ridges parallel to the ice front. Lakes in terminal moraine are irregular in outline with few sandy beaches and contain many bouldery islands. Outwash deposits which contained many residual ice masses (Fig. 3) have been mistaken for moraines in many ground surveys. From above, the sandy soil photographs in light tints and the many rounded kettles containing lakes and marshes give the landscape a mottled appearance. The example shown displays a cultivated area which is almost free from kettles, as well as a district where the ice masses lay so close together that the only outwash consists of narrow ridges often termed "crevasse fillings." When it is necessary to map an esker, or ridge of sand or gravel outside of an outwash deposit, the value of vertical aerial photographs is perhaps greater than in any other application to glacial geology. When an esker appears to end within a cedar swamp the photograph provides a final answer to the old conundrum of whether or not there is another section of the esker and, if so, in what direction it lies (Fig. 4). Photographs also aid in many other branches of the subject which are not illustrated here. Among these may be mentioned discrimination of thinly drift-covered rock hills, of shore lines and deposits of glacial lakes, erosion forms produced by glacial waters, in many localities before all the buried ice masses had melted to leave kettles, as well as of sand dunes on outwash plains, lake shores, and lake bottoms. Many photographs display curious soil mottling which is commonly not visible on the ground. In some cases the long-abandoned courses of glacial streams are obvious in the picture because the soil holds more moisture in these stream beds than under adjacent higher areas.

In making maps from the photographs a stereocomparator is most desirable, particularly if elevation data are needed and ground elevations have already been determined. Much information can be sketched directly from the pictures. In areas covered by a reasonably reliable public land survey the photographic data can be adjusted to fit section lines without need for radial line and ground control.

The photographs were supplied by the Wisconsin Highway Commission from Department of Agriculture surveys. All are from northeastern Wisconsin and have been previously published in the "Outline of Glacial Geology" by the present writer.

GEOLOGIC INTERPRETATION OF TRIMETROGON PHOTOGRAPHS—NORTHERN ALASKA

Sherman A. Wengerd

INTRODUCTION

The Problem

The U. S. Navy Department was authorized by Congress in 1944 to explore U. S. Naval Petroleum Reserve No. 4 in an attempt to develop quickly and efficiently the potential oil resources of northern Alaska (Foran—1946, p. 96). Initial Naval explorations in 1944 by Lieutenant Commander William T. Foran, who had in 1923 mapped parts of the Reserve as a geologist for the U. S. Geological Survey, resulted in reports of excellent seeps, reservoir rocks and adequate structure in the southeast part of N. P. R. No. 4.

The pressure of war, remoteness of the area, and difficulty of ground exploration led Lieut. Comdr. Foran to recommend complete photogeological and photogrammetric mapping to precede the detailed geologic and geophysical investigations which were carried on in 1945 based on earlier ground exploration. The plan of aerial photography and geologic interpretation was approved by Commodore W. G. Greenman, Director, U. S. Naval Petroleum Reserves, and carried out under the direction of Captain Bart Gillespie of the Bureau of Yards and Docks.

The immediate problem of rapid reconnaissance involved computation of flight coverage by trimetrogon photography, photography of the area, interpretation of vertical and oblique aerial photographs, and localization of prominent structures on adequate base maps. Long range plans called for: (1) delineation of anticlines from trimetrogon photographs, (2) vertical photography of those anticlines, (3) establishment of horizontal and vertical ground control by geodetic and plane table triangulation, (4) radial-line triangulation of the vertical photographs, (5) construction of controlled mosaics, and (6) multiplex compilation of elevations on photographically interpreted contacts for the construction of structural contour maps.

Owing to weather conditions over northern Alaska in 1945, there were only five clear days for photography during the time photographic aircraft were available. The time was expended in gaining an excellent set of trimetrogon photographs with few "holidays," and a complete vertical coverage of the Umiat Mountain area on Prince Creek anticline. The end of World War II, plus continued poor weather conditions, allowed only the completion of the preliminary photogeological reconnaissance. The release from service of experienced key personnel in the Naval Exploration program obviated immediate completion of the final photogeologic phases of the project for the entire Reserve area.

This paper is a summary of the preliminary photogeological reconnaissance which resulted in the map shown in Figure 8. The methods used are neither highly technical nor suited to all types of terrane, but their value was soon recognized in the broad planning of a detailed Arctic exploration program from preliminary photographic reconnaissance. Each new area presents slightly different geologic phenomena which are recorded on aerial photographs. A discussion of these involves the interpretational residue of attempts to construct a suitable geologic planning map.

Location and Character of the Area

U. S. Naval Petroleum Reserve No. 4 is located in northern Alaska between Latitudes 68° North and 71° North, Longitudes 154° West and 162° West (see Fig. 1). The Reserve, approximately 35,000 square miles, lies over the Alaskan portion of the great Arctic geosyncline. This sector of the Arctic geosyncline, named the Barrow basin of sedimentation (Foran—1946, p. 99), is underlain by approximately 35,000 feet of marine sedimentary rock of which the upper 12,000 foot section is believed to contain numerous reservoir sandstones.

Topographically the region is divisible into three west-trending areas: (1) the coastal plain province on the north, (2) the plateau province, (3) the mountain province on the south. The coastal plain province is characterized by thousands of oval lakes, sluggish meandering streams, and tundra underlain by Pliocene and Pleistocene gravels, sands, and silts. The plateau province is underlain by gently folded Upper Cretaceous rocks dissected by streams which have etched the underlying rocks to form prominent west-trending cuestas. The map (Fig. 8) shows the adjustment of drainage to these persistent gentle folds. The underlying shales and sandstones are eroded in a manner which shows the general coincidence of topographic and structural "Highs." The plateau province merges southward into foothills underlain by more steeply dipping lower Cretaceous strata which outcrop north of the sharply folded Triassic and Devonian rocks of the Brooks Range. Maximum topographic relief in the folded plateau province is approximately 650 feet at Umiat Mountain. Average relief on the plateau is 300 feet. The predominant west-trending cuestas, underlain by strata which dip between 3 and 5 degrees, are best developed on the south

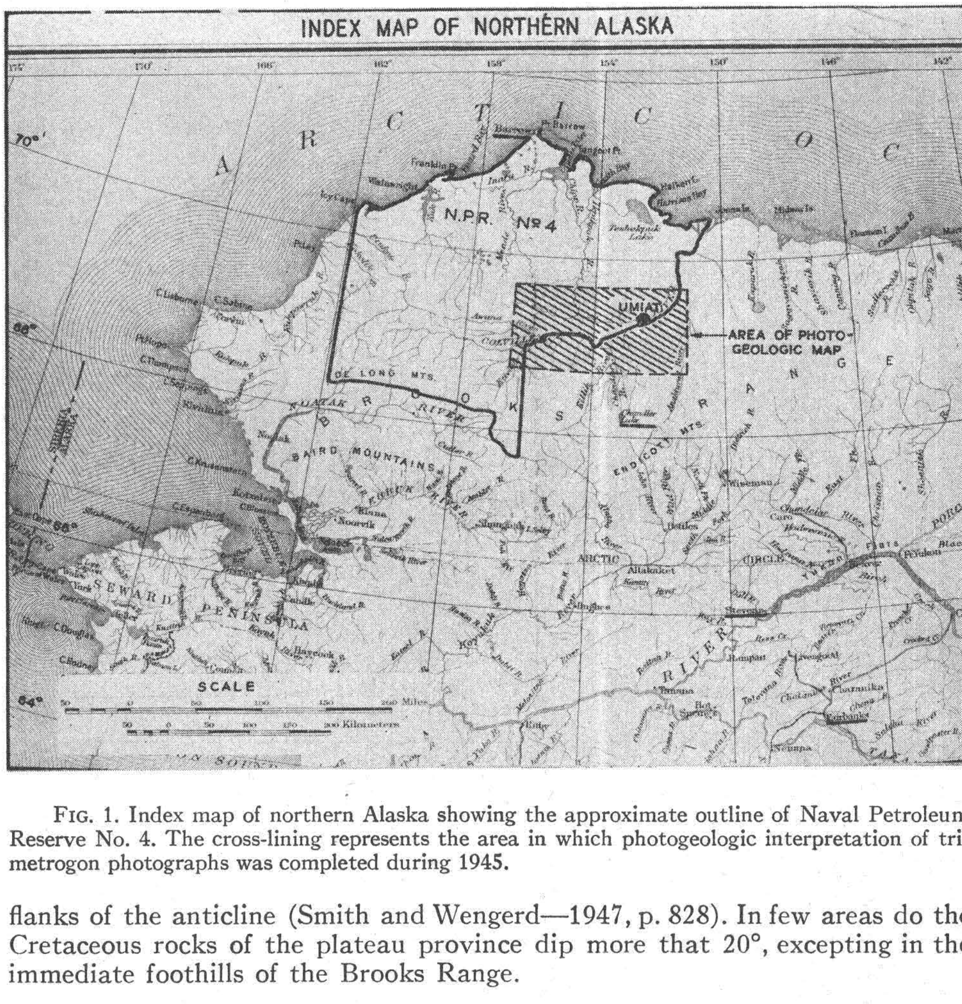

FIG. 1. Index map of northern Alaska showing the approximate outline of Naval Petroleum Reserve No. 4. The cross-lining represents the area in which photogeologic interpretation of trimetrogon photographs was completed during 1945.

flanks of the anticline (Smith and Wengerd—1947, p. 828). In few areas do the Cretaceous rocks of the plateau province dip more that 20°, excepting in the immediate foothills of the Brooks Range.

Area of Investigation

Though every effort was made to fly the broad plateau province from the east side of the Reserve to the west side, only the area shown on Figure 1 could be covered photographically for geologic interpretation. A large sector of the coastal plain was flown for final compilation of photogrammetric maps on which to plot traverses of the aerial magnetometer, but Quaternary sediments effectively cover the gently folded underlying structure and make accurate geologic interpretation impossible. The area of photogeologic reconnaissance included approximately 11,250 square miles of the eastern plateau province (see Fig. 1).

Acknowledgments

Commodore W. G. Greenman, U.S.N., Captain Bart Gillespie, U.S.N.R., and Lieut. Commander W. T. Foran, U.S.N.R., by their cooperation, their willingness to try new techniques, and their recognition of the problems involved in photogeological reconnaissance, made possible this preliminary work which resulted in the photogeologic map. Lieut. Norman C. Smith, who became

FIG. 2. Six inch focal-length vertical photograph taken at 12,000 feet with the central camera of a trimetrogon unit. During stereoscopic examination, symbols are placed on each photograph prior to transfer to the base map. Dashed lines show the axis of a sharp anticline and a small syncline depicted on the photogeologic map at Latitude 68° 45′ North, Longitude 152° 55′ West. The white outcrops are bentonite beds. (Photo courtesy—U. S. Navy.)

photogeologist for the Director, U. S. Naval Petroleum Reserves, after the writer's separation from the Navy, completed a major part of the photogeologic interpretation and the drafting of the final map. Lieut. Henry Biehusen, U.S.A.A.F., was in charge of the Army Air Forces detachment that so ably photographed the assigned areas despite severe handicaps.

AERIAL PHOTOGRAPHY

Trimetrogon Photography, 1944

Northern Alaska was flown by the U. S. Army Air Forces in 1944 to obtain trimetrogon photographic coverage for the construction of flight charts by the Aeronautical Chart Service. Reconnaissance photographic aircraft carrying trimetrogon cameras flew the area at an altitude of 20,000 feet with westerly-trending flight lines spaced between 20 and 30 miles apart.

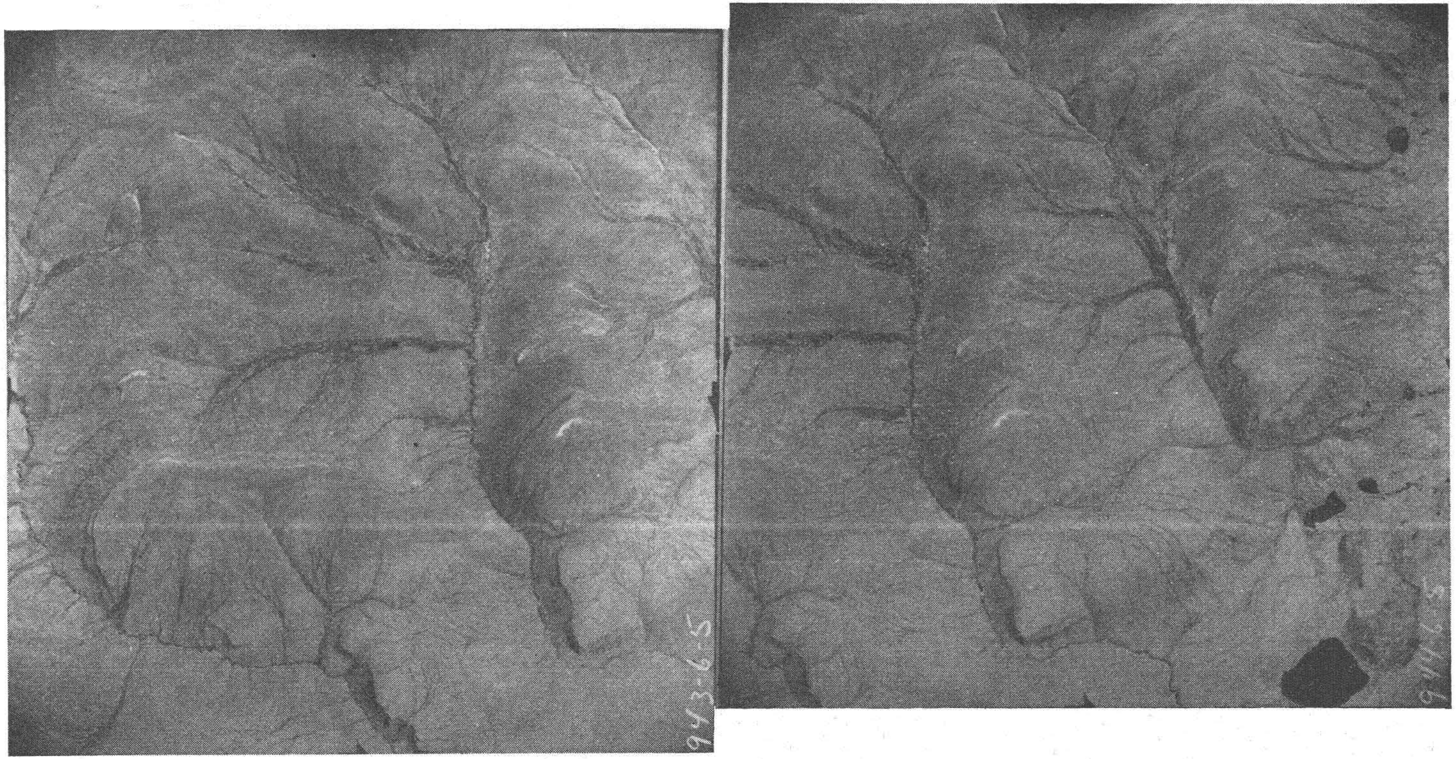

FIG. 3. Stereocouplet of two trimetrogon vertical photographs. The couplet gives a strong stereoscopic image if held between 18 and 24 inches from the observer. Note the large V pointing downstream (the direction of the collimation arrows between the two photographs). With the aid of multiplex elevations on interpreted contacts, photographs of this type enable the photogeologist to construct accurate structural contour maps. (Photo courtesy—U. S. Navy.)

Aerial photographs, with some notable "holidays" due to adverse weather and heavy cloud cover, were flown early in the season when much of the Arctic coastal plain was covered with snow. The plateau province, however, had an optimum snow cover which allowed a preliminary delineation of major structures despite the otherwise relatively poor quality of the photographs (see Fig. 10, Reed—1946). The 1944 photographic coverage was not computed or flown for geological reconnaissance, hence its utilization was limited for geologic interpretation.

Trimetrogon Photography, 1945

Utilizing the 1944 photographic coverage and preliminary trimetrogon compilations, a new coverage was planned specifically to gain better photographs for more definitive geologic reconnaissance and the final compilation of accurate base maps on which to plot geologic and geophysical data from all field and laboratory studies of the area. Trimetrogon flight lines were planned at a heading of N 30° E over the plateau province and N 60° W over the coastal plain with a 10 mile flight line spacing. The cameras were to be flown at 12,000 feet to insure adequate coverage. Flight lines were drawn on advance copies of 1:500,000 scale aeronautical charts for guidance of the pilots.

Four F-11 photographic aircraft were temporarily loaned to the Navy by the 311th Photographic Reconnaissance Wing and sent to Alaska as a detached photographic squadron. The squadron began flying the area early in July and in approximately five flight days covered over half of Naval Petroleum Reserve No. 4. Excellent trimetrogon photographs of a part of the area and vertical photographs of the Umiat dome on Prince Creek anticline were delivered to Naval personnel during the field season. Poor flying conditions limited the trimetrogon coverage to 18,000 square miles, chiefly over the northern and eastern parts of the Reserve.

Vertical Photography, 1945

Early plans for complete photogeological analysis of the plateau area called for the immediate choice, by interpretation of the trimetrogon photographs, of prominent anticlines which were to be covered with vertical photography. Five prominent areas were chosen where final structural maps could be compiled by utilizing the multiplex to obtain elevations on interpreted contacts. Flight maps were constructed of these areas west of the Naval surface parties doing geological work. It was hoped that their elevations could be utilized and elevation control extended by bridging between low gradient streams. Unfortunately, only the vertical photographs over Umiat dome could be taken during 1945 owing to anomalous cloud cover over the plateau province. An uncontrolled aerial mosaic was constructed by Lieut. Comdr. Foran, however, and these vertical photographs were used in locating the first test of the area, Umiat No. 1. Without suitable vertical photographs outside the area worked by the surface parties, the photogeological program was replanned to gain all possible geological information from the trimetrogon photographs.

PHOTOGRAMMETRIC BASE MAPS

Base Map, 1944

The trimetrogon aerial photographic coverage of 1944, though made for the construction of aeronautical charts, resulted in base maps suitable for the reconnaissance exploration of Naval Petroleum Reserve No. 4. Planimetric maps were compiled in the Trimetrogon Compilation Unit of the U. S. Geological Survey under the direction of Mr. Jesse Mundine, and Colonel Gerald Fitzgerald, Commanding Officer of the Aeronautical Chart Service, U.S.A.A.F.

Eleven astronomic control points, plus control outside the Reserve area, were utilized to orient and bring to a common scale the planimetric details from the 1944 trimetrogon photographs. The control was assembled from early reconnaissance in nothern Alaska by U.S.G.S. field parties and astronomic observations by Army Air Force parties utilizing astrolabes or equiangulators.

Base maps, compiled on the Lambert conformal projection at a scale of 1:100,00 showed all streams, lakes, cuestas, and islands in the major rivers. These maps were made available as ozalid prints of the original trimetrogon compilation sheets to facilitate planning early in 1945 and actual reconnaissance during the field season. The ozalid prints, controlled by scalar lines to preserve orientation and scale, were photographed with accurate copy cameras to two scales: 1:100,000 and 1:200,000.

The 1:100,000 map was thus made into a planning map and also used as a flight base map for areas which showed promising structures on the 1945 aerial photographs. The 1:200,000 scale map became the planimetric base on which 1945 trimetrogon photographs were indexed to facilitate the construction of a reconnaissance photogeologic map. Initial post-flight indexing of the aerial photographic coverage was done on the 1:500,000 scale aeronautical chart, itself constructed as a preliminary edition by the U.S.A.A.F. from the trimetrogon compilation of 1944.

Base Map, 1945

The trimetrogon photographs of 1945 were compiled by the U. S. Geological Survey into a new base map at a scale of 1:48,000 for the western half of the plateau and the greater part of the coastal plain. The scale was based on the scale of the plane table sheets of the Naval geological parties. The plane-table control gained by these parties, plus later control by Army astronomic parties, was used in compiling the final planimetric map. Subsequent to the compilation of the reconnaissance photogeological map, the newer compilation was to have been used as a base on which all exploratory data were entered. This phase of operations is still in progress and the results are confidential.

GEOLOGIC INTERPRETATION

General Features

Photogeologic reconnaissance of the area shown in Figure 1 involved the study of 2,565 aerial photographs of which two-thirds were obliques. Inasmuch as the problem resolved itself to qualitative interpretation, with insufficient vertical photography or ground control to allow the preparation of structrual contour maps, the prime data sought on the photographs were dip criteria indicative of surface structure in upper Cretaceous strata. Obviously, in Naval Petroleum Reserve No. 4, where the gentlest dips are generally present in rocks the farthest from the Brooks Range, qualitative interpretation of dip and strike was impossible where the upper Cretaceous strata were masked by Quaternary sediments of the Coastal Plain. Consequently only the photographs over Cretaceous terrane were studied in detail.

Whole flight lines of photographs, crossing the geological structure approximately at right angles to the axes, were laid out and examined prior to detailed study under the stereoscope. Small folding steresocopes facilitated study of the trimetrogon triplet as a unit. The obliques were rather easily examined stereoscopically by keeping the principal lines of adjacent wing prints parallel and by sliding the prints to the eye-base width over any part of the two oblique images. The vertical prints were studied in the usual manner and all dips and strikes were recorded on the prints with a sharp china marker.

Direct Observation of the Outcrop

The predominating feature of upper Cretaceous strata in the interpreted area is the abundance of shale and thin bentonites. Sandstones notable on the photographs appear to make up only about one-fourth of the exposed section. In some low-dip areas, thick shale sections, without notable sandstone, underlie hundreds of square miles of the plateau province. This predominance of shale facilitates slumping, solifluction, burial of thinner but more resistant sandstone, development of low rounded mounds, and the formation of a deep tundra which literally defies accurate structural interpretation.

Where sandstones and shales are in the usual ratio of abundance, long sinuous cuestas and steep V-shaped river valleys, breaching anticlines laterally or longitudinally, contain outcrops in which bedding can be examined directly. These contacts, best exposed in stream valley walls and in water gaps through the cuestas, allow immediate and easy interpretation of the structural attitude of the strata as distant as the principal point on the obliques.

In some localities the more resistant sandstones form triangular facets, unrelated to faulting, from which the shale has been stripped to reveal a bedding surface. The sandstones in the eastern part of the area overlie conspicuous bentonite beds which erode and spread whole mantles down over the shale slopes. Upper edges of these bentonite talus slopes are almost invariably coincident with bedding contacts visible on the up-dip face of a cuesta upheld by low-dipping sandstone. Down-dip contacts of similar beds are revealed where the slope is greater than the dip of rock, but the pattern is generally highly irregular and the bentonite talus is spottily covered by shale debris from beds above the more resistant sandstone (see Fig. 4). Bentonite beds are exposed as white streamers within the confused dendritic drainage on the back slopes of some cuestas underlain by less resistant sandstone. Traces of these streamers to their origins on parallel systems of dendritic drainage result in a reliable strike line, with the dip almost always in the direction of stream flow (see Fig. 4).

These direct stratal observations are possible on obliques as readily as on verticals but rapid scale change with distance in an oblique photograph obviates any but the most generalized dip and strike observation beyond the principal point. Every effort was made to use and extend to the obliques the easily interpreted dip and strike on the vertical photographs. The prime reason for orienting the 1945 flight lines N 30° E was to obviate the difficulty experienced in interpreting the 1944 photographs, which were flown essentially parallel to the structural axes. Through this planning directly observed outcrops yielded dips and strikes on the verticals and those data could be noted far out into the oblique photographs where they could be picked up on the next flight line.

Topographic Expression of Strata

The deep tundra, swamp, and talus cover of much of the plateau necessitated interpretation by less direct means than the examination of outcrops on the photographs. The dissection of an interbedded shale and sandstone section resulted in the formation of sharp breaks in slope on the flanks of all major anticlines. Oblique rays of the Arctic sun cause strong linear shadows along high cuestas. Where sandstones are thick, these long cuestas stand on the flanks of the folds. Especially where breached by streams do they reveal the dip of strata.

Excepting parallel steep slopes on the same sides of contiguous hills where back slopes were gentle, it was difficult to interpret the attitude of strata in shale terranes which contained no massive sandstones. Differential slopes on shale

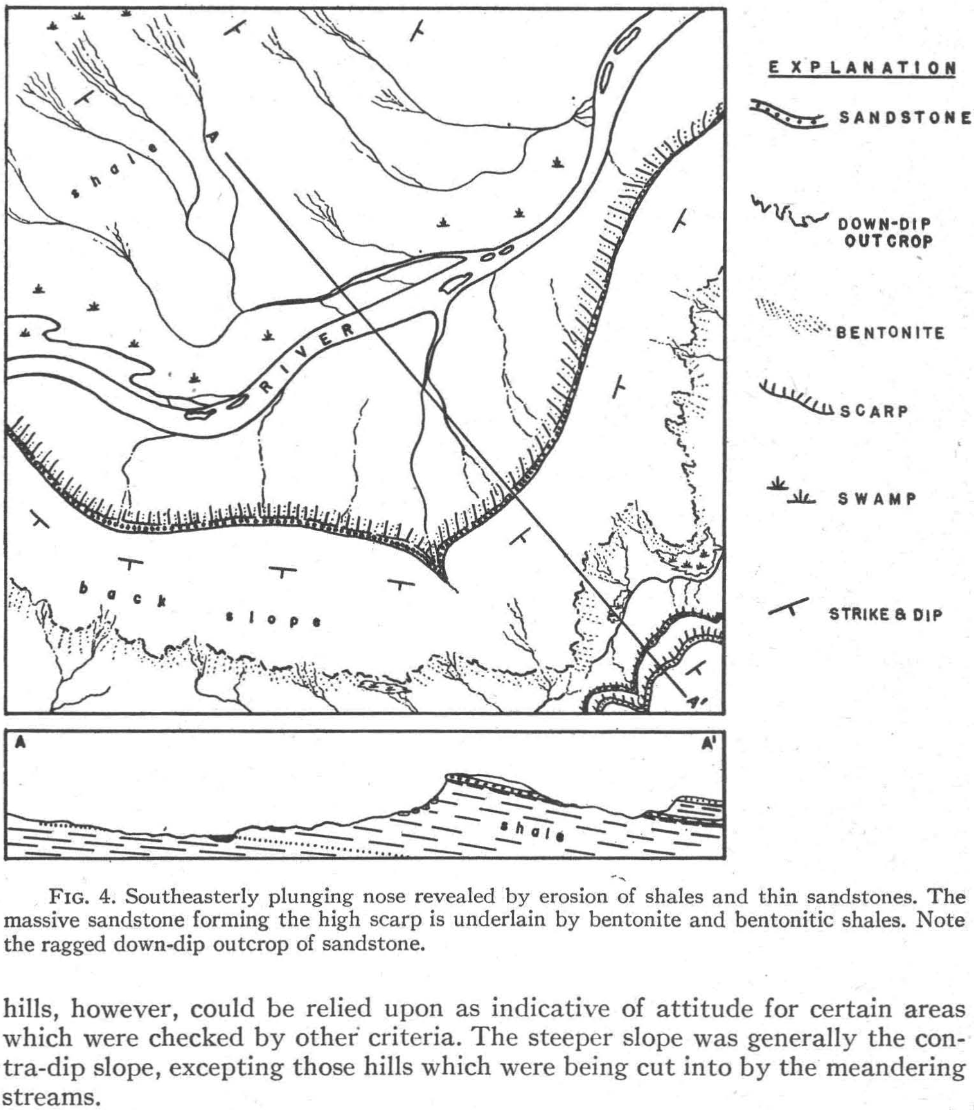

FIG. 4. Southeasterly plunging nose revealed by erosion of shales and thin sandstones. The massive sandstone forming the high scarp is underlain by bentonite and bentonitic shales. Note the ragged down-dip outcrop of sandstone.

hills, however, could be relied upon as indicative of attitude for certain areas which were checked by other criteria. The steeper slope was generally the contra-dip slope, excepting those hills which were being cut into by the meandering streams.

Only where beds dip less than two degrees are topographic criteria of little value. Where strata dip more than 5°, characteristic "hump and spur" V's are formed which always point *up dip* contrary to the stream V's which dip downstream where dip of the beds is greater than the gradient of the stream.

Topographic interpretation of stratal attitude in this area was thus not unusual. Loss of outcrop occurred on down-dip back slopes and accentuation of outcrop invariably occurred on the up-dip edge of the true cuestas. Only in areas where stream erosion was actively reducing high banks to form scarps could serious topographic misinterpretation of the trimetrogon photographs readily occur. These same scarps generally exposed thick sections of fresh sedimentary rocks in which bedding surfaces could be seen.

Drainage Patterns

Examination of the 1944 planimetric base map of U. S. Naval Petroleum Reserve No. 4 revealed the presence of peculiar drainage patterns between the Brooks Range on the south and the Arctic coastal plain on the north. Figure 8

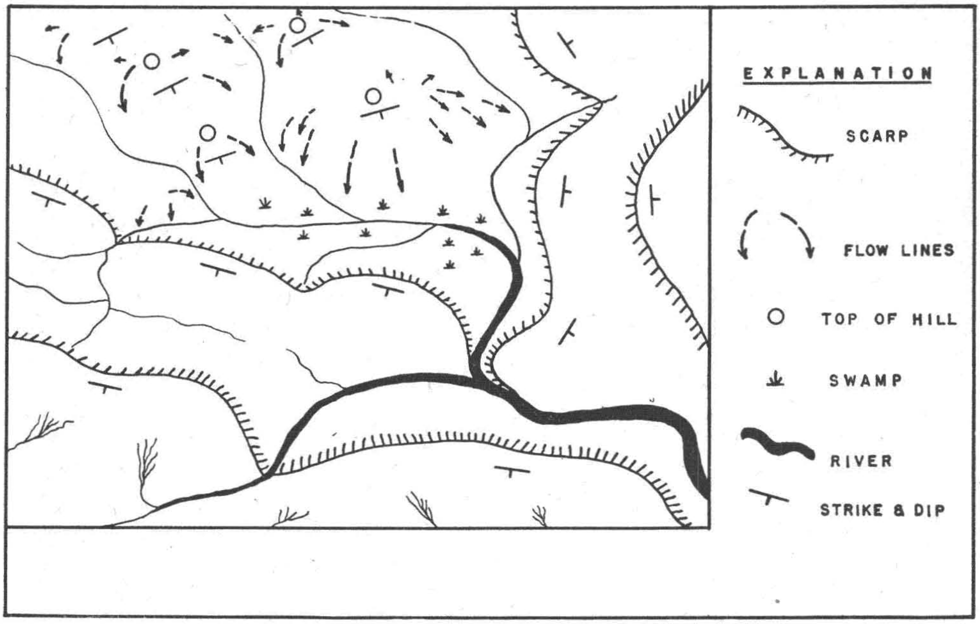

FIG. 5. Soil flow lines on shale hills bounded in part by low scarps upheld by thin sandstones. The predominant direction of solifluction is approximately parallel to the dip of the strata on the southeasterly dipping nose.

shows the relation of these stream patterns to the structure. Where sharp cuestas and other topographic criteria were not evident, the distribution of streams provided a general key to the underlying structure. It was found that the widely curving streams northwest of Umiat No. 1 were sliding down the plunge of the Prince Creek anticline, cutting steep slopes on the down-dip side and leaving low banks on the contra or up-dip side of the streams. Earlier field work in 1944 established the existence of this great structure and the stream pattern was used as a criterion for any area apparently underlain by similar stratigraphic sequence. By thus checking data on the photographs against earlier field observations, N. C. Smith was able to tabulate several principal criteria which could be used where the drainage was adjusted and strata dipped less than 15°. Following is the tabulation: (Smith and Wengerd—1947, pp. 825–826).

A. *Stream course and intermittent tributaries well developed*
 1. If stream course tends to parallel strike of strata:
  a. Up-dip wall of valley wider and more gently inclined than down-dip wall of valley.

b. Up-dip drainage profuse, anastomosing runnel pattern developed upslope from normal dendritic (see Fig. 4).
c. Drainage on down-dip wall commonly undeveloped, or where present, shows orderly appearance of near parallel runnels upslope from normal dendritic (see Fig. 4).
2. If stream course normal to strike of strata, symmetrical "V's" formed (Use rule of V's).
3. If stream course more nearly normal to than parallel with strike of strata, asymmetrical V's formed:
a. If V's point upstream, the strike is more nearly parallel with long or open leg of the V's.
b. If V's point downstream, the strike is more nearly parallel with the short or closed legs.

B. *Where drainage is not well developed*
1. In areas of mild dip, cuestas appear to be more prominent on south flanks of anticlines.
2. Broad synclinal troughs, usually poorly drained and characterized by low, swampy, ponded tundra.

The streams in synclines are sluggish and meandering; their banks are low, and swampy borders with meandering tributaries are common, whereas the stream breaching anticlines are steep-walled and less meandering in their course. The run-off from down-dip outcrops of sandstones appears to feed hillside swamps, though drilling has proved the water in the strata to be frozen far beneath the surface. Small hillside swamps generally parallel the strike of the strata. Profuse distributaries head in these swamps and the combination is indicative of minor stream flow in the direction of dip. The same stream pattern related to swamps occurs in the bottoms of several of the synclines, hence the relation to appreciable slope must be considered in order to err on the side of safety during interpretation. Aquifer action, normal in such terranes in temperate climates, appears to have little influence on the widespread formation of swamps in Arctic terranes.

Soil and Solifluction Patterns

Static soil patterns appear to have little relation to geologic structure where strata are overlain by tundra in this area. The mottled patterns of tundra are obviously caused by local, temporary, ground water conditions or by differences in vegetation supported by the water-logged soil. Summer thaw of the permanently frozen ground is not deep and the soil profile apparently develops without conspicuous differences related to underlying strata.

Solifluction patterns, however, were found of value in areas underlain by shales with thin sandstone interbeds. Curved linear patterns, on opposing slopes of hills underlain by such terrane, were characteristically developed in the western part of the area. Shale areas in which dip and strike could be ascertained by other criteria, contain features which made it possible to establish that soil creep down slopes was guided and directed at oblique angles rather than the normal course directly down slope. It was also noted that soils on certain layers apparently moved faster owing to differential plasticity and the different directions the slopes faced. Surficial solifluction thus gave rise to curved U shapes whose closed ends at the top of hill slopes invariably pointed up-dip. Where soil flow lines from contiguous hills meet at the bases of hills in valleys drained by small intermittent streams incompetent to carry away the slope debris, a set of V's is formed which point down the dip of the shales (see Fig. 5). Though this criterion was checked photographically over terrane of known dip it was not checked in the field because it couldn't be recognized on the surface; hence it was used sparingly. It was found, however, to be the only photogeologic criterion available in a predominantly shale terrane in the plateau province where the dips are over three degrees and slopes are relatively steep. Soil flow patterns, somewhat similar, but more irregular, were found on talus slopes which masked the underlying rock. Solifluction lines simply did not exist as recognizable patterns in the low-dip shale area north of 69°30′, just south of the coastal plain.

Vegetational Patterns

The upland part of the plateau province is covered with tundra grasses and caribou moss, whereas the stream valleys and some hill-side swamps contain

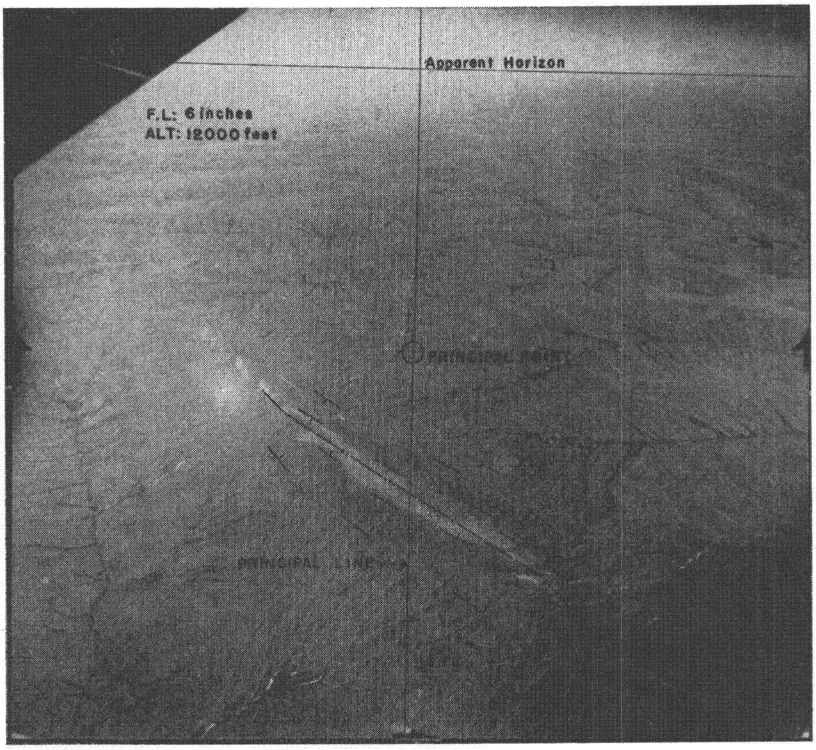

FIG. 6. Right wing trimetrogon photograph of syncline in upper Cretaceous rocks. Interpretation of oblique wing prints is greatly facilitated by stereoscopic examination with adjacent wing prints. The apparent horizon, computed true horizon, principal point, and the principal line joining the horizon and the principal point are photogrammetric data required to compute and place over the photograph the oblique grid as shown in Figure 7. (Photo courtesy—U. S. Navy.)

willow, dwarf brush, and small alder. With the exception of some of the dwarf evergreen which grew on shaly sandstone outcrops, the vegetation which could be recognized in aerial photographs grows near the streams. Numerous confusing grass patterns of various densities and shapes, complicated by small round swamps, appeared to have little relation to the attitude of strata in areas whose structural disposition could be recognized by other criteria.

Erroneous Interpretations

Early interpretation led to erroneous conclusions which were revised as the work proceeded. As in all of the geological sciences, one criterion was considered insufficient and as many data as could possibly be interpreted were assembled to set up criteria for this particular area. Nevertheless, some geomorphic features invariably caused difficulty because they simulated so closely certain basic features related to the attitude of the subjacent rock.

Two scarp forms belied the rocks beneath them: (1) scarps formed by consolidated river gravels in terraces and benches, or remnants of elevated valleys. (See Fig. 3, top center of couplet); (2) river meander scarps whose back slopes simulate dip slopes.

Both false forms led to the plotting of erroneous strikes and dips on aerial

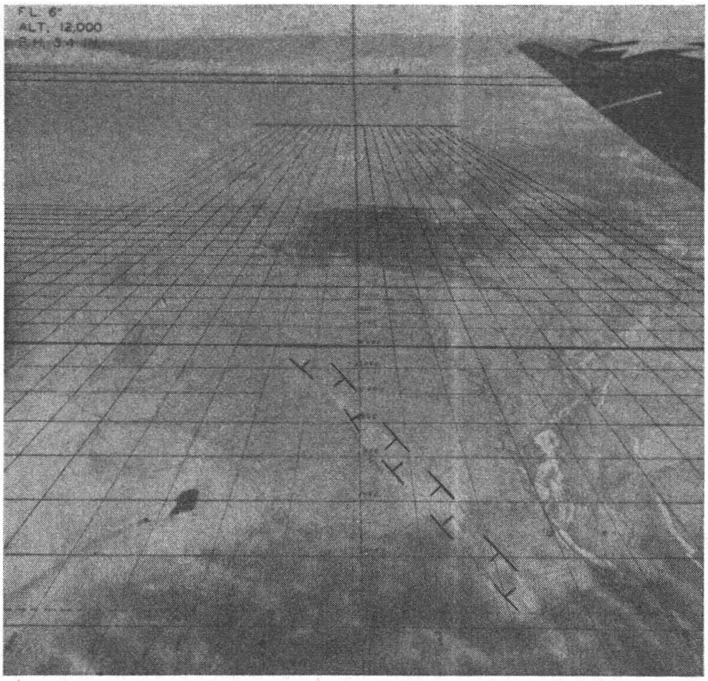

FIG. 7. Canadian grid superposed on a left wing oblique photograph. The interpreted strikes and dips mapped on the photograph may be plotted on an orthographic projection of the grid at any desired scale and then transferred to the base map or they may be plotted directly on the base map through the use of grid templates adjusted relative to natural features. Grid blocks shown are 2,000 feet square. In this area, with topographic relief less than 400 feet, the symbols were located on a 1944 trimetrogon base map with an accuracy commensurate to that of the planimetric detail on the map. The photograph shows a part of the tightly folded syncline forming a ridge at Lat. 69° 10′ North, Longitude 156° West on the photogeologic map. (Photo courtesy—U. S. Navy.)

photographs, but the regional pattern plotted by correlating many surrounding photographs revealed these unreliable anomalies.

COMPILATION OF PHOTOGEOLOGIC DATA

General Features

The most advanced and astute geologic interpretation of aerial photographs is of little value unless the data can be assembled into map form, or onto a mosaic, which allows easy summarization of the structural picture. No quantitative data were available for the compilation of the photogeology, hence the problem was resolved to placing the qualitative interpretations from the photograph to the base map by some easy, accurate, method.

Results of Geologic Interpretation

Photographic interpretation of the geology of Naval Petroleum Reserve No. 4 resulted in thousands of strike and dip symbols marked directly on the vertical and oblique photographs. The haste which necessitated completion of the project before high point Naval personnel were released to civilian occupations did not allow time to await the compilation of the 1945 trimetrogon photographs into a planimetric base map. The 1:200,000 base map compiled from 1944 photographs was selected as a base for the assembly of all strike and dip symbols and the delineation of structural axes.

Map Plotting

Average relief of the terrane in the plateau province is considerably under 400 feet. The photography was flown at an altitude of 12,000 feet with 6 inch focal length lens. Radial displacement of relief (and the strike and dip symbols) was thus negligible and could be ignored in the direct transfer of the symbols from the vertical photographs to the map.

A scaled acetate template was constructed representing the photographic coverage of a trimetrogon triplet (two obliques and the vertical photograph), at the scale of the map. A similar template was constructed at the scale of the aerial photographs after computation of an oblique grid (Wengerd—1945). The grid was computed as an average grid with a principal point to horizon distance of 3.4 inches. Though the PH distance varies depending upon the list of the airplane, this variation caused misplacement errors but slightly greater in the final plot than original misplacement of detail compilation of the 1944 base map.

The small template was laid on the map as exactly as possible to gain the nadir of the aircraft during the exposure of the trimetrogon triplet. The large oblique and vertical grid was laid over the trimetrogon triplet of photographs. After matching the photographed natural features exactly to the mapped features, the position of the aircraft and the resultant position of the photographic triplet was outlined on the map. Because the location of the vertical, and the principal lines and side to side coverage of the wing obliques, is based on graphical resection from natural features represented on the map, this initial location of every third trimetrogon triplet on the map is based upon the map's initial accuracy.

Interpreted strike and dip symbols were then located simply and quickly through the use of the grids. The symbols were made as small as possible on the map and by their distribution and density delineated the areas where complete photographic coverage was available and in turn where the greatest structural deformation had occurred, or doubtful structure existed. After the painstaking job of transferring symbols, the over all map interpretation resulted in delineation of structural axes of the anticlines and synclines.

The base map, redrafted to eliminate the symbols and retain the axes, yielded the reconnaissance structural picture as shown in Figure 8.

CONCLUSIONS

This relatively non-technical early use of photogeology in petroleum exploration by the U. S. Navy illustrates the facility with which regional studies can be handled. The assembling of preliminary data with a minimum of time and personnel contributes greatly to a well organized and successful field program. The collation of new vertical photographic interpretation and surface work now being done on contract should yield excellent quantitative data on the structural features of U. S. Naval Petroleum Reserve No. 4 in Alaska.

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RECONNAISSANCE MAPPING FROM OBLIQUE AERIAL PHOTOGRAPHS WITHOUT GROUND CONTROL

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IN THE course of reconnaissance from the air many occasions arise when it would be desirable to be able to make a map—even though it were not entirely accurate—that would show the spacial relations of objects on the ground more definitely than they could be judged from photographs alone. The geologist, for instance, might desire to show the locations and relative trends of features such as contacts or faults, or he might wish to determine approximately the dips and strikes of strata in rough terrain.

All of these things could be done fairly simply if overlapping vertical photographs could be made, but in ordinary reconnaissance work this is not likely to be feasible. A method for accomplishing the purpose by the use of oblique photographs would be useful.

About two years ago the writer hit upon a method for making a reconnaissance map from oblique photographs which does not require ground control and which, unlike the Canadian grid method or the spot-location method recently described by Desjardins,[1] does not require that the entire area be essentially flat, but is applicable to rough or mountainous terrain provided that two starting points that are at essentially the same elevation can be found. The writer recently had opportunity to test the method on two separate sets of photographs[2] and found that it is capable of yielding surprisingly good results.

[1] Desjardins, Louis, "Useful Graphical Constructions on Aerial Photographs," PHOTOGRAMMETRIC ENGINEERING, Vol. XI, No. 3, 1945, pp. 194–229.

[2] Grateful acknowledgement is made to Dr. Edward S. Wood, Jr., of Harvard Institute of Geographical Exploration who kindly supplied a set of four photographs for the test.