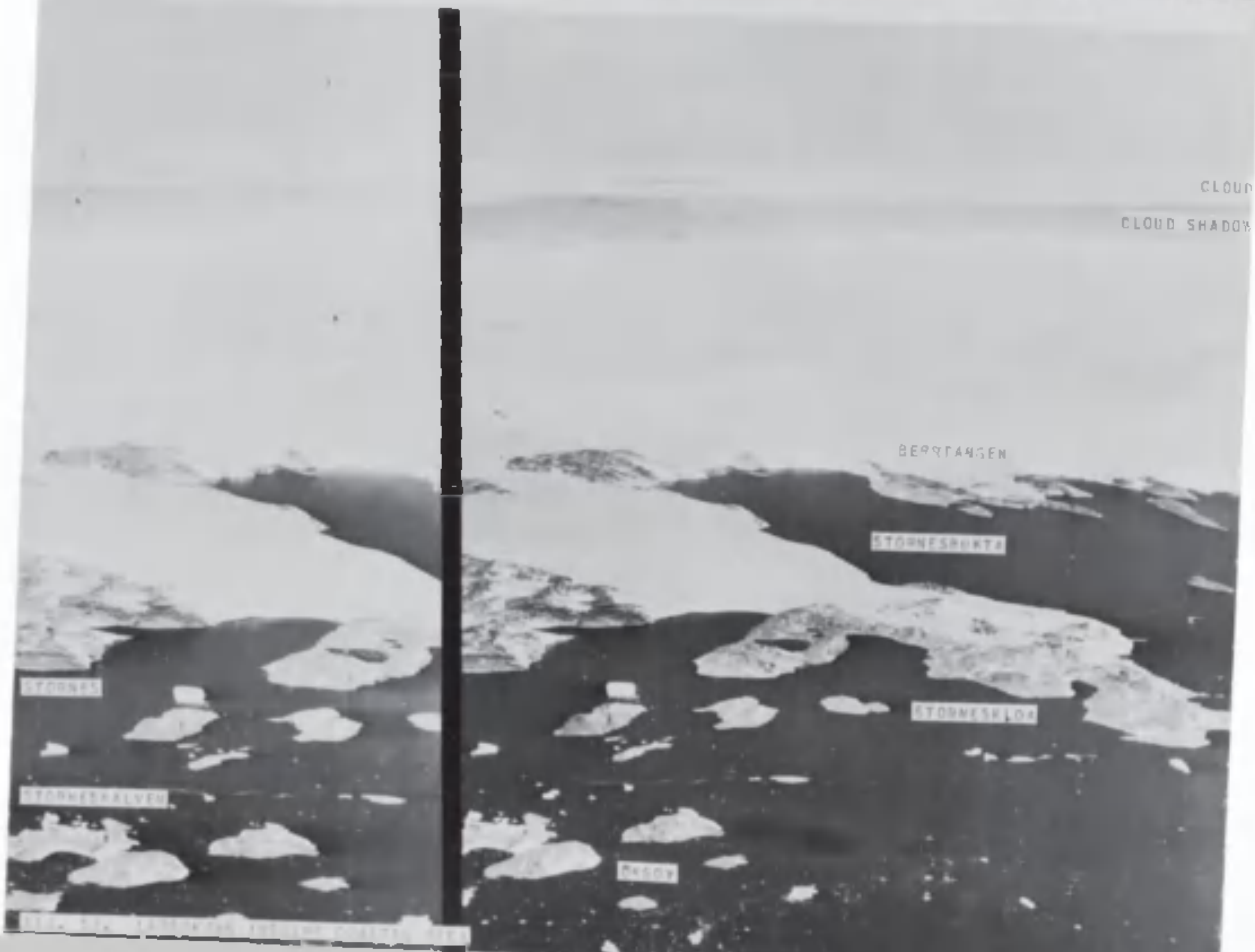


FIG. 60. LARSEMANN INSULAR COASTAL AREA



LARSEMANN INSULAR COASTAL AREA


CLOUD SHADO
CONTINENTAL GLACIE
BROVNES
POLEN
STORNES
INSULAR COASTAL AREA


CLOUD
CLOUD SHADOW
BERRTANGEN
STORNESBUKTA
STORNES
STORNESKLOA
STORNESHALVEN


CLOUD SHADOW
SEA ICE
STORØY
SEA ICE
STORØY
BOLINGEN ISLANDS

FIG. 66. BÖLINGEN ISLANDS

FIG. 67. BÖLINGEN ISLANDS

FIG. 72. PUBLICATION GLACIER TONGUES

FIG. 73. PUBLICATION GLACIER TONGUES

FIG. 74. PUBLICATION GLACIER TONGUES

FIG. 75. PUBLICATION GLACIER TONGUES

FIG. 76. PUBLICATION GLACIER TONGUES

FIG. 77. PUBLICATION GLACIER TONGUES

FIG. 78. PUBLICATION GLACIER TONGUES

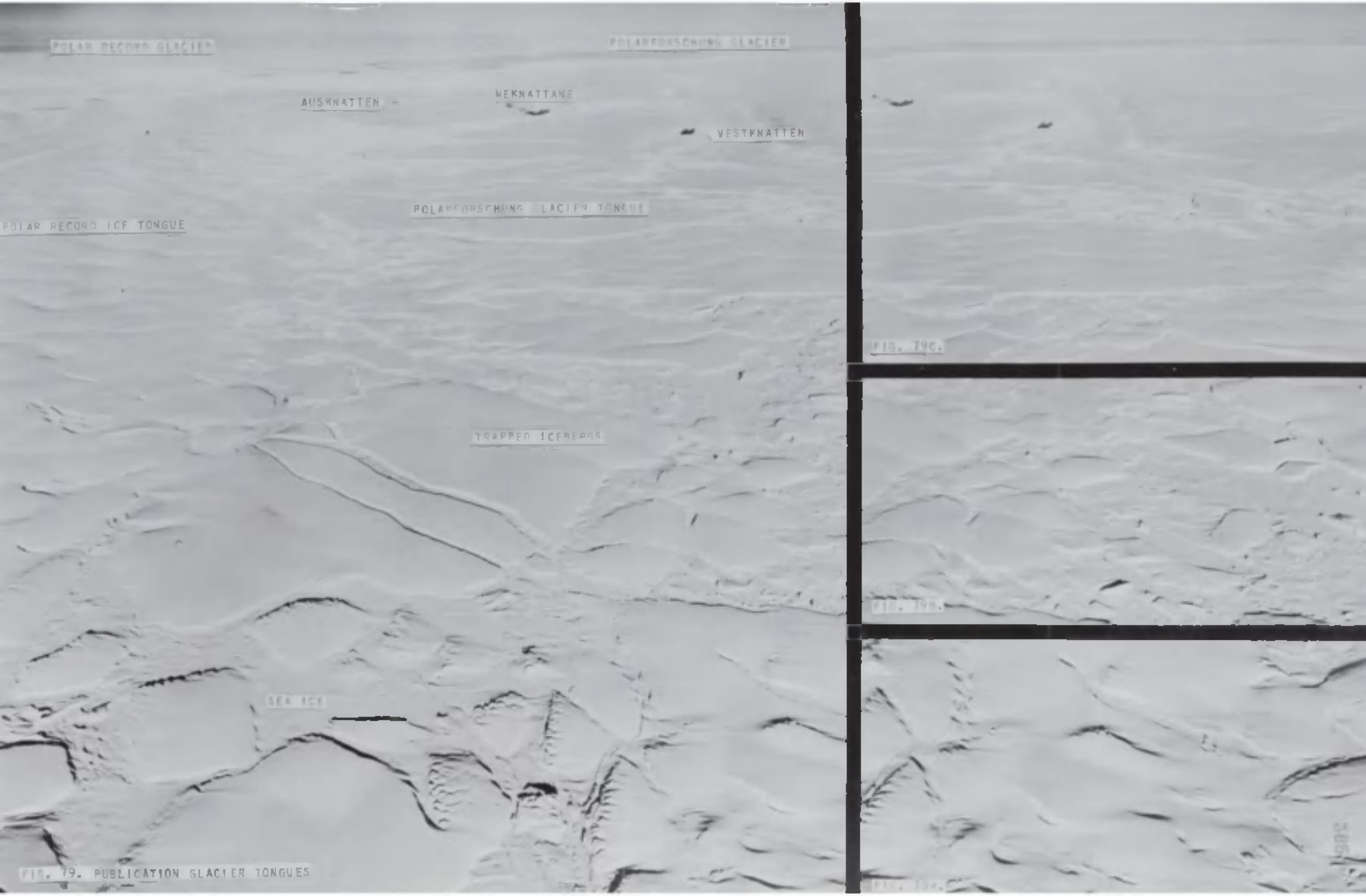


FIG. 79. PUBLICATION GLACIER TONGUES

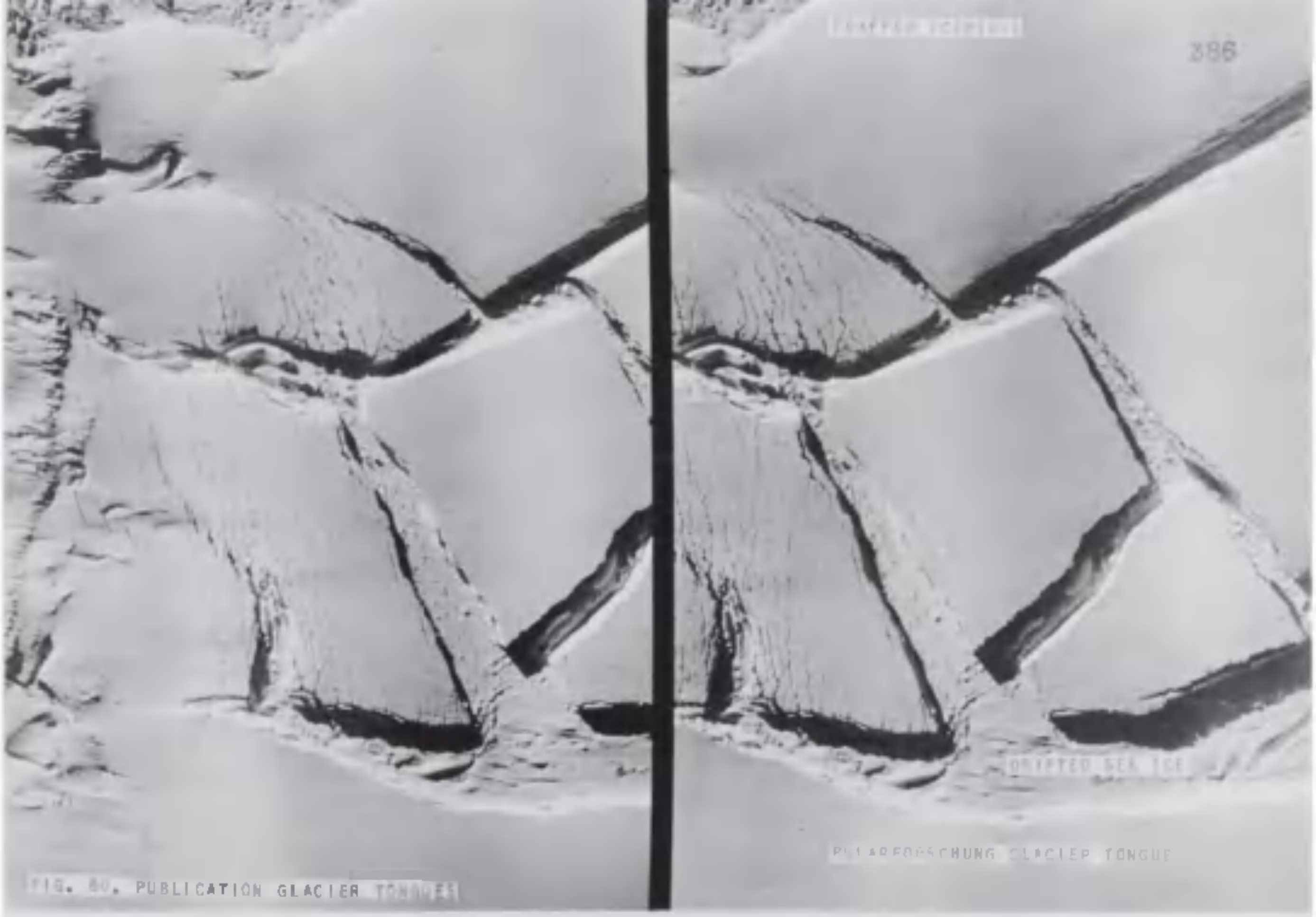


FIG. 80. PUBLICATION GLACIER TONGUES

FIG. 81. PUBLICATION GLACIER TONGUES

FIG. 82. PUBLICATION GLACIER TONGUES

FIG. 83. PUBLICATION GLACIER TONGUES

FIG. 84. PUBLICATION GLACIER TONGUES

FIG. 85. PUBLICATION GLACIER TONGUES

FIG. 86. PUBLICATION GLACIER TONGUES, SANDEFJORD ICE BAY.

FIG. 87. PUBLICATION GLACIER TONGUES. SANDEFJORD ICE BAY.

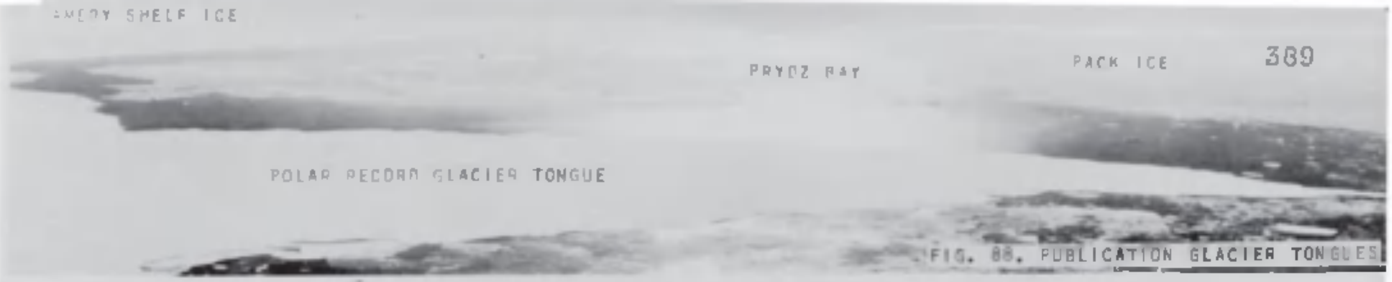


FIG. 88. PUBLICATION GLACIER TONGUES

FIG. 89. PUBLICATION GLACIER TONGUES, SANDEFJORD ICE BAY

FIG. 90. PUBLICATION GLACIER TONGUES, SANDEFJORD ICE BAY

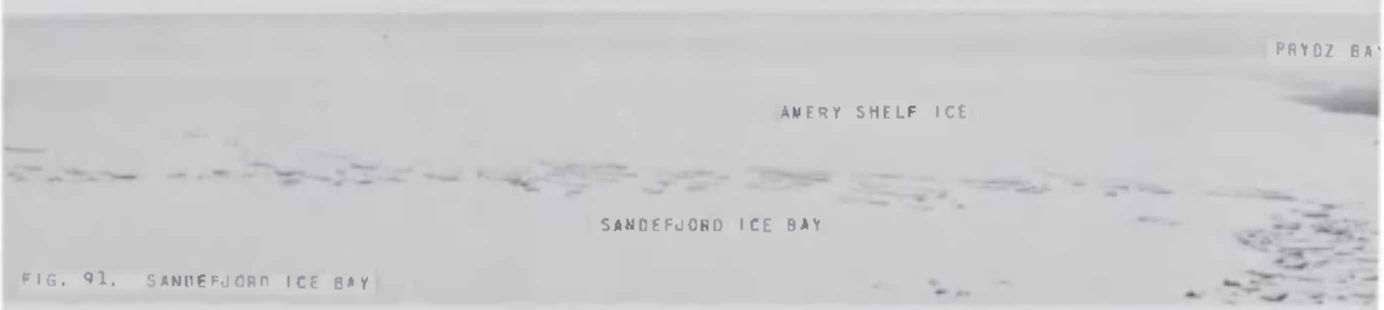


FIG. 91. SANDEFJORD ICE BAY

FIG. 92. SANDEFJORD ICE BAY, SANDEFJORD INSULAR COAST

FIG. 93. SANDEFJORD INSULAR COAST

FIG. 94. SANDEFJORD INSULAR COAST

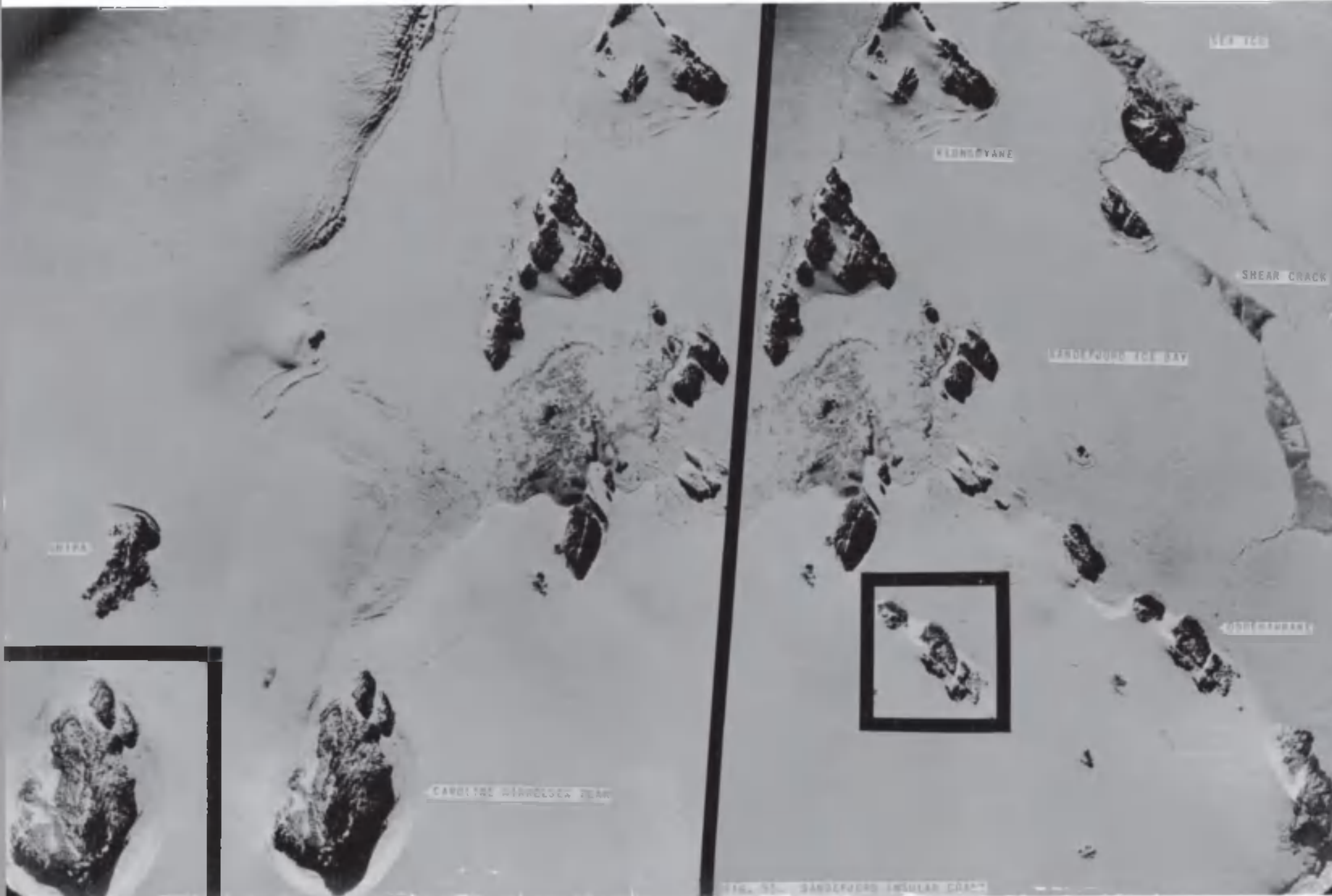
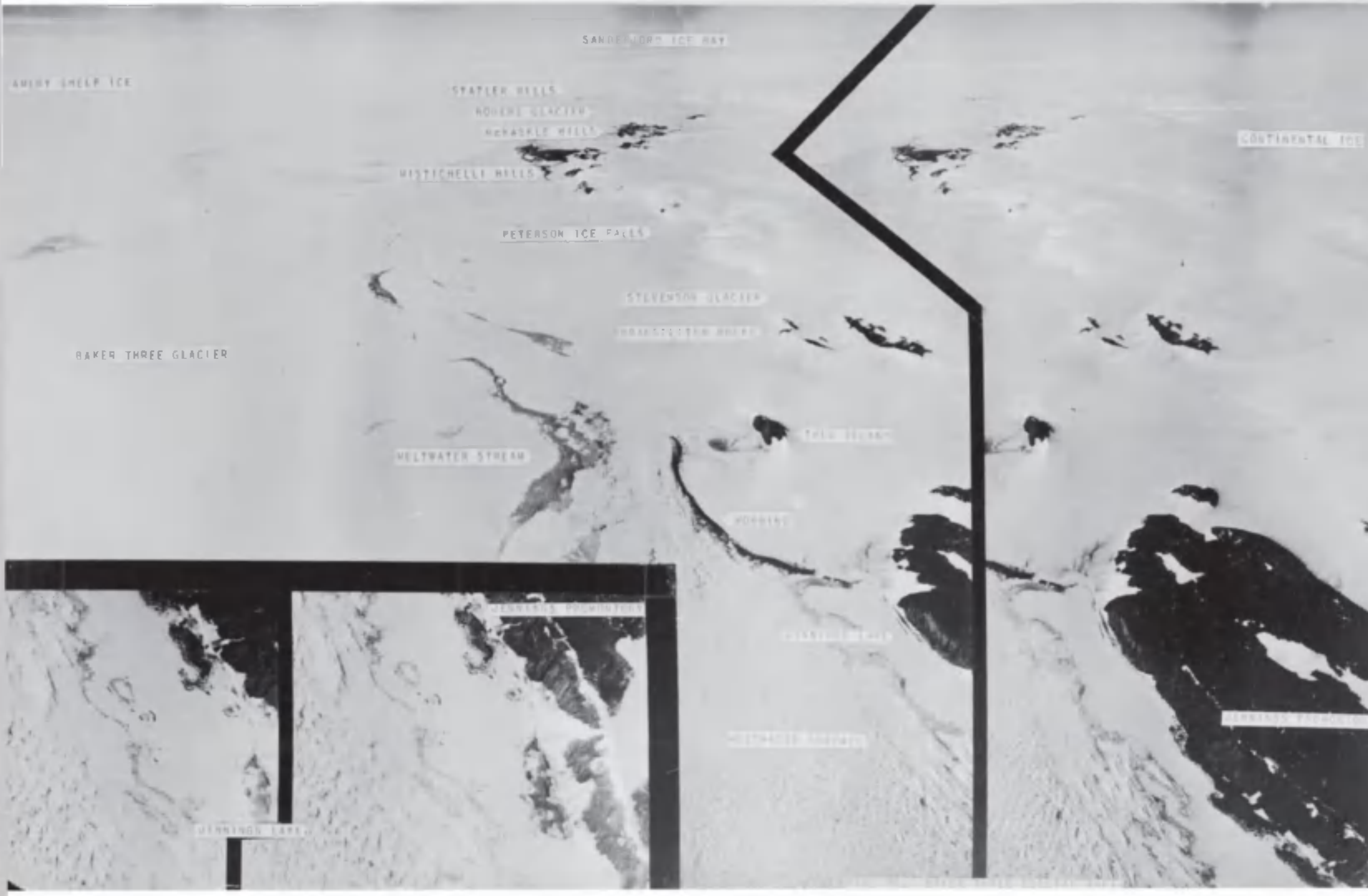


FIG. 51. SANDEFJORD INSULAR COAST


STATLER HILLS
PETERSON ICE FALLS
BAKER THREE GLACIER
MELTWATER STREAM
CONTINENTAL ICE

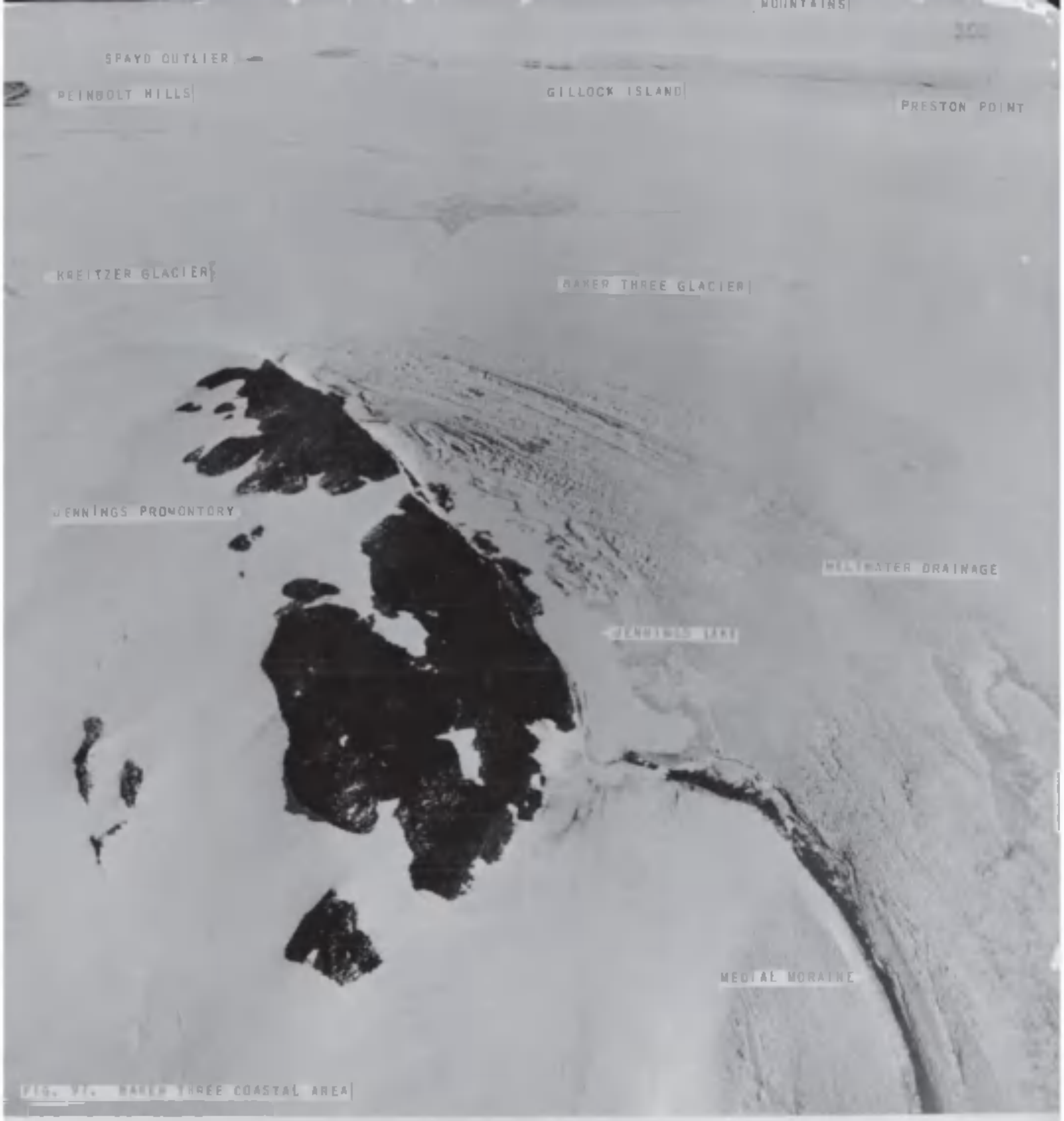


FIG. 97. BAKER THREE COASTAL AREA

FIG. 98. BAKER THREE COASTAL AREA

FIG. 99. BAKER THREE COASTAL AREA

FIG. 100. BAKER THREE COASTAL AREA

FIG. 101. BAKER THREE COASTAL AREA

CHAPTER VII

SUMMARY AND CONCLUSIONS

<u>Summary</u>. Myriads of airphoto images present landscape information in encyclopedic detail and variety. Accordingly, it is not possible for the airphoto interpreter to recognize, analyze and interpret all airphoto images which may be present on his aerial photography. Specifically, he will not be able to interpret with complete reliability the airphoto images of objects, conditions and situations with which he has not had experience on the ground.

Since no photo interpreter can be familiar with all, or even a substantially large portion of the images which appear on airphotos, it becomes necessary to find a method by which the photo interpreter may correctly analyze photo images with which he is partially or wholly unfamiliar. The most practical system developed thus far to solve this problem involves the systematic derivation of annotated airphoto images, called photo interpretation keys, which may be classified according to area, subject or both. Chapter V is such an assemblage of photo images.

The scientist who derives and compiles photo interpretation keys must be thoroughly familiar with the subject, the area or the analogous factors concerned. Such keys cannot be established from the study and analysis of airphotos alone. Field study is required, for only by comparing airphotos with actual conditions observed on the ground can one readily learn to recognize the important indicator keys and to differentiate between them and such images as may not remain constant or may not be of diagnostic value. Field inspection is also required to recognize what Smith (1947,

p. 518) calls ". . . . the subtle markings that characterize innumerable obscure features, and . . . . differences between things which seem similar, and the similarities between things which seem different."

A universal or world-wide set of aerial photo interpretation keys would be so voluminous and would require so much research, that its compilation is not feasible at present. Photo interpretation keys for certain geographic regions or for individual subjects, e.g., railroads, sand dunes, crops, anti-aircraft defense positions, and various industries, are feasible, however, and a limited number of them have already been established.

Each iceform, landform and natural feature on the earth's surface is unique. No two glaciers, crevasses, mountain peaks or other natural features are exactly alike. Within any one class of natural features, however, there may be a substantial number of characteristics which are repeated in the great majority of the features falling within that class. The selection of keys, therefore, must be based upon diagnostic characteristics which are of statistically significant recurrence. Objects, conditions and situations are symbolized when portrayed on maps, but the airphoto images of these very same objects, conditions and situations vary in appearance. This variation in appearance is the principal difference between airphoto interpretation keys and the symbols of the map legend.

While the existence of photo interpretation keys makes possible a preliminary analysis of airphotos by other than qualified field investigators, it should be emphasized that, in the hands of professionally trained personnel, such keys result in far more adequate and accurate analyses than when the same keys are utilized by individuals who have had no special training in the subject concerned or in a closely allied field. More generally, it can be said that the degree of effectiveness in the utilization of photo interpretation keys varies directly with the amount of interpretation experience and the professional competence of the individual photo interpreter.

In special instances which stem from the extent of the area concerned, the scope or character of the investigation, or the inaccessibility of the area, keys may have to be relied upon without confirmation by field checking. Where areas are inaccessible because of political, physical or financial reasons, the use of photo interpretation keys may provide the only acceptable alternative either to field examination or to photo interpretation with field checks.

The conventional methods for the study of an area such as the analysis of the pertinent literature and maps, are also useful in the interpretation of airphotos of that area. In fact, it is mandatory that the competent photo interpreter be aware not only of the sources of literature pertaining to subjects and areas within his own field of endeavor, but also of the sources of pertinent subject and regional literature concerning the related earth sciences.

The "photogeographer." The term "photogeographer" may, in a manner of speaking, be likened to such terms as "field geographer" and "armchair geographer." Each plays a necessary role. The "photogeographer" conducts his research primarily from airphotos, using field examination, maps and literature for supplementary purposes. The "field geographer" bases his studies on field examination, using maps, literature and airphotos for supplementary purposes. The "armchair geographer" bases his work on literature, on maps and (less often) on airphotos as examined in the office.

But individual geographers are not always confronted with the same types of problems. Perhaps a more realistic method of analyzing the situation would be to divide the problems that geographers study into three groups, viz. (1) the problems best solved by the utilization of photo interpretation as a primary method, (2) the problems to which airphoto interpretation can make significant contributions and (3) the problems best solved without the use of airphotos.[1] When the geographic problems, rather than the geographers, are so divided, it is at once clear that an individual may act as a "photogeographer" in solving one problem and an "armchair geographer" in his approach to the next. Moreover, the methodology adopted in each instance may be the most sound one for the particular problem at hand.

It is equally apparent that it is not necessary for the geographer to become a specialist in photo interpretation. Photogeography is, and should remain, one of the important techniques for the analysis of geographic problems. Therefore, photogeography cannot be likened to such subjects as soil geography, urban geography or biogeography, for these are systematic branches within the broad field of geography. Neither can photogeography be likened to cartography, though both are service techniques for the various systematic branches of geography. Photogeography is more nearly the equivalent of field geography, that is, a method of geographical investigation, rather than any other aspect of the discipline.

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[1]The author's examination of the current list of titles of recently completed dissertations for the degree of Doctor of Philosophy in Geography compiled by Hewes (1951), reveals that 30 per cent of these theses may fall within the first category, 40 per cent within the second category and the remaining 30 per cent into the third category.

The photogeographer, then, must first of all be a geographer who, by virtue of his background of general experience, professional training and airphoto interpretation experience, attacks pertinent problems in geography by means of the analysis of airphotos.

The "airphoto landscape." Without question, the landscape as described by the photogeographer solely on the basis of airphoto analysis differs somewhat from reality. Often the extent of this difference will depend in large measure upon the type of landscape concerned. For example, assuming the same degree of technical skill on the part of the interpreter, desert landscapes and polar landscapes may be interpreted with greater accuracy than landscapes which include a complex cultural morphology.

Because of the differences between the actual landscape and the one conceived solely from airphotos, it is suggested that geographers and other investigators differentiate between the two by calling the latter the "airphoto landscape" and the former the "terrestrial landscape" or merely "landscape." Field and library research can be applied to the "airphoto landscape" to derive the "terrestrial landscape."[2]

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[2]In actual practice, the "airphoto landscape" is merely a concept, for, whenever he can, the photogeographer makes field traverses with the airphotos in hand, studies the maps and reads the literature concerning the area concurrently with his airphoto analysis. In this way, the "airphoto landscape stage" is circumvented except in the instances of inaccessible areas where the "airphoto landscape" becomes the immediate goal of the research problem. This concept of "airphoto landscape" is a useful one, however, because it enables us to determine the extent of the contribution of photogeography to the methods and techniques and to the various branches of geography. While normally it is necessary to secure additional details or confirmation of data from field inventory or library research in order to resolve the differences between the "airphoto landscape" and the "terrestrial landscape," it must be remembered that such factors as the vertical or oblique air view, the viewing of many square miles of area simultaneously, and the use of distinctive film-filter combinations may introduce certain details into the "airphoto landscape" which, although a part of the actual landscape, could not be obtained from field examination, no matter how thorough it may be.

<u>Validity of photogeographical methods</u>. Do photogeographical techniques provide a sound basis for geographical investigation? This depends upon the degree to which observable surface features may be recognized from their photo images as well as the degree to which the images of the various surface features provide a basis for evaluating the many features of landscape which may not be imaged in themselves, e.g., climate, vegetation-covered soils, hydrology, etc.

Since, in most instances, the photo images of surface features can be recognized on aerial photographs and since known relationships of these observable features to invisible, but significant, factors provide much of the information required for the proper evaluation of landscape, it is possible to determine many of the essential elements of an area from its aerial photography. The resulting study, however, must be recognized as one of an "airphoto landscape." In order to determine the geography of the actual landscape, the study must be carried to its conclusion by means of library research, field examination and other appropriate means of investigation. Normally, however, the geographer bypasses the "airphoto landscape" stage by utilizing other methods of area research concurrently with his analysis of the aerial photography.

The validity of photogeographical methods, such as those demonstrated in Chapters V and VI, depends upon such factors as the type of problem to be solved, the nature of the source materials and the competence of the photogeographer. The validity of the individual photogeographical study is also affected by the scope of the problem, including evaluation of whole landscapes or individual landscape components, the kind of landscape, the scale of the investigation and the reliability of the known photo image indicators or diagnostic keys.

Systematic research in photogeography is still in its initial stages, but while the basis for final judgment on the substance and value of this technique is still quite limited, it can be said that, aside from intensive field investigation, no other known medium can offer the geographer such complete and such accurate data concerning the landscape, its condition, the distribution and spatial interrelationships of its component parts and the physical expression of man's adjustment to it. This information, however, is in the form of raw data which must be selected and analyzed by the photogeographer. Since no geographic information is available from the airphotos until after they have been analyzed by the photogeographer, it is at once apparent that it is his competence and industry that are the determining factors in the derivation of geographical knowledge from aerial photographs.

The Ingrid Christensen Coast: A demonstration. The analysis of the Ingrid Christensen Coast by photogeographical methods (Chapter VI) has presented new disclosures of moment such as the existance of the Baker Three coastal area, the true nature of the Publication Glacier Tongues, the ephemeral character of Sandefjord Ice Bay and the evidence of an isostatic or elastic response to the glacial unloading in the Vestfold Hills coastal area. In addition, it has resulted in a considerably better understanding of the geography of this area, an understanding which differs materially from any that may have been gained by even the most exhaustive examination of the existing literature. Moreover, the new understanding is substantiated by evidence in the form of annotated aerial photographs and stereograms which permits competent professional personnel in a wide variety of disciplines to examine and determine for themselves the validity of the specific statements in the text of this study or to elaborate upon points peculiar to their individual professional interests.

More important than this extension of the boundaries of knowledge by the photogeographic analysis of the Ingrid Christensen Coast, however, is the fact that this study did not require the presence of the investigator in the area concerned. Therefore, to the extent that this study can be said to possess genuine geographic value, geographers have a useful and productive method, hitherto little used by them, available for attacking problems in areas or subjects of their special interests. The method is an especially valuable one for utilization in areas of limited accessibility.

Objectives of the study. The two primary objectives of this investigation, as cited in Chapter I, have been:

1. To contribute to the knowledge of the ice forms typical of the Antarctic continental glacier in general, and to the morphology and reconnaissance geography of one typical Antarctic region in particular through the use of airphoto interpretation as a geographic technique, and in so doing

2. To investigate the use, value and limitations of airphoto interpretation as a geographic technique for the inventory and analysis of landscapes, particularly those landscapes which occur in areas of limited accessibility.

It is desirable at this stage to examine and summarize the contributions contained in this study in order to ascertain to what extent the goals of the investigation have been attained and to draw conclusions regarding the merits of photogeographical methods.

Contributions. Some of the significant, original contributions which have accrued from this investigation include:

1. A comprehensive description and analysis of photo reading, photo interpretation and photo intelligence.

2. A summation of the history of photo interpretation.
3. A comprehensive analysis of the concept, the methods of derivation and the use of photo interpretation keys.
4. The development of the concept of photogeography, a valuable method of geographic research.
5. An analysis of the regional limitations to photo reconnaissance and photo interpretation imposed by the Antarctic environment.
6. The derivation and establishment of several hundred annotated, regional photo interpretation keys of the Antarctic and subject photo interpretation keys of landforms and iceforms associated with active continental glaciers.
7. The analysis and classification of major and minor ice formations associated with active continental ice masses, including Antarctic types of glaciers, ice tongues, crevasses, etc.
8. The illustration, description, analysis and naming of a number of iceforms not previously recognized or not known to have been mentioned in existing scientific literature, such as "channel glacier," "floating fissure," "reentrant rift," " ice morass" and "right angle drift."
9. The presentation of new and significant information, derived from aerial photographs, concerning the morphological characteristics and the development of such iceforms and landforms as shelf ice, hinge line depressions, sastrugi, snowdrifts, meltwater lakes, moraines and polygonal terrain. Information derived from airphotos is also presented about such processes as continental ice recession, glacial dissipation by blizzards and the "white day" phenomenon.

10. A demonstration of the feasibility of accomplishing a reconnaissance geographic study from aerial photography, even though no geographer or other scientist, including the investigator, has ever visited the area. This demonstration has been accomplished by means of a photogeographic analysis of the Ingrid Christensen Coast, an Antarctic coastal area of approximately 400 miles in length with widely varied but typical Antarctic iceforms and landforms.

11. A revision of the currently existing maps of the Ingrid Christensen Coast with an improved delineation of the coastline, including islands, ice tongues, fiords and inland features.

12. The first precise description of the major physiographic features of the Ingrid Christensen Coast.

13. The presentation of evidence of the metamorphic character of the bed rock along the Ingrid Christensen Coast.

14. The presentation of evidence relating to a probable uplift of the Westfold Hills coastal area resulting from the unloading of glacier ice.

15. The discovery of the true character of numerous specific physiographic features of the Ingrid Christensen Coast, the most important of which are:

    a. The Sandefjord Ice Bay. The delineation, mapping and analysis of an unstable ice bay bounded by glacier ice and the continental coastline at its head, and formed by dynamic projections of glacier ice tongues and shelf ice. The discovery of the fact that, for the period from 1937 to 1947, the dynamic land-formed ice creating the bay and causing its ephemeral shape, advanced at a rate of more than six times that of the ice forming the unstable Bay of Whales, the only well-known ice bay in Antarctica.

b. The Publication Glacier Tongues. The delineation, mapping and analysis of an area formerly described as shelf ice.

c. The Baker Three coastal area. The discovery, delineation, mapping and analysis of a previously unknown coastal area, an ice-bound, southwestward extension of the Ingrid Christensen Coast.

16. The isolation of numerous problems which merit further investigation.

Additional contributions resulting from the investigation include:

17. A summary, compilation and index map of the existing aerial photographic coverage of Antarctica.

18. The compilation of nomographs illustrating the duration of sunlight and civil twilight in the Antarctic for any given date and latitude.

19. An analysis and chart of Antarctic surface trafficability by 20 methods of transport (see also Keys 285-320) over 24 kinds of typical Antarctic surfaces.

20. The submission of proposed place names for the larger and more significant physiographic features described in the area under consideration to the U. S. Board on Geographical Names and the tentative approval of these names by that board (Maps 13, 14, 15).

21. A bibliography of Antarctic bibliographies.

22. A bibliography of photo interpretation bibliographies.

23. The concept of the "airphoto landscape."

Conclusions. In comparing the findings with the original objectives of the investigation, it may be concluded that these aims have essentially been achieved. In view of this fact, the following conclusions have been drawn:

1. That the photogeographical method is a valid technique for geographical research and a particularly valuable geographical research technique for use in areas of limited accessibility to field investigators.
2. That by means of photogeographical methods, the geographer is enabled to capture the geographical essence of an area and isolate the problems and the places within the area which require or most merit field analysis or detailed study.

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APPENDIX

I MAPS AND CHARTS OF ANTARCTICA

No complete listing of the maps and charts of Antarctica is known to exist. Antarctic maps and charts of historical interest and those published before World War I are listed by Denuce (1913) and [Roscoe] (1951). In this study, the principal hydrographic charts of Antarctic areas are indexed on Maps 7 and 8. This appendix, designed to accompany Maps 7 and 8, is divided into the following sections:

1. Key to Map 7, H. O. Misc. No. 15040.
2. Key to Map 8, H. O. Misc. No. 15040-1.
3. Maps and Charts of Antarctica Not Indexed on Maps 7 and 8.

KEY TO MAP 7, H. O. MISC. NO. 15040

Chart No.	Title	Scale 1/-
	U.S.H.O. CHARTS (Shown in Red)	
0823	S. Pacific Ocean & W. Coast of S. America, Sh. I	5,990,157
0824	S. Pacific Ocean, Sh. II	5,990,157
0825	S. Pacific Ocean, Sh. III	5,990,157
0826	S. Pacific Ocean, Sh. IV	5,990,157
0958	S. Atlantic Ocean, Southwestern Part	5,174,016
0959	S. Atlantic Ocean, Eastern Part	6,454,331
1071	S. Atlantic Ocean	8,441,572
1500	Pacific Ocean	21,912,992
5411	Antarctic Regions	1,659,812
5412	Antarctic Regions	1,088,081
5446	Indian Ocean	7,599,716
5801	Pacific Ocean, Southwest Part, Sh. II	6,624,080

Chart No.	Title	Scale 1/-
6654	Antarctica, Cape Adare to Minna Bluff (Ross Sea)	203,080
2562	Antarctica, General Chart	11,250,000
V-30-105	Antarctica, Air Navigation Chart	2,188,800
V-30-107	Antarctica, Air Navigation Chart	2,188,800
V-30-SP	Antarctica, Air Navigation Chart	2,188,800
V-30-SP-1	Antarctica, Air Navigation Chart	2,188,800
V-30-SP-2	Antarctica, Air Navigation Chart	2,188,800
V-30-SP-3	Antarctica, Air Navigation Chart	2,188,800
V-30-SP-4	Antarctica, Air Navigation Chart	2,188,800

BRITISH ADMIRALTY CHARTS
(Shown in Green)

1775	South Orkney Islands Plans:	
	Uruguay Cove	25,000
	Scotia Bay and Mill Cove	25,000
	Powell Island and Washington Strait	100,000
	Ellefsen Harbour	12,500
	Queens or Borge Bay	12,500
	Signy Island	50,000
	Sandefjord Bay	25,000
3170	Antarctic Regions, Sh. I	2,600,000
3171	Antarctic Regions, Sh. II	2,600,000
3172	Antarctic Regions, Sh. III	2,600,000
3173	Antarctic Regions, Sh. IV	2,600,000
3174	Antarctic Regions, Sh. V	2,600,000
3175	Antarctic Regions, Sh. VI	2,600,000
	Plan: Peter I Island	200,000
3176	Antarctic Regions, Sh. VII	2,600,000

Chart No.	Title	Scale 1/-
3177	Ross Sea to South Pole	3,800,000
3206	Antarctic Regions, Sh. VIII	2,600,000
3593	South Sandwich Islands	500,000
	Plans: Nelson Strait	50,000
	Ferguson Bay	25,000

GERMAN CHARTS
(Shown in Brown)

Ger 1057	Fahrt um Kaphoorn	1,500,000
Ger 1061	Drake Strasse bis 20° Ost	5,000,000
Ger 1062	15° Ost bis Knox Land	5,000,000
Ger 1063	Knox Land bis 160° West	5,000,000
Ger 1064	165° West bis Drake Strasse	5,000,000
	Plan: Peter I Insel	256,000

AUSTRALIAN CHART
(Shown in Brown)

Aus A, B	Antarctica, General Chart	7,500,000

NORWEGIAN CHARTS
(Shown in Blue)

Note: The following Norwegian nautical charts were prepared for Hvalfangernes Assuranceforening, Sandefjord by Norges Geografiske Oppmaling, 1939:

H-1	Sydishavet	5,000,000
	Plan: Bouvet Øen	
H-2	Sydishavet	5,000,000
	Plans: Heard Øen	
	Kerguelen I, Gazelle Havna	
	Kerguelen I, Christmas Havna	

Chart No.	Title	Scale 1/-
	Kerguelen I, Accessible Bukte, Betsy Vika	
	Kerguelen I, Island Havna, Royal Sund	
	Kerguelen	1,105,377
H-3	Sydishavet	5,000,000
	Plans: Macquarie Øen, Hasseborough Bukt	354,890
	Aukland Øen	386,360
	Campbell Øen	
	Antipodes Øen	
H-4	Sydishavet	5,000,000
	Plan: Peter I Øen	
H-5	Rosshavet	2,000,000

Note: The following Norwegian charts were published from the work of the Lars Christensen Expedition, 1936-1937 by Norges Geografiske Opmaling, 1946:

Chart No.	Title	Scale 1/-
C-1	Antarctica, Lat. 69°10'S. to Lat. 72°30'S. Long. 21°00'E. to Long. 27°00'E.	500,000
C-2	Antarctica, Lat. 68°40'S. to Lat. 70°20'S. Long. 36°50'E. to Long 40°20'E.	250,000
C-3—C-12	Antarctica, Lat. 65°30'S. to Lat. 70°10'S. Long. 52°00'E. to Long. 82°00'E.	250,000

Note: The H or C before each chart number above is an arbitrary designation for use of the U. S. Hydrographic Office. It does not appear on the face of the chart.

KEY TO MAP 8, H. O. MISC. 15040-1

Chart No.	Title	Scale 1/-
	U.S.H.O. CHARTS (Shown in Red)	
6650	Plans on the west coast of the Palmer Peninsula	
	Hackapike Bay	4,050
	Mutton Cove	4,080
	Black Island to Uruguay Island	7,680
	Schollaert Channel to Neumayer Channel	201,350
6651	Debenham Islands	3,580
6652	Black Thumb Mountain to Bigourdan Fjord	109,490
6653	Cape Evensen to Anvers Island	251,200
	Plan: Port Lockroy	10,040
	BRITISH ADMIRALTY CHARTS (Shown in Green)	
3205	South Shetlands and adjoining islands and lands	670,000
	Plans: Deception Island	100,000
	King George Bay	112,500
	Pendulum Cove	18,060
	Neptune's Bellows	18,060
3213	Plans in the South Shetlands and vicinity of Graham Land	
	Schollaert and Neumayer Channels	200,000
	Melchoir Harbour	35,000
	Discovery Sound	12,500
	Argentine Islands	15,000
	Port Lockroy	10,000
	Admiralty Bay	100,000
	Visca or North Anchorage	25,000
	Debenham Islands	12,500

Chart No.	Title	Scale 1/-
	FRENCH CHARTS (Shown in Brown)	
Fr 5448	Baie de l'Amirauté	50,000
Fr 5449	Isla Déception	50,000
	Plans: Pendulum Cove	10,000
	Passe du Challenger et Anse des Baleiniers	10,000
Fr 5452	Shetlands du Sud	846,500
	ARGENTINE CHARTS (Shown in Brown)	
Arg 100	Isla Decepción	50,000
Arg 101	Archipiélago Melchior	20,000

MAPS AND CHARTS OF ANTARCTICA NOT INDEXED ON MAPS 7 AND 8

In addition to the maps and charts indexed on Maps 7 and 8, numerous maps, charts, plans and plotting sheets are available for reference purposes at the U. S. Navy Hydrographic Office. These do not, by any means, constitute a complete listing of Antarctic maps and charts.

AMERICAN CHARTS OF ANTARCTICA

Chart No.	Title	Scale 1° Long. =
5609	Meteorological Plotting Chart	
5693	Meteorological Plotting Chart	
5840	Meteorological Plotting Chart	
2601	Pilot Chart of the South Pacific Ocean (quarterly)	
2603	Pilot Chart of the Indian Ocean (monthly)	
1701-S	Horizontal Intensity of the Earth's Magnetic Force for the Year 1945, South Polar Area	

Chart No.	Title	Scale 1° Long. =
1703-S	Total Intensity of the Earth's Magnetic Force for the Year 1945, South Polar Area	
1705-S	The East Component of the Earth for the Year 1945, South Polar Area	
1706-S	Variation of the Compass for the Year 1945, South Polar Area	
5192	Time Zone Chart of the World	
11993 Misc.	Antarctic Ice and Current Chart	
	Note: The following are H.O. Position Plotting Sheets. Each covers a definite band of latitude and is applicable to any longitude. In the 3000 (1 to 18) series the over-all size is 35 x 46 inches.	
3000-10	Lat. 49° -- Lat. 54° N. or S.	2 inches
3000-11	Lat. 53° -- Lat. 57° N. or S.	2 inches
3000-12	Lat. 56° -- Lat. 60° N. or S.	2 inches
3000-13	Lat. 59° -- Lat. 63° N. or S.	2 inches
3000-14	Lat. 62° -- Lat. 65° N. or S.	2 inches
3000-15	Lat. 64° -- Lat. 71° N. or S.	2 inches
3000-16	Lat. 70° -- Lat. 75° N. or S.	2 inches
3000-17	Lat. 74° -- Lat. 78° N. or S.	2 inches
3000-18	Lat. 77° -- Lat. 81° N. or S.	2 inches
3000-r	Lat. 80° -- Lat. 89° N. or S.	0.14 inches
3000-s	Lat. 89° -- Lat. 89°45' N. or S.	0.14 inches
11960-1 Misc.	Lat. 63° -- Lat. 66° N. or S.	3.2 inches
11960-2 Misc.	Lat. 66° -- Lat. 69° N. or S.	3.2 inches
11960-3 Misc.	Lat. 69° -- Lat. 72° N. or S.	3.2 inches
11960-4 Misc.	Lat. 72° -- Lat. 75° N. or S.	3.2 inches

Chart No.	Title	Scale 1° Long. =
5600	Polar Plotting Sheet (azimuthal, equidistant, stereographic and gnomonic projections)	
9906 Misc.	Polar Coordinate Plotting Chart	
2601	Pilot Chart of the South Pacific. Index of pilot chart articles, navigation, ice, ocean currents, waves and meteorological information from Jan. 1942 to Dec. 1947.	

Note: The U. S. Navy Hydrographic Office has in its reference files the following surveys:

Title	Scale 1/-
East Base and Vicinity, from Neny Fiord to Bills Gulch. A survey by the U. S. Antarctic Service Expedition of 1939-41.	183,000
Neny and Stonington Islands. (Triangulation survey.)	20,000
Anchorage of the U.S.S. Bear in Horseshoe Island Cove. (Sketch.)	13,000
Andersen Harbor, Melchior Islands. A survey by the U.S.S. North Star.	3,500
East Base, Stonington Island. A plan by the U. S. Antarctic Service Expedition, 1939-41.	1,000

BRITISH CHARTS OF ANTARCTICA

Title	Scale 1/-
The percentage of saturation with oxygen of a surface stratum 100 m. deep in the Falkland sector. Discovery Reports, 1933, Vol. 7, Fig. 17.	
The Salinity of a surface stratum 100 m. deep in the Falkland sector. Discovery Reports, 1933, Vol. 7, Fig. 13.	
Temperature of a surface stratum 100 m. deep in the Falkland sector (°C). Discovery Reports, 1933, Vol. 7, Fig. 12.	
Antarctic and Subtropical convergences; the boundary between Weddell Sea and Bellingshausen Sea waters. Discovery Reports, 1933, Vol. 7, Fig. 8.	
The temperature of the warm deep water in the Falkland sector (°C). Discovery Reports, 1933, Vol. 7, Fig. 24.	

Title	Scale 1/-
Ross Island - West Coast. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map V.	100,000
Plan: Summit of Erebus	50,000
Cape Evans, Ross Island. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map VIII.	12,500
Hut Point Peninsula, Ross Island. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map X.	50,000
Erebus Bay, Ross Island. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map XI.	50,000
Cape Royds District, Ross Island. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map IX.	25,000
McMurdo Sound Region, Ross Sea. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map IV.	500,000
The surface isotherms and currents in the Falkland sector. Discovery Reports, 1933, Vol. 7, Fig. 8.	
Granite Harbour, Ross Sea. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map VI.	100,000
Ferrar-Koettlitz District, McMurdo Sound. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map VII.	200,000
Terra Nova Bay, Ross Sea. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova). Map XIV.	250,000
Robertson Bay and Cape Adare. Report on Surveys, British Antarctic Expedition, 1910-13 (Terra Nova).	100,000
Plan: Ridley Beach, Cape Adare	15,000
Graham Land Peninsula and adjacent islands, showing localities where collections of lichens have been made. Discovery Reports, Vol. 25, p. 4.	
Plan: South Orkneys	
The east coast of the Trinity Peninsula, Graham Land, showing positions of the collecting stations. (Based on the survey made by Major Andrew Taylor, R.C.E., assisted by Capt. Victor Russell, R.E., in 1945.)	611,700

Chart No.	Title	Scale 1/-
BA 18-A	Gnomonic Chart, South Atlantic and Southern Oceans	
BA 53-A	Gnomonic Chart, South Pacific and Southern Oceans	

Chart No.	Title	Scale 1/-
BA 1241	Ice Chart of the Southern Hemisphere	
BA 5301	World Climatic Chart I (January)	
BA 5302	World Climatic Chart II (July)	
BA Pub 163	Atlas of Meteorological Charts of the World	

GERMAN CHARTS OF ANTARCTICA

Chart No.	Title	Scale 1/-
Ger 2802	Weltkarte, Zur Übersicht der Meeresströmungen	28,000,000
Ger 2704	Grosskreiskarte des Südlichen Stillen Ozeans	
Ger 2703	Grosskreiskarte des Indischen Ozeans	
Ger 2701	Grosskreiskarte des Südatlantischen Ozeans	

Title	Scale 1/-
Atlantisches Südpolarmeer, Mittlere Wasserbewegung an der Oberfläche im Südsommer. Deutsche Antarktische Expedition, 1938-39 (Ritscher, 1943, p. 98).	
Oberflächentemperatur des Weddellmeeres im Südsommer. Archiv der Deutschen Seewarte, 1921, Vol. 39, p. 44. Deutsche Antarktische Expedition, 1911-12.	
Wetterlage am 20 Januar 1939 und Zugbahn eines Tiefs vom 20-24 Jan. Archiv der Deutschen Seewarte, Aug. 1939, p. 34. Deutsche Antarktische Expedition, 1938-39.	
Das Schelfeis der Posadowsky Bai. Deutsche Südpolar Expedition, 1901-03.	250,000
Das Inlandeis am Gaussberg. Deutsche Südpolar Expedition, 1901-03.	15,000
Neu-Schwabenland. Deutsche Antarktische Expedition, 1938-39 (Ritscher, 1943).	1,500,000
Wohlthat-Massiv, Neu-Schwabenland. Deutsche Antarktische Expedition, 1938-39 (Ritscher, 1943, Map I).	50,000
Alexander von Humboldt Gebirge, Neu-Schwabenland. Deutsche Antarktische Expedition, 1938-39 (Ritscher, 1943, Map II).	50,000

Title	Scale 1/-
Neu-Schwabenland. Deutsche Antarktische Expedition, 1938-39 (Ritscher, 1943, Map III).	500,000
[Surface currents in the Atlantic South Polar Seas in the southern summer.] Deutsche Antarktische Expedition, 1938-39 (Ritscher, 1943).	
[Surface temperature of the Weddell and Scotia Seas in the southern summer.] Deutsche Antarktische Expedition, 1911-12.	

AUSTRALIAN CHARTS OF ANTARCTICA

Title	Scale
King George Land. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1.	1.45" = 30 mi.
The coast of Adelie Land and sledge tracks of the Western Sledge Party. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Plate VII.	1/ 1,433,055
Cape Denison, rising slope of the inland ice sheet. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1.	0.89" = 220 yds.
Adelie Land and King George Land adjacent to Cape Denison. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Pl. VI.	1.32" = 10 mi.
Tracks of the Aurora off the coast of Adelie Land and King George Land. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Pl. II.	1/1,433,055
Portion of King George Land and the Mertz Glacier Tongue. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Pl. IV.	1.32" = 10 mi.
Wilkes Coast outlined by Capt. Davis on board the Aurora after its discovery in Jan. 1912. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1.	1/1,244,055
The Charnockite Coast and sledge tracks of the Near-East Party. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Map V.	1.7" = 5 mi.

Title	Scale
The MacKellar Islets and anchorage off Cape Denison. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Fig. 4.	2.52" = 1 n. mi.
MacKellar Islets. (Mawson, 1915, Vol. II, p. 257).	0.85" = 1,000'
David Island and portion of Queen Mary Land. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Fig. 24.	0.76" = 4 mi.
Haswell Id. (View looking north across Haswell Island) Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Fig. 27.	0.76" = 10 chains
Western Base Station. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1.	2.52" = 50 mi.
Track of the S.Y. Aurora on three Antarctic voyages. Australasian Antarctic Expedition, 1911-14 (Aurora). Scientific Reports, Series A, Vol. 1, Fig. 2.	

NORWEGIAN CHARTS OF ANTARCTICA

Title
Vind og Lufttempertur. Atlas over Antarktis og Sydishavet (Hansen, 1936, p.4).
The wind conditions over the Atlantic Antarctic Ocean in summer. In: Mosby, The sea surface and the air. Det. Norske Videnskapsakademi, Oslo, 1933, Fig. 15.
Pakkisgrenser for 1 November, 15 Desember, 15 Januar, 1 Mars. Atlas over Antarktis og Sydishavet (Hansen, 1936, p.3).

Note: The following charts are based upon the scientific results of the Norwegian Antarctic Expedition, 1927-1928 and may be found in: Mosby, The waters of the Atlantic Antarctic Ocean. Det. Norske Videnskapsakademi, Oslo, 1934.

Maximum temperature of the hydrosphere (Fig. 5, p. 20).

Depth of discontinuity between tropo- and strato-hydrosphere (Fig. 6, p. 22).

Temperature of winter water compared to freezing point (t-r) (Fig. 7, p. 25).

Bottom temperature of the Atlantic Antarctic Ocean (Fig. 10, p. 32).

Title
Horizontal distribution of temperature, salinity and density σ_t at 2,000 m. (Fig. 20, p. 44).
Horizontal distribution of temperature, salinity and density σ_t at 1,000 m. (Fig. 21, p. 45).
Horizontal distribution of temperature, salinity and density σ_t at 400 m. (Fig. 22, p. 46).
Horizontal distribution of temperature, salinity and density σ_t at 75 m. (Fig. 23, p. 47).
Relative topography, 1,000-2,000 decibars (Fig. 24, p. 51).
Relative topography, 1,000-400 decibars (Fig. 25, p. 53).
Relative topography, 1,000-75 decibars (Fig. 26, p. 54).
Relative topography, 1,000-0 decibars (Fig. 27, p. 55).
Relative topography, 2,000-0 decibars (Fig. 28, p. 56).

FRENCH CHARTS OF ANTARCTICA

Title	Scale 1/-
Abords de Port Lockroy, Ile Wiencke. Expédition Antarctique Française, 1903-1905.	20,000
Plan: Port Lockroy	5,000
Ile Petermann. Deuxième Expédition Antarctique Françiase, 1908-1010, Pl. V.	4,065
Plans des installations d'hivernage à Port Charcot. Expédition Antarctique Française, 1903-1905, Fig. 37.	2,000
Ile Booth (Wandel). Expédition Antarctique Française, 1903-1905, Pl. V.	20,000
Port Circoncision (Ile Petermann). Deuxième Expédition Antarctique Française, 1908-1910, Pl. VI.	1,000
Port Charcot (Ile Wandel). Expédition Antarctique Française, 1903-1905, Pl. VI.	5,000
Environs de la station d'hivernage. Deuxième Expédition Antarctique Française, 1908-1910, Pl. IV.	66,666
Archipel de Palmer, Expédition Antarctique Française, 1903-1905, Pl. III.	

APPENDIX

II GEOGRAPHIC SOURCE MATERIALS FOR THE INGRID CHRISTENSEN COAST

Primary source materials for the geography of the Ingrid Christensen Coast are confined largely to ships' logs, personal unpublished diaries and brief or popular articles by Mikkelsen (Polar Record, 1935), Christensen (1938, 1939a, 1939b), Ellsworth (1939a, 1939b) and Hansen's atlas (1946).

Secondary source materials, careful analyses of the references cited above, including ships' logs and diaries, have given the best composite picture of the area previously available. The most authoritative of these sources are the United States Navy Department's Hydrographic Office Publication No. 138, Sailing Directions for Antarctica, 1943; the British Admiralty's Antarctic Pilot, 1948; and the United States Board on Geographical Names' Special Publication No. 86, 1947.

The portions of the U. S. Navy and British Admiralty publications relevant to the region concerned are reproduced in full by photostat on the next three pages. This is followed by pertinent excerpts from the decisions rendered on Antarctic place names by the U. S. Board on Geographical Names in its Special Publication No. 86.

Careful analysis of the materials contained herein reveals a general lack of agreement among the authorities. Comparison with the photogeographical analysis of the area in Chapter VI demonstrates all previous sources, both primary and secondary, to suffer considerably from incorrect statements, omissions and failure to capture the geographic character of the coast. Portions of the appended parts of these publications which are definitely in error have been crossed out. Information relative to latitude and longitude, other doubtful information and immaterial information has not been so indicated. The greatest errors, of course, are those of omission.

Vestfold Mountains
Christensen

The Ingrid Christensen Coast lies approximately between 73° and 81° E. The interior as far as 7[illegible] S. has been named **American Highland** by Ellsworth. About ~~[illegible] miles~~ of this coast line is free of ice and snow. Many landing places and suitable base sites are available. ~~Fresh~~ water lakes, penguins, and seals are to be found in great numbers. ~~Due to the prevailing easterly winds, the coast line may be ice free the greater part of the year.~~

On February 19, 1935, the *Thorshavn* reached 67°38′ S., 80°35′ E., from which position Capt. K. Mikkelsen sighted the West Shelf Ice. A landing was made at 68°29′ S., 78°36′ E., and a depot of provisions established.

The *Thorshavn* then skirted the coast southwestward until sighting Mount Caroline Mikkelsen, then turned northwestward, skirting the Mackenzie Sea shelf ice as far as 68°51′ S., 73°32′ E.

On January 27, 1937, the whale catcher *Firern* was off this coast, and Lars Christensen made a series of flights mapping this region from the air.

In January 1939, the *Wyatt Earp* cruised along this coast, and on January 11, 1939, Ellsworth and Lymburner flew southward from 68°30′ S., 79° E. to 72° S., 79° E.

Coast.—From Cape Penck the ice-covered coast trends west southwestward about 90 miles then turns southward between parallels 67° and 68° S., this portion of the coast being fronted by the West Shelf Ice. The coast then takes a southwesterly trend for about 150 miles where it forms the eastern shore of the ~~**Mackenzie Sea**.~~

The southern limit of the West Barrier is approximately in 68° S., 81° E., where the western edge of the barrier and the continental shore line form Olaf Prydz Bay. Here the coast line continues as an ice cliff, terminating the ice cascades descending from the high interior. ~~Many rock outcrops jut through the ice cliffs and numerous islets and~~ skerries lie close to the shore. A sounding of 19 fathoms (34.7 m.) was recorded by the *Thorshavn* in 68°37′ S., 77°40′ E.

Rocks.—Submerged rocks and pinnacles abound and navigators are cautioned to proceed carefully in these waters and maintain a lookout aloft. When cruising in the vicinity of land, a small boat should be sent ahead of the ship to sound the approach which may shoal rapidly.

Current.—A west setting current has been observed along this coast.

Depot.—A cache of provisions is placed on a rocky headland near the northern end of the Vestfold Mountains in 68°29′ S., 78°36′ E. This site is a rocky snow-free peninsula marking the junction of the ice cliffs with the Vestfold ~~range~~. A chain of islets and skerries stretches from the northern extremity of the peninsula to the mainland. A landing may be made in a small bay on the southern shore of the peninsula between two ridges. The uneven land slopes steeply to two ridges about 410 feet (125.0 m.) high. The depot site is on the western side of the easternmost of the two ridges. ~~No vegetation exists here~~. The rock is of sedimentary origin. A small gully between the ridges leads to an inland fresh-water lake situated about 100 feet (30.5 m.) above sea level, from which a creek flows westward to the sea. A large penguin rookery exists on the bare rocks in this region. The ~~entire~~ coast offers several good landing places, good water, and protected flat sites for huts and bases. Detailed investigation may disclose good harbors. The long ice-free coast line, and the abundance of seals and penguins, suggests accessibility by ship each year, and hence an ideal region for future exploration.

The Vestfold ~~**Mountains**, from 600 to 1,000 feet (182.9 to 304.8 m.) high~~, extend from the depot site southwestward ~~about 40 miles~~. These barren, rounded, and jagged hills jut seaward from the continental ice edge for a distance of ~~about 8 miles~~ and are mostly insular with thick fast ice interlocking the land masses. The land ice behind these hills is high and is broken by vast crevasses and hummocks.

The Sörsdal ~~**Glacier**~~ lies southwestward of the Vestfold ~~Mountains~~. It is about 10 miles wide ~~and of unknown length~~. The blue ice surface is ~~chaotic in appearance with ice pinnacles, broken icefalls, and~~ crevasses. Calving of this ~~glacier~~ face occurs during the summer months.

Rauer Islands, a group of ~~six islets~~ with many smaller rocks, lie about 2 miles westward of the Sorsdal Glacier. These snow-free islets are dome-shaped and ice-polished, consisting principally of granite and gneiss.

~~**The Ranvik Mountains**, from 150 to 300 feet (45.7 to 91.4 m.) high, front the coast southwestward of the Sorsdal Glacier for a distance of about 11 miles. This range consists of low, rounded, snow-free hills, insular in type, which for the greater part extend seaward of the continental ice slope, and are similar in appearance to the Vestfold Mountains.~~

~~Southwestward of the~~ Ranvik Mountains the coast line for the next 10 miles is formed by an ice ~~cliff~~ from 164 to 328 feet (50.0 to 100.0 m.) high.

Southwestward of ~~this stretch of ice-bound coast~~ are the Larsemann Mountains, ~~similar in character to the Ranvik Mountains, but which extend for some distance inland~~, where the ice slopes rise above ice-covered land. These mountains form the coast line for a distance of 11 miles. ~~Thick fast ice envelopes the shores of the archipelago, and this ice is held in place by submerged rocks and shoals~~. The strongly glaciated outlines of the ~~mountains~~ of Ingrid Christensen coast are proof that, at one time, the continental ice sheet was more extensive. ~~The~~ snow-free ~~mountain~~ coasts are yellow in color and indicate the presence of large penguin rookeries with vast guano deposits.

The Svenner Islands *(69°10′ S., 76°30′ E.)*, a group of 10 small islands, lie about 2 miles from the continental ice. These dome-shaped islands consist of granite and gneiss with veins of hornblende and quartz which yield quantities of garnets and mineral ores. (See view on p. 238.)

The Söstrene Islands (**The Sisters**), ~~two rounded~~ islands, lie ~~about 25 miles southwestward of the Svenner Islands and~~ about 3 miles from the coast. ~~The islands are somewhat larger than those lying to the northward.~~

The coast line opposite the Söstrene Islands trends southwestward about 45 miles to ~~Mount~~ Caroline Mikkelsen, ~~about 1,475 feet (449.6 m.) high~~ located in 69°49′ S., 74°01′ E. ~~From this peak the coast line trends northward~~, thus forming Sandefjord Bay at the head of the ~~Mackenzie Sea~~. About 5 miles southward of the Söstrene Islands is ~~shelf ice having an average width of about 40 miles and which skirts the shore line of Sandefjord Bay~~, behind which the inland ice rises in steep slopes.

Excerpt from the /British/ Admiralty's The Antarctic Pilot, 1948.

Ingrid Christensen coast.—In about long. 76° E., the coast recedes southward to about Lat. 69° 50′ S., the bight thus formed being named Sandefiord bay. Near the head of this bay the coast is fringed by numerous small rocks, and, in January, 1937, Lars Christensen reported that it was filled with firm sea-ice, in which numerous icebergs were frozen. Mount Caroline Mikkelsen, ~~about 1,500 feet (457m2) high~~, lies close within the head of this bay.

From the southernmost part of Sandefiord bay, the edge of the ~~shelf-ice~~ trends in a north-easterly direction and, in places, the coast is very broken, with numerous off-lying islands. Søstrene islands lie offshore about 40 miles north-eastward of Mount Caroline Mikkelsen. ~~This part of the coast is ice-free and is backed by Larsemann mountains,~~ which trend in a north-easterly direction for about 14 miles. ~~This ice-free stretch of coast is followed by another stretch, about 10 miles long, which is ice-covered.~~ Off ~~the edge of~~ the ice, ~~which is between 150 and 330 feet (45m7 and 100m6) high~~, lie Svenner islands. Thence the coast, still trending north-eastward, again becomes ice-free and is ~~backed by Ranvik mountains~~, which extend about 11 miles. North-eastward of the northern limit of these mountains a large glacier, about 9 miles wide, reaches the sea. ~~Its surface is reported to be very rough.~~ Rauer islands, a group of numerous small rocky islands, lie close off-shore near the foot of this glacier. From this ~~glacier~~ an ice-free stretch of coast trends north-eastward for ~~about 40 miles~~, ~~being backed by Vestfold mountains, which rise to elevations of 660 to 1,000 feet (201m2 to 304m8)~~. Behind these ~~mountains~~ the ice-cap can, ~~in places~~, be seen rising above them. In 1937, Lars Christensen reported seeing many ice-free ~~freshwater~~ lakes in these mountains. These were again seen by the United States Navy Antarctic expedition in 1946–47, ~~and were reported, by this expedition, to cover an area of more than 100 square miles~~.

In 1935, a depôt of stores was laid, at an elevation of about 150 feet (45m7), near a small ridge close to a fresh-water lake in lat. 68° 29′ S., long. 78° 36′ E. A landing was made in a cove between two ridges on the southern side of a small peninsula.

Klarius Mikkelsen, when describing this coast in general in 1935, stated that he thought it is approachable for a period every year. The relatively extensive snow- and ice-free areas, and the large penguin rookeries in this region would seem to indicate this. He stated that there are numerous good landing places where fresh water is available; that food in the form of penguins eggs, young penguins and seal can be found in plenty; and that there are also many places where expedition huts could be erected.

Beyond Vestfold mountains, little is known of the coast, though it is reported to trend north-eastward for ~~about 60 miles~~ before turning northward to King Leopold and Queen Astrid coast.

Chart 1240.

Pertinent Excerpts from Special Publication No. 86 of the United States Board on Geographical Names, 1947:

Ingrid Christensen Coast: that portion of the coast of Antarctica extending from Mount Caroline Mikkelsen at the head of Sandefjord Bay, in about 74°E. to about 81°E. Discovered by Capt. Klarius Mikkelsen of the Thorshavn, who landed here in 1935. Named for Ingrid Christensen, who sailed in Antarctic waters with her husband. Not: Ingrid Christensen Land. (p. 182)

Vestfold Hills: barren, rounded, and jagged hills, from 600 to 1,000 feet high, extending for about 20 miles northeastward of the Sørsdal Glacier, on the Ingrid Christensen Coast; in 68°40'S. 77°50'E. Discovered on February 20, 1935 by Capt. Klarius Mikkelsen in the Thorshavn, Norwegian whaling ship sent out by Lars Christensen. Vestfold is a county in Norway where Sandefjord, headquarters of the whaling industry, is located. Not: Vestfold Mountains. (p. 245)

Sørsdal Glacier: a glacier, about 8 miles wide and of unknown length, lying south of the Vestfold Hills, on the Ingrid Christensen Coast; in 69°40'S. 77°50'E. Discovered February 20, 1935 by Capt. Klarius Mikkelsen in the Thorshavn, Norwegian whaling ship sent out by Lars Christensen. Not: Soredal Glacier, Sörsdal Glacier. (p. 234)

Rauer Islands: a group of rocky islands lying southwest of the Sørsdal Glacier along the Ingrid Christensen Coast; in 68°55'S. 77°20'E. Discovered February 20, 1935 by Capt. Klarius Mikkelsen in the Thorshavn, Norwegian whaling ship sent out by Lars Christensen. Not: Rauer Group. (p. 217)

Ranvik Bay: an embayment lying southward of the Rauer Islands along the Ingrid Christensen Coast; in 69°07'S. 77°15' E. Discovered and charted in February 1935 by Capt. Klarius Mikkelsen in the Thorshavn. Named for the town of Ranvik, Norway. (p. 217)

Svenner Islands: a group of 10 small, rocky islands lying off the Ingrid Christensen Coast in the southern part of Prydz Bay; in 69°06'S. 76°25'E. Discovered and charted in February 1935 by Capt. Klarius Mikkelsen in the Thorshavn. Named for the Svenner Islands of Norway. (p. 239)

Larsemann Hills: low, rounded hills which mark the shore line for a distance of about 10 miles along the Ingrid Christensen Coast; in about 69°30'S. 75°40'E. Discovered February 20, 1935 by Capt. Klarius Mikkelsen in the Thorshavn, Norwegian whaling ship sent out by Lars Christensen. Not: Larsemann Mountains. (p. 190)

Bølingen Islands: a group of islands lying off the Ingrid Christensen Coast, at the eastern entrance to Sandefjord Bay; centering in 69°33' S. 75°10'E. Discovered and charted in February 1935 by Capt. Klarius Mikkelsen in the Thorshavn. (p. 138)

Søstrene Islands: two small islands lying southwestward of the Bølingen Islands and about 7 miles off the Ingrid Christensen Coast; in 68°48'S. 77°50'E. Discovered and charted in February 1935 by Capt. Klarius Mikkelsen in the Thorshavn. Named for the Søstrene Islands of Norway. Not: Söstrene Islands, Söstvene Islands, The Sisters. (p. 234)

Sandefjord Bay: a bay lying in the southwestern portion of Prydz Bay, along the shore of the Lars Christensen and Ingrid Christensen Coasts; in about 69°40'S. 74°30'E. Discovered in February 1935 by Capt. Klarius Mikkelsen in the Thorshavn, a whaling ship sent out by Lars Christensen.

Named for the town of Sandefjord, Norway, center of the Norwegian whaling industry. (p. 225)

Caroline Mikkelsen, Mount: a mountain peak, about 800 feet high, lying on the Ingrid Christensen Coast at the head of Sandefjord Bay; in 69°49'S. 73°50'E. Discovered February 20, 1935 by Capt. Klarius Mikkelsen in the *Thorshavn*, Norwegian whaling ship sent out by Lars Christensen. Named for the wife of Capt. Klarius Mikkelsen who accompanied her husband on this voyage. (p. 144)

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University of California at L.A.	1939		
Syracuse University	1939-41	M.S.	15 August 1941
University of California at L.A.	1941		
University of Maryland	1949-52		

Publications: Author or co-author of numerous classified, government publications. Unclassified publications include:

Bibliography of photographic interpretation: selected with emphasis upon keys, techniques and research. Report No. 102A/50, U.S. Naval Photographic Interpretation Center, Washington, D.C. 15 February 1950.

Antarctic bibliography. Published by the direction of the Chief of the Bureau of Aeronautics, Department of the Navy, Washington, D.C. 1 February 1951. (For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.)

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Undergraduate Assistant, Syracuse University
Graduate Assistant, Syracuse University
Graduate Assistant, University of California at Los Angeles
Assistant and Associate Professor, University of Georgia
Lecturer, George Washington University
Lecturer, Montgomery Junior College
Instructor in Air Force, Navy and Marine Corps Schools during World War II

Other positions held:

Photo Interpreter, A-2, War Department
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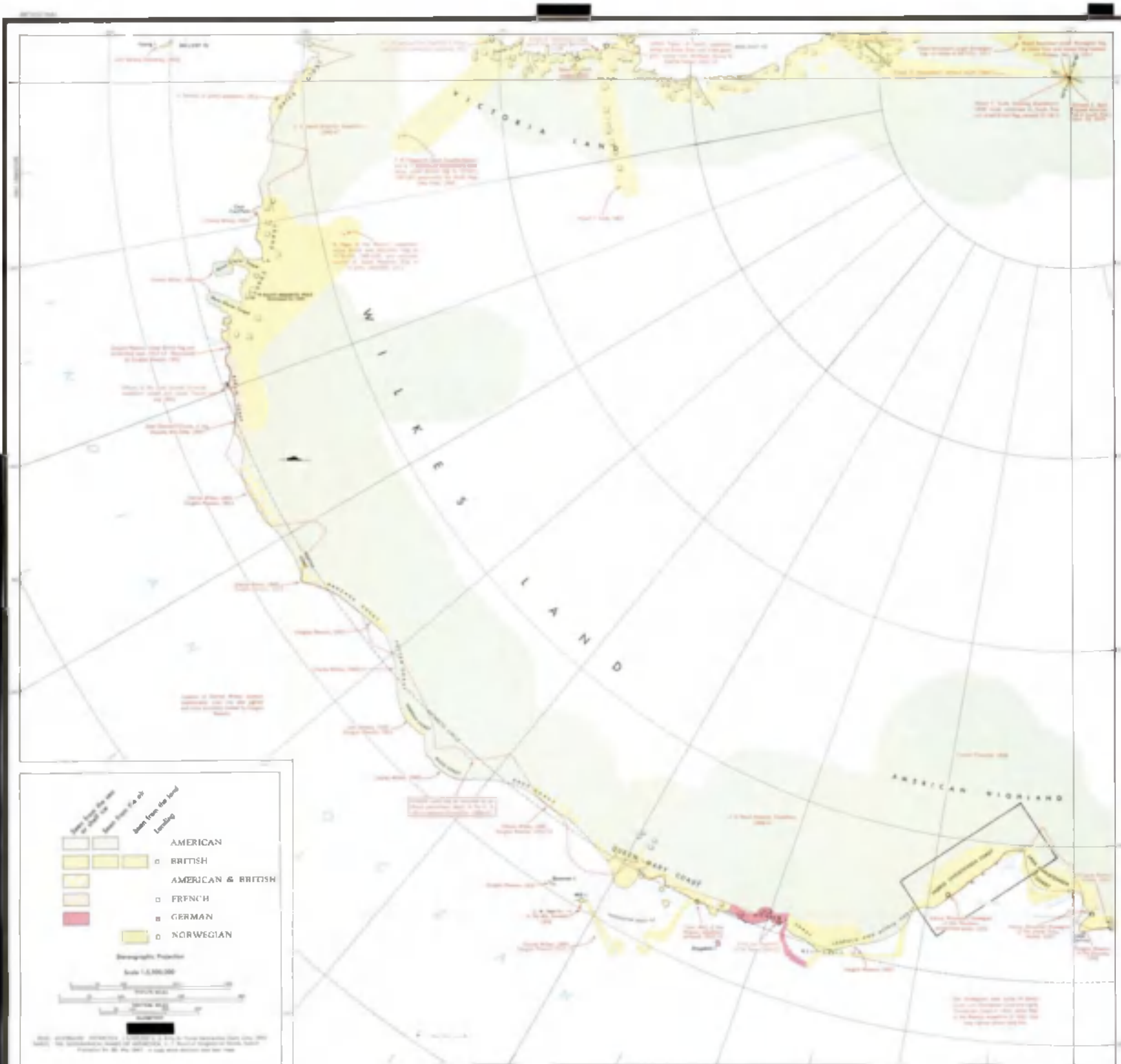
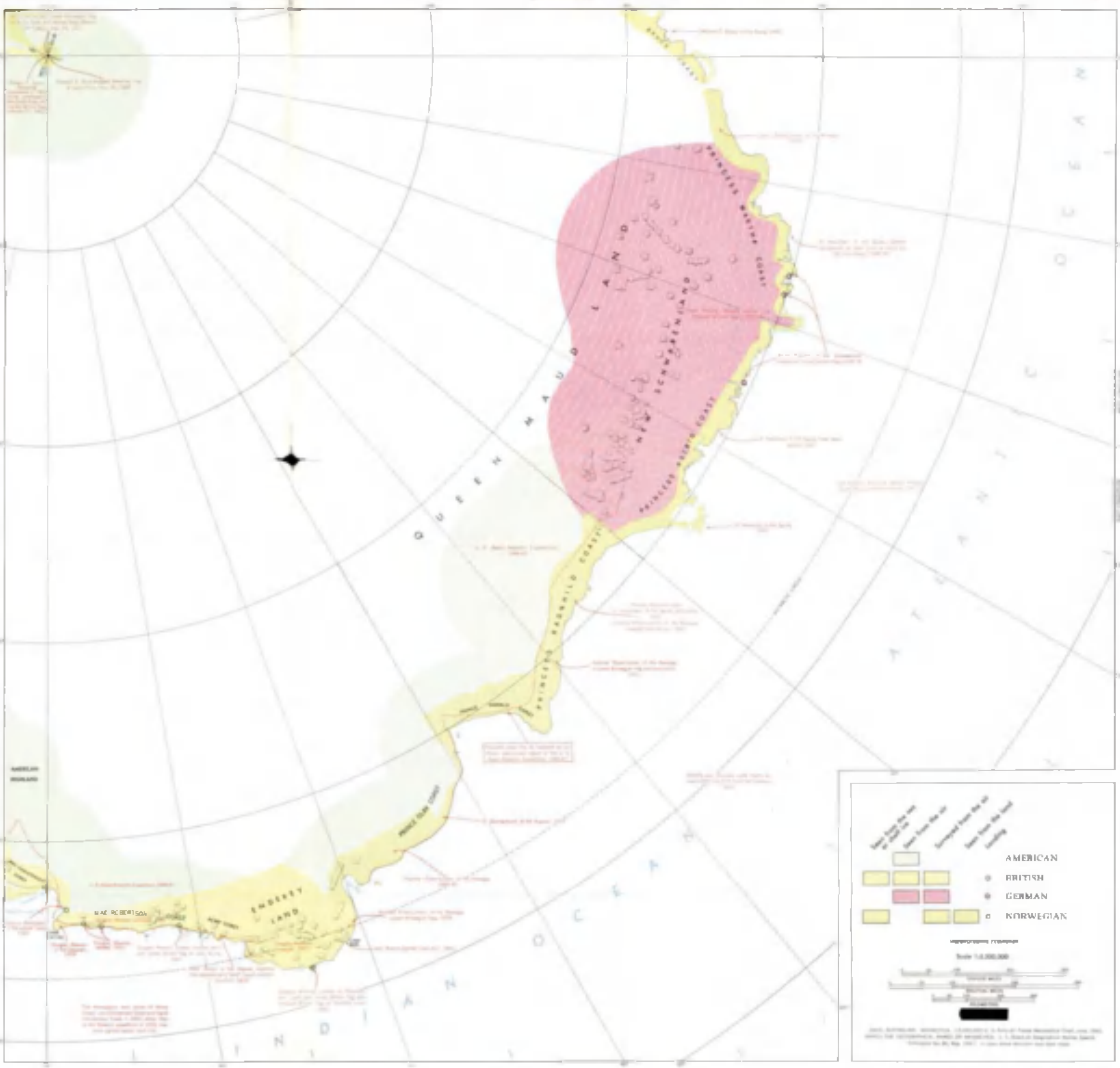
Head, Physical Vulnerability Section
Head, Geographic Analysis Section
Head, Research and Analysis Division
Reconnaissance Branch, Dir. Intelligence, Hq U.S. Air Force
Chief, Geographic Unit
Chief, Photo Reconnaissance Utilization Section



DISCOVERY AND EXPLORATION IN ANTARCTICA

INDIC QUADRANT (160°E–70°E)

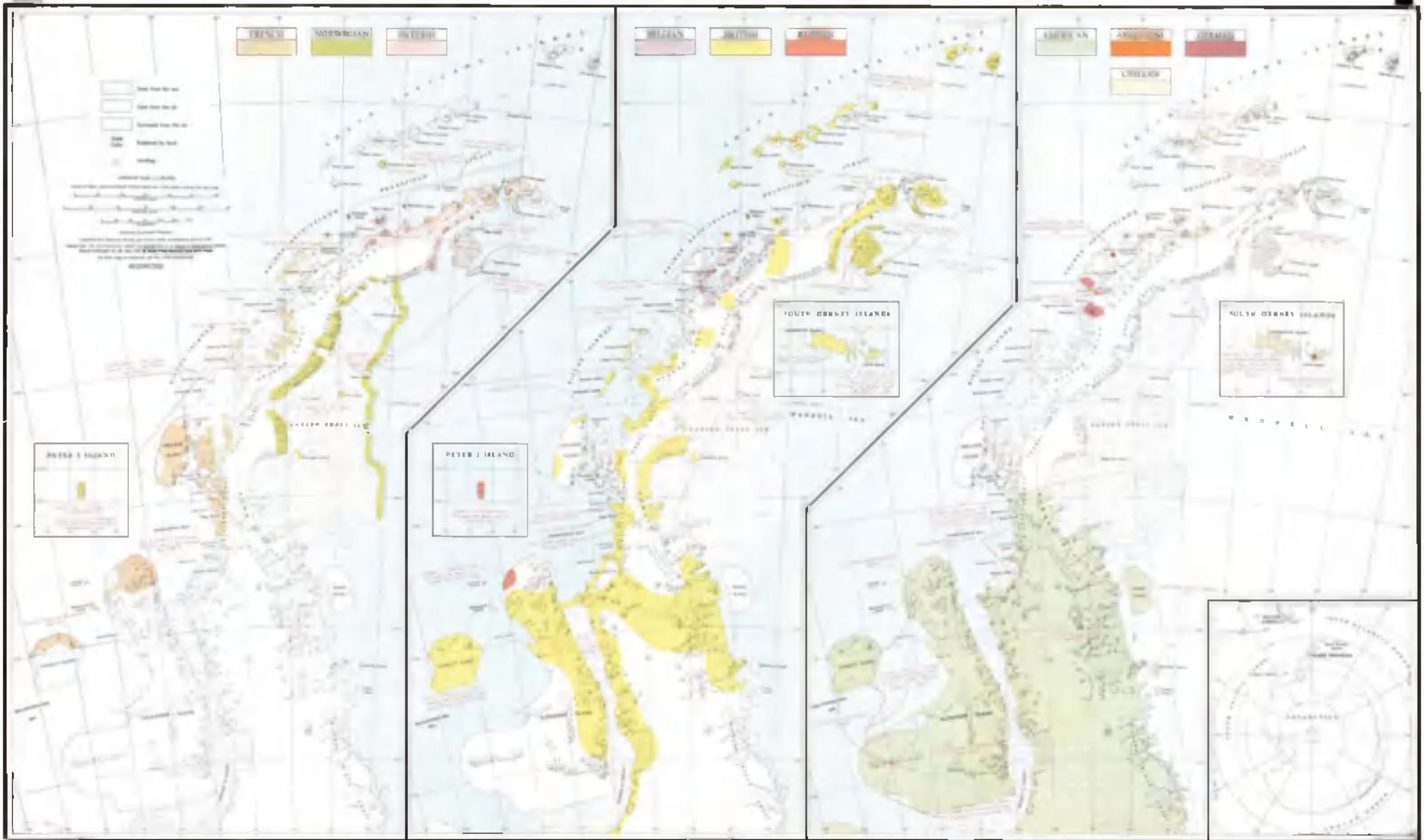
DISCOVERY AND EXPLORATION IN ANTARCTICA
PACIFIC QUADRANT (110°W–160°E)



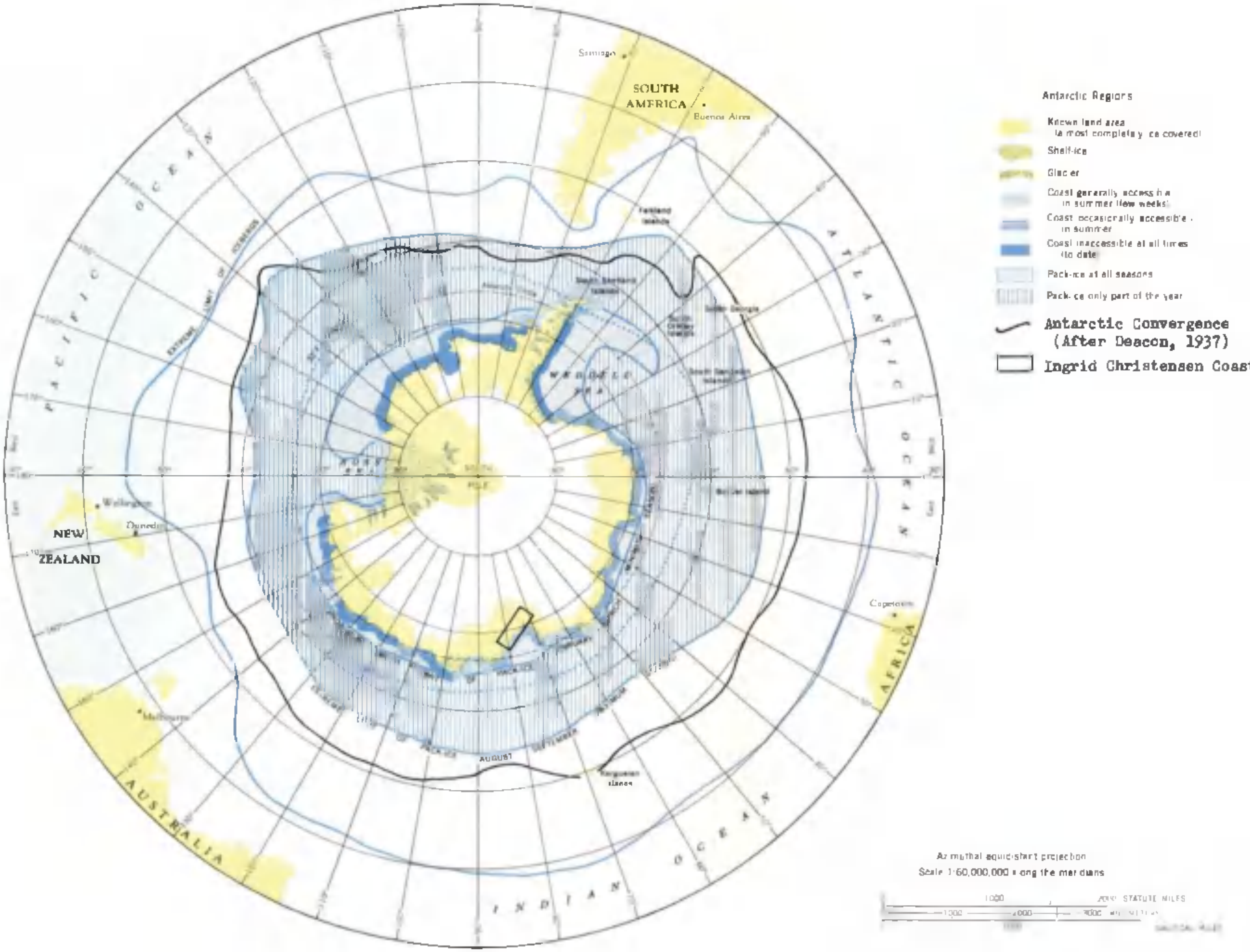
DISCOVERY AND EXPLORATION IN ANTARCTICA
AFRICAN QUADRANT (70°E–20°W)

DISCOVERY AND EXPLORATION IN ANTARCTICA
SOUTH AMERICAN QUADRANT (20°W - 110°W)

DISCOVERY AND EXPLORATION IN ANTARCTICA: PALMER PENINSULA




ANTARCTICA
ANTARCTIC
CONTINENT

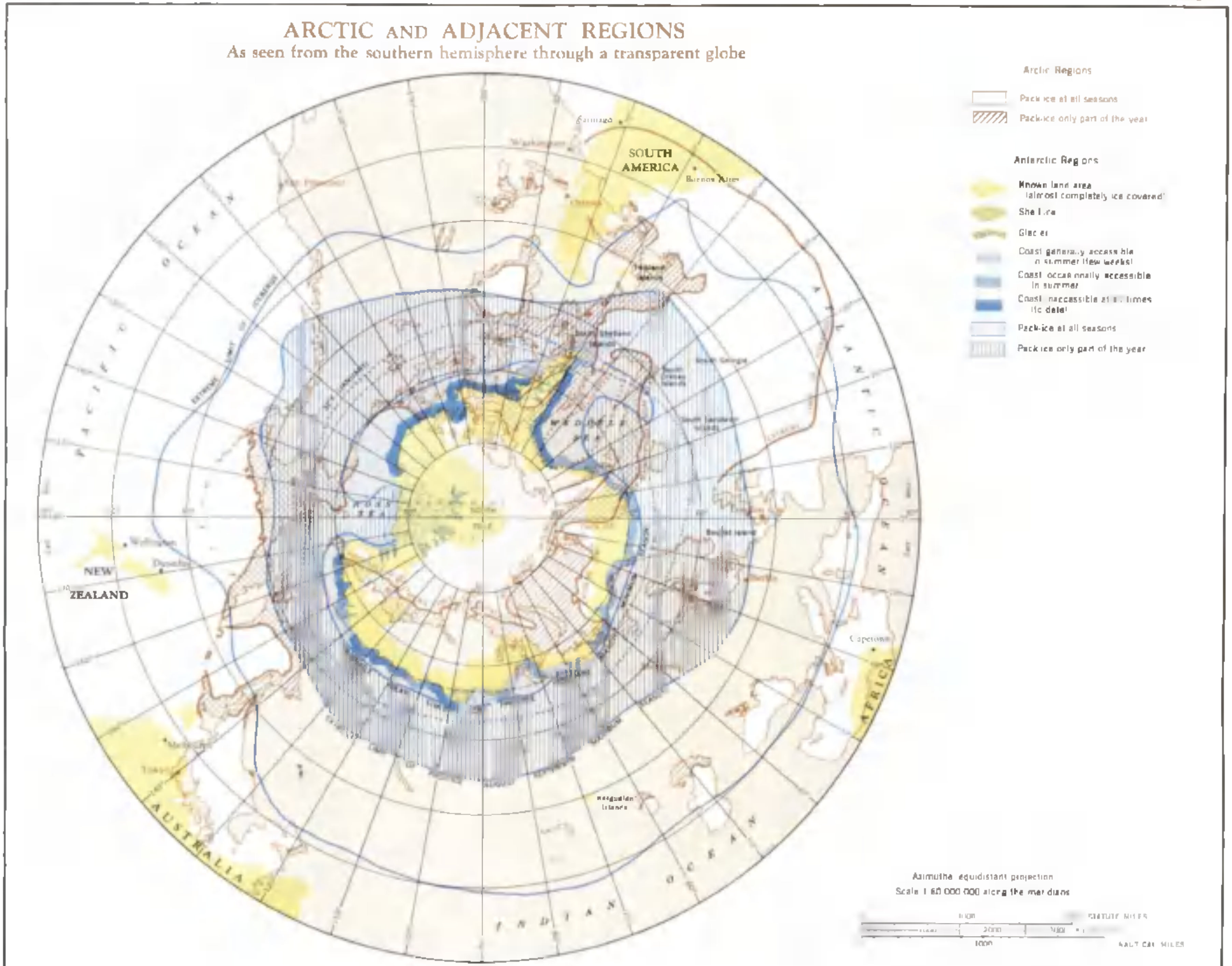


ANTARCTICA

RELATIVE ACCESSIBILITY,* PACK-ICE, ICEBERGS, 32°F. ISOTHERM OF THE WARMEST MONTH

*Accessibility by conventional surface ships

Compiled and drawn for the U. S. Department of State, November 15, 1948



ANTARCTICA

RELATIVE ACCESSIBILITY,* PACK-ICE, ICEBERGS, 32 F. ISOTHERM OF THE WARMEST MONTH.

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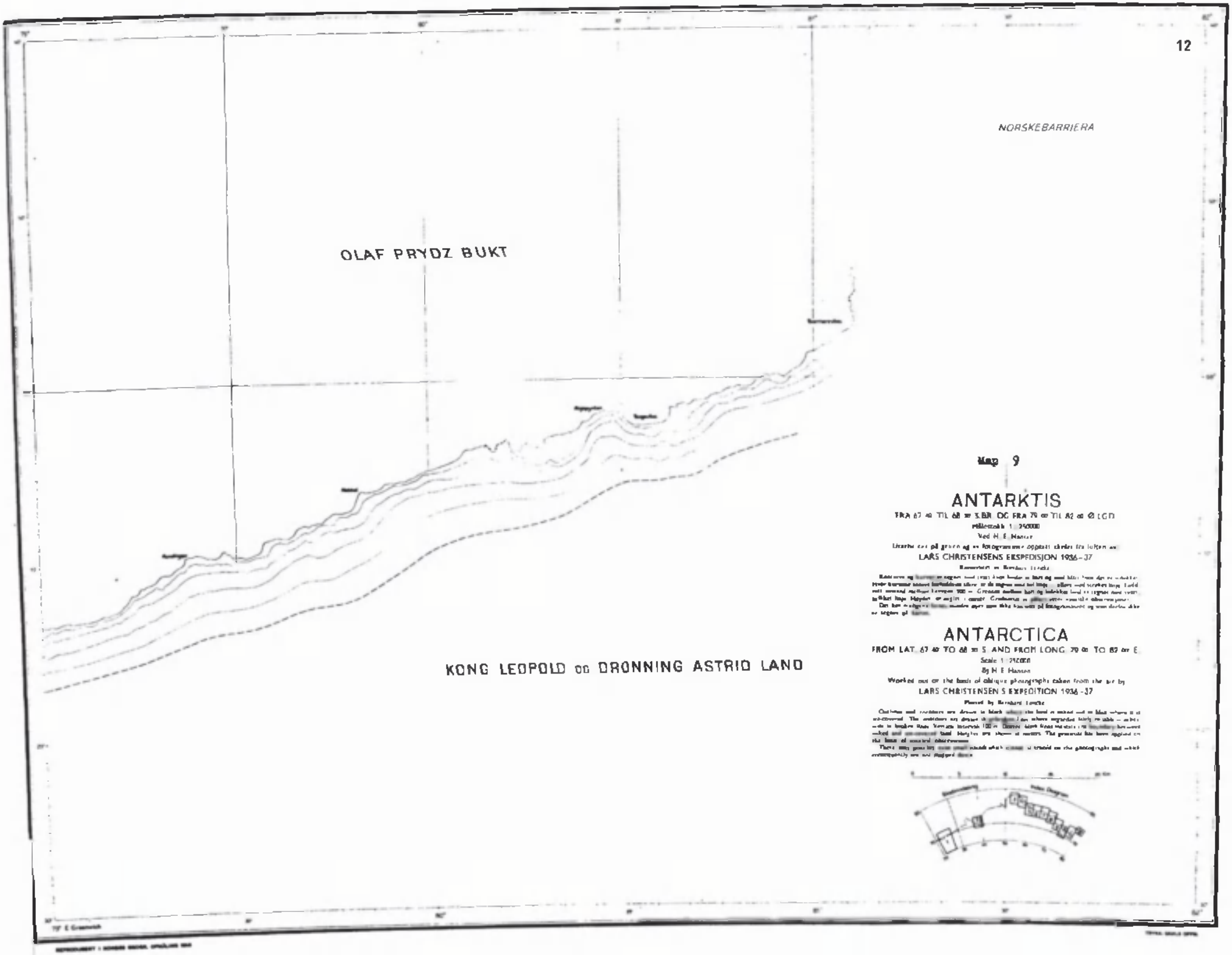
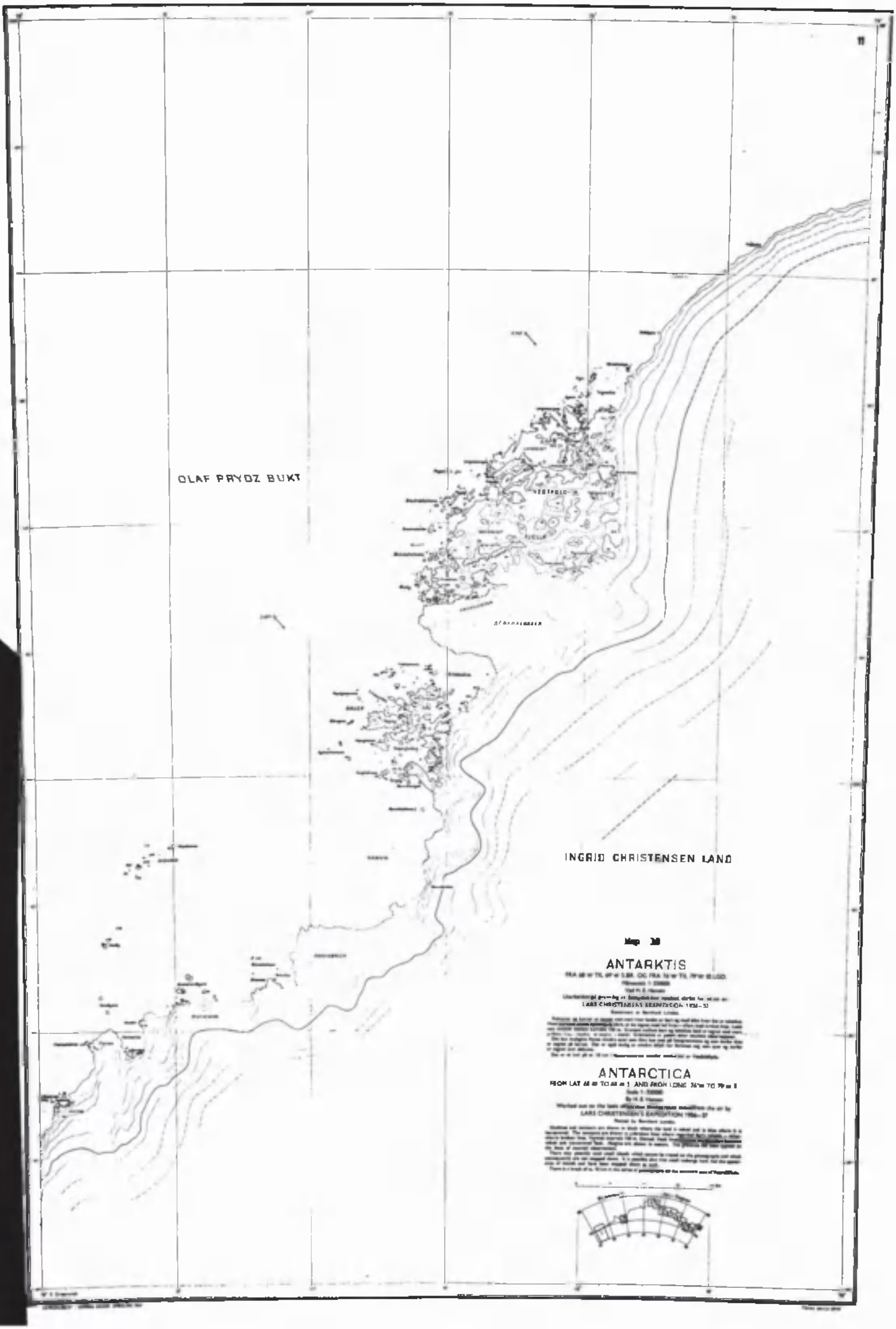
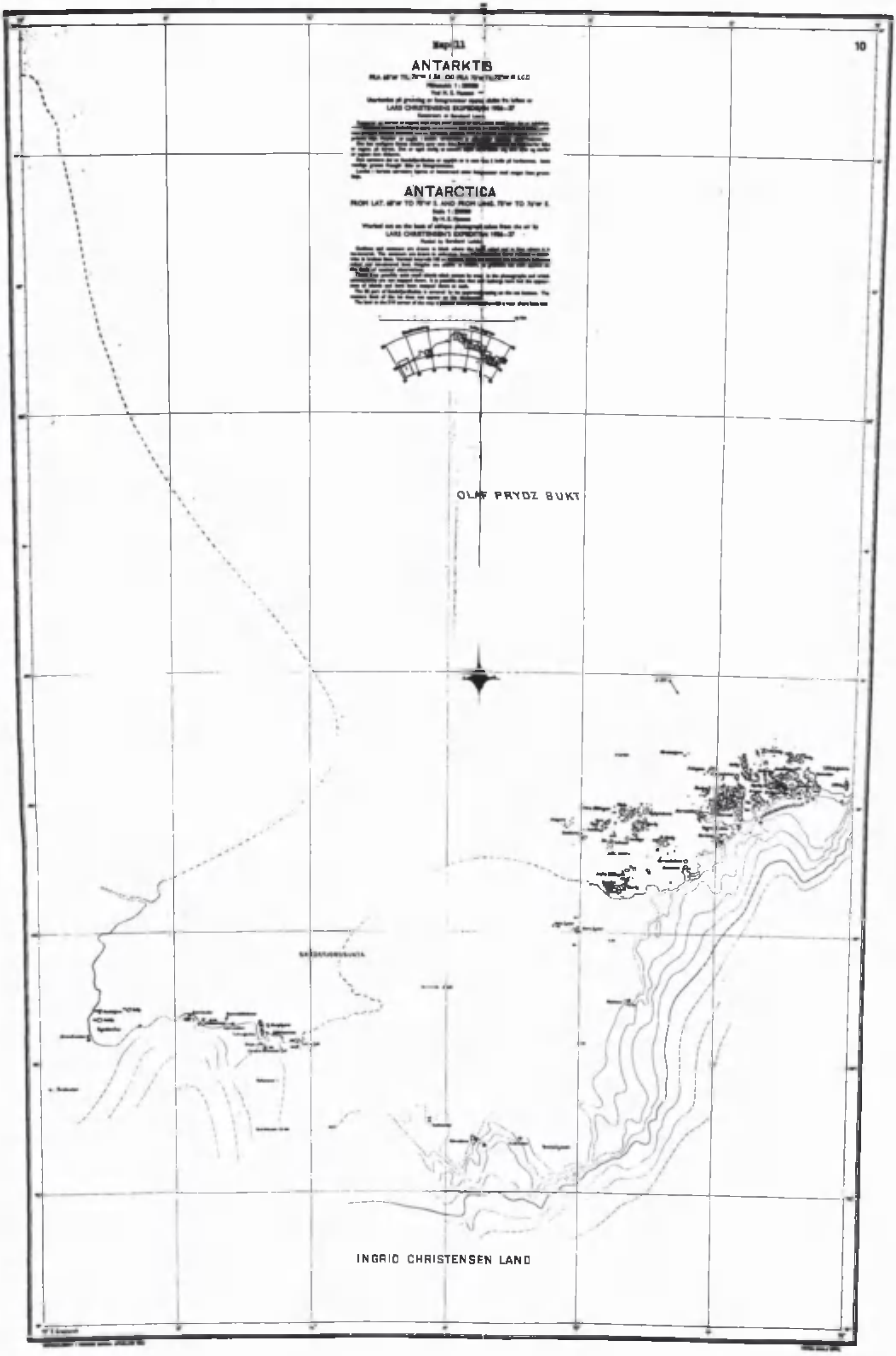


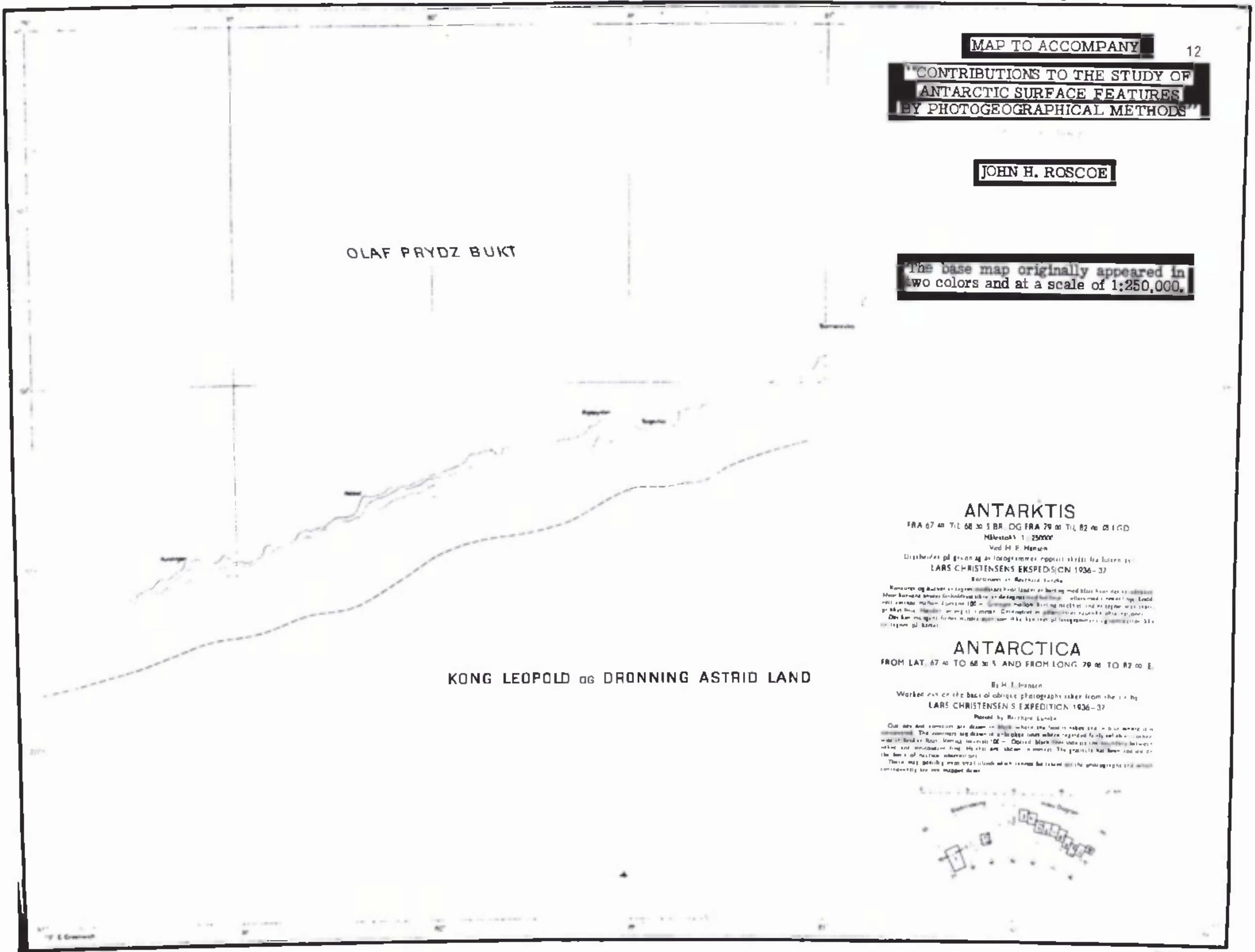
NORSKEBARRIERA
OLAF PRYDZ BUKT
KONG LEOPOLD OG DRONNING ASTRID LAND
Map 9
ANTARKTIS
Ved H. E. Hansen
LARS CHRISTENSENS EKSPEDISJON 1936–37
ANTARCTICA
FROM LAT. 67 40 TO 68 30 S. AND FROM LONG. 79 00 TO 82 00 E.
Scale 1 : 250000
By H. E. Hansen
Worked out on the basis of oblique photographs taken from the air by
LARS CHRISTENSEN'S EXPEDITION 1936–37

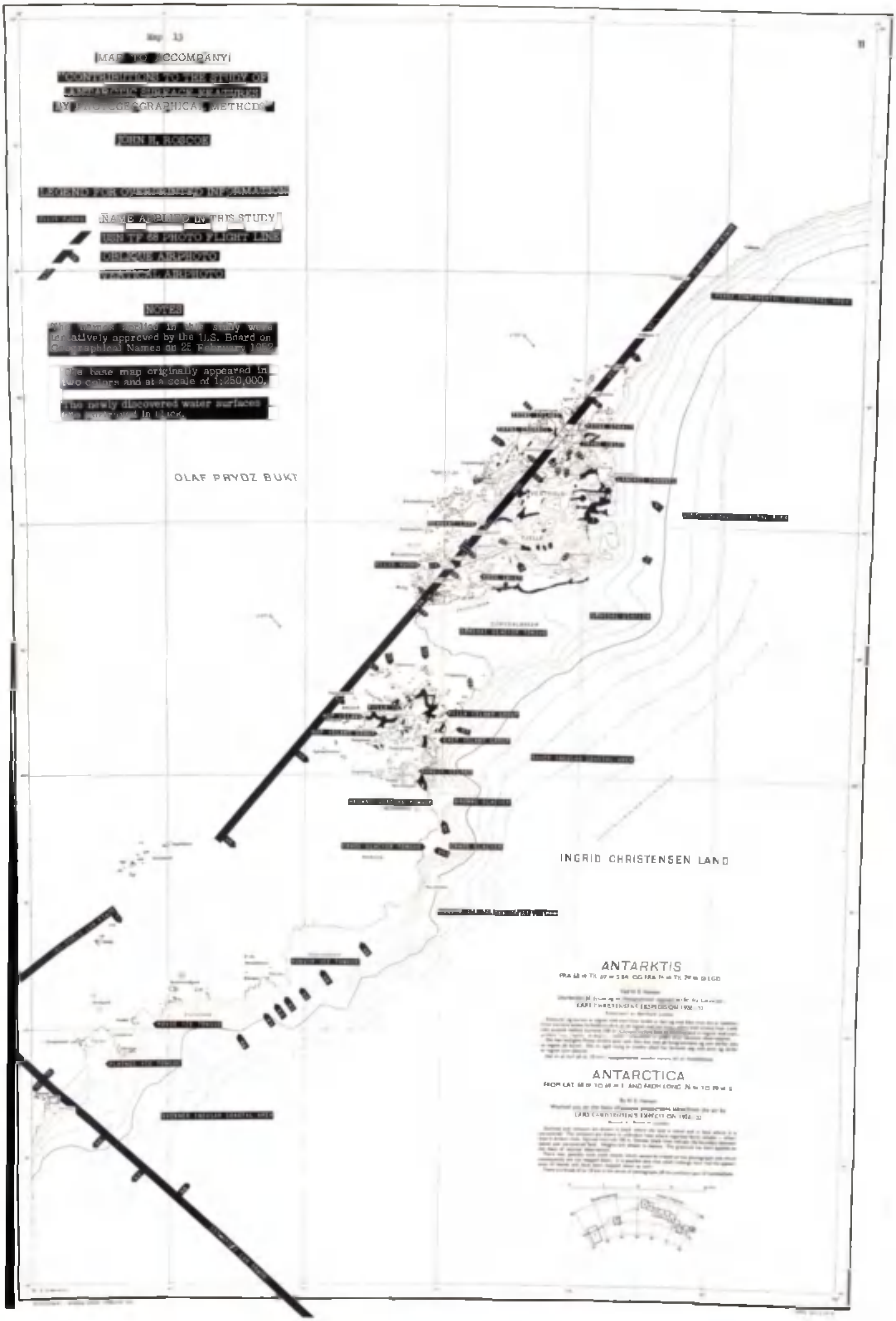


OLAF PRYDZ BUKT
INGRID CHRISTENSEN LAND
ANTARKTIS
ANTARCTICA



10
ANTARKTI
ANTARCTICA
OLAF PRYDZ BUKT
INGRID CHRISTENSEN LAND


MAP TO ACCOMPANY
12
"CONTRIBUTIONS TO THE STUDY OF ANTARCTIC SURFACE FEATURES BY PHOTOGEOGRAPHICAL METHODS"
JOHN H. ROSCOE
The base map originally appeared in two colors and at a scale of 1:250,000.
OLAF PRYDZ BUKT
KONG LEOPOLD og DRONNING ASTRID LAND
ANTARKTIS
Målestokk 1:250000
Ved H. E. Hansen
LARS CHRISTENSENS EKSPEDISJON 1936–37
ANTARCTICA
By H. E. Hansen
LARS CHRISTENSEN'S EXPEDITION 1936–37



Map 13
MAP TO ACCOMPANY
JOHN H. ROSCOE
NAME APPLIED IN THIS STUDY
NOTES
tentatively approved by the U.S. Board on
The base map originally appeared in
two colors and at a scale of 1:250,000.
OLAF PRYDZ BUKT
INGRID CHRISTENSEN LAND
ANTARKTIS
ANTARCTICA

H. O. Misc. No. 15040-1

Chart titles and scales are listed on accompanying key

RESTRICTED

H. O. Misc. No. 15040-1

RESTRICTED

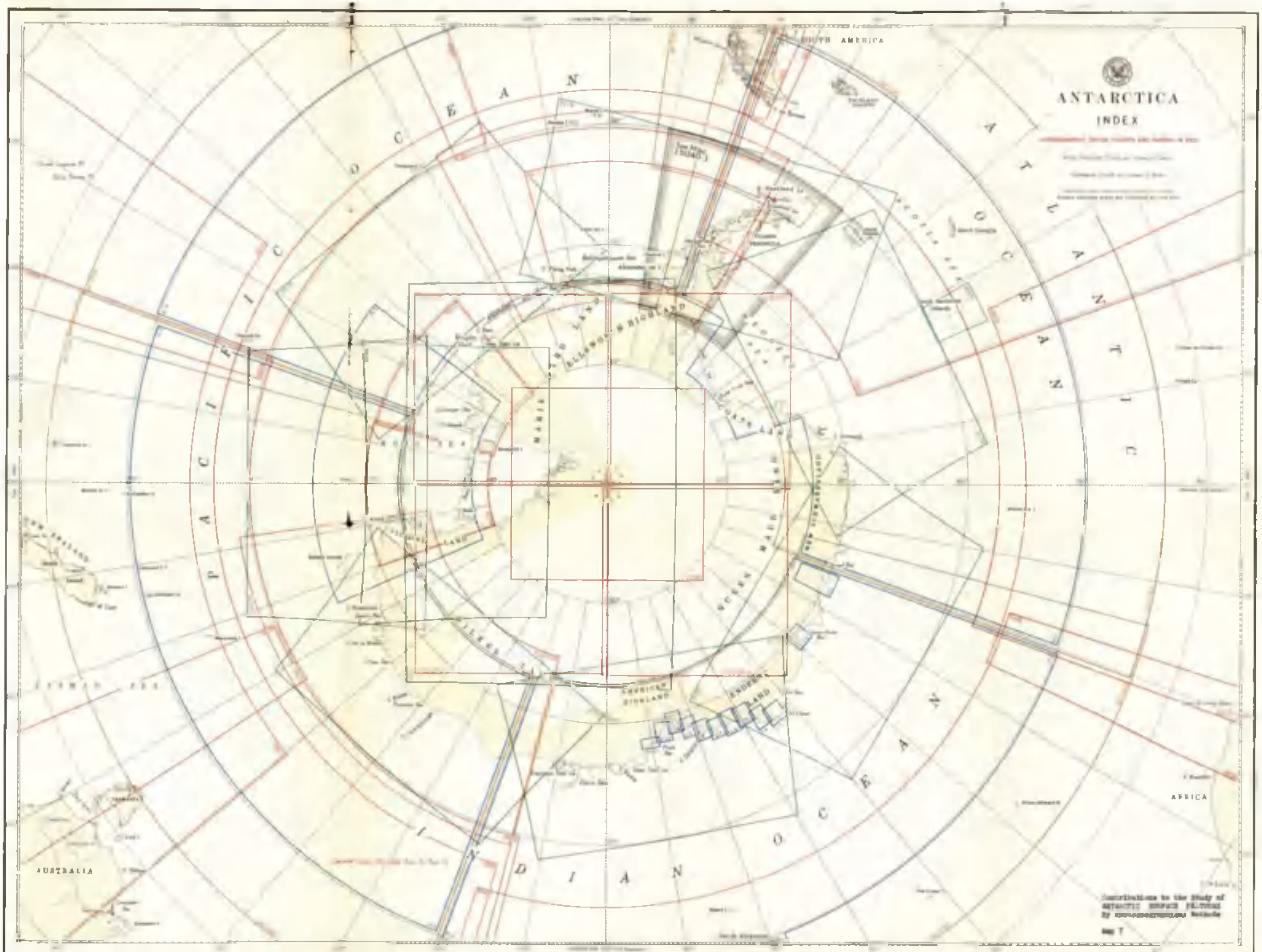
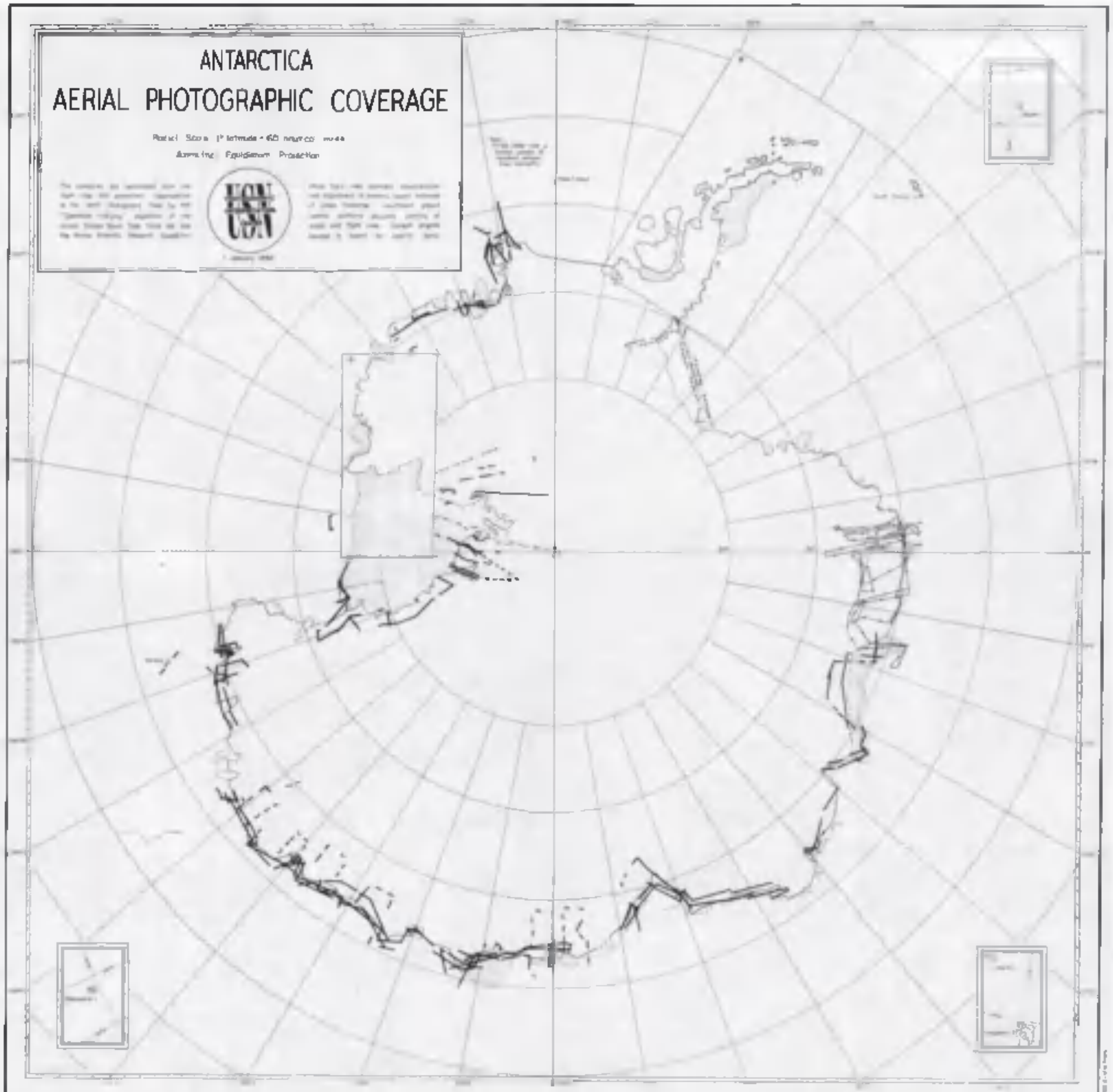


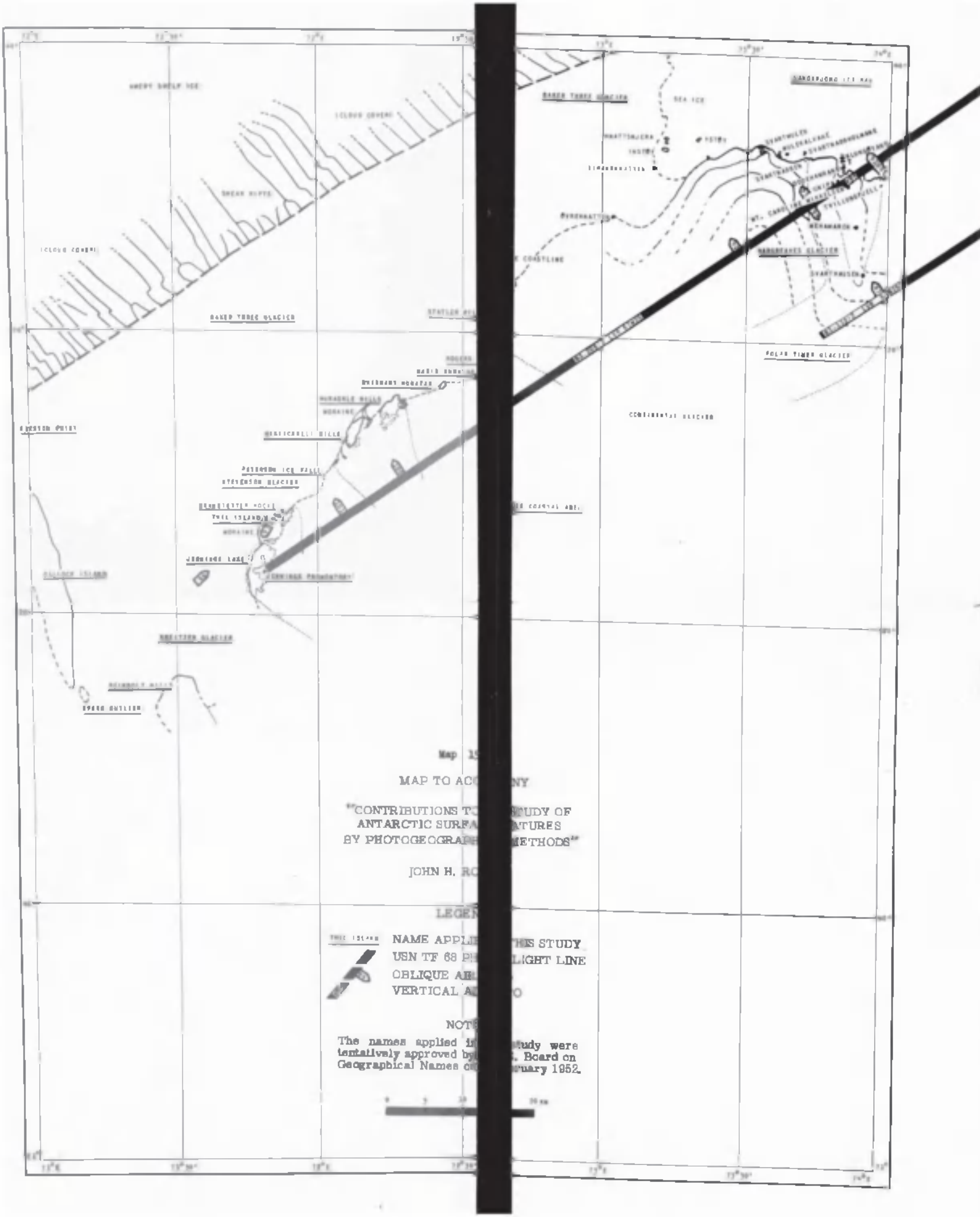
Chart titles and scales are listed on accompanying key

LEGEND

SYMBOL GROUPINGS BY NATIONALITY

DATE	NAME	SYMBOL	SOURCE	PHOTOGRAPHY
[illegible]	WILKINS-HEARST 1st EXPEDITION	[illegible]	[illegible]	[illegible]
[illegible]	BYRD 1st EXPEDITION	[illegible]	[illegible]	[illegible]
[illegible]	WILKINS-HEARST 2nd EXPEDITION	[illegible]	[illegible]	[illegible]
[illegible]	BRITISH, AUSTRALIAN, NEW ZEALAND (BANZARE)	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	BYRD 2nd EXPEDITION	[illegible]	[illegible]	[illegible]
[illegible]	BRITISH GRAHAM LAND	[illegible]	[illegible]	[illegible]
[illegible]	ELLSWORTH 3rd EXPEDITION	[illegible]	[illegible]	[illegible]
[illegible]	CHRISTENSEN [illegible] EXPEDITION	[illegible]	[illegible]	[illegible]
[illegible]	DEUTSCHE ANTARKTISCHE EXPEDITION	[illegible]	[illegible]	[illegible]
[illegible]	UNITED STATES ANTARCTIC SERVICE	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	U.S. NAVAL TASK FORCE [illegible]	[illegible]	[illegible]	[illegible]
1947	AUSTRALIAN	[illegible]	[illegible]	[illegible]
[illegible]	RONNE ANTARCTIC RESEARCH EXPEDITION	[illegible]	[illegible]	[illegible]
[illegible]	U.S. NAVAL TASK FORCE 39	[illegible]	[illegible]	[illegible]
[illegible]	AUSTRALIAN	[illegible]	[illegible]	[illegible]





AMERY SHELF ICE
(CLOUD COVER)
BAKER THREE GLACIER
SEA ICE
STEVENSON GLACIER
JENNINGS PROMONTORY
CONTINENTAL GLACIER
Map
MAP TO
"CONTRIBUTIONS STUDY OF
ANTARCTIC FEATURES
BY METHODS"
JOHN H.
NAME STUDY
USN TF 68 LINE
OBLIQUE
VERTICAL
The names applied study were
tentatively approved Board on
Geographical Names 1952.