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CORPS OF ENGINEERS
U. S. ARMY

VOL. I

EVALUATION OF SOILS AND PERMAFROST CONDITIONS

IN THE

TERRITORY OF ALASKA

BY MEANS OF

AERIAL PHOTOGRAPHS

PREPARED BY

ENGINEERING EXPERIMENT STATION
PURDUE UNIVERSITY

UNDER CONTRACT WITH

ST. PAUL DISTRICT
CORPS OF ENGINEERS

FOR

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AIRFIELDS BRANCH
ENGINEERING DIVISION
MILITARY CONSTRUCTION

SEPTEMBER 1950

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Prepared by

ROBERT E. FROST, Research Engineer

September 1950

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St. Paul District, Corps of Engineers
Department of the Army

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FOREWORD

THIS REPORT, entitled "Evaluation of Soils and Permafrost Conditions in The Territory of Alaska by Means of Aerial Photographs," presents the results of one phase of the investigation of airfield construction in arctic and subarctic regions being conducted by the St. Paul District, Corps of Engineers, Department of the Army. The overall investigation has as its objective the determination of design criteria and construction methods for areas of permanently frozen ground. The objective of this phase of the investigation has been the development of a technique whereby engineering soils and permafrost conditions could be evaluated from aerial photographs.

For many years various federal and state agencies as well as commercial interests have been utilizing aerial photographs in many fields of endeavor. During the past decade, pedologists have used aerial photographs as an aid in the preparation of county agricultural soil maps throughout the United States *(1, 2)**. Similarly, the United States Geological Survey has made extensive use of aerial photographs in the preparation of geologic and topographic maps. Other agencies, such as the Soil Conservation Service, Forestry Service, Tennessee Valley Authority, Civil Aeronautics Administration, Bureau of Reclamation, and the Military Services, also have used airphotos extensively in their various surveys *(3 to 9, inclusive)*. Added to this group are the many state highway departments which are using aerial photographs in many ways *(10 to 15, inclusive)*. Several universities are either providing instruction or conducting research in the development of techniques of photo interpretation *(16, 17, and 18)*. At the time of the present writing there are several texts on various phases of aerial photographic interpretation. A few of these are listed in the bibliography *(19 to 26, inclusive)*.

For several years, the Joint Highway Research Project of Purdue University has been studying the use of airphotos in identifying soils, rocks, and constructional materials and for use in location work for highways and airports. One active project at the University consists of the preparation of a series of county drainage maps made to the scale of one inch equals one mile. To date (1950) 50 counties have been mapped. Another active project consists of producing a state engineering soils map. This is being done both on a county basis and on a soil area basis. The technique has been used extensively in Indiana for highway engineering purposes. These have been described in various bulletins and reprints of the University; some have been described in engineering periodicals *(27 to 52, inclusive)*. Several graduate students have performed research in airphoto interpretation and have submitted theses to the University *(53 to 69, inclusive)*.

The Civil Aeronautics Administration became interested in the airphoto interpretation technique as an aid in the location of airports and financed such a study at Purdue University during the war. During the war, soil surveys were made from aerial photos of 36 airfields for the C.A.A. for use in their site-selection program. A report on this work was published in May, 1946, and a supplement to this report was published in August, 1948 *(70 and 71)*. In addition, engineering soils surveys from airphotos were made for 16 airfields in Indiana for the Indiana Economics Council and the Indiana Aeronautics Commission.

Chapter III of this report presents a detailed review of the lecture notes of the airphoto interpretation course as taught to civil engineering students at Purdue University. From the military standpoint this chapter provides a basic course outline for soils interpretation. With specific regard to the military application of the training methods as developed and taught at the University, it is the concluded opinion of those teaching airphotos that should the military command concentrate on these procedures, an intensive training program could be developed so that moderate numbers could be trained to proficiency in a short period of time.

In using aerial photographs for evaluating soil conditions, it is of importance to note that the photograph records the results of natural processes in the development of residual soils and in the occurrence of transported soils. The configuration of surface features which include drainage lines, vegetation, land form, color tones, etc. produces a pattern on the airphoto which can be correlated with actual ground conditions. Repeated field checks have shown that similar patterns in aerial photographs indicate similar materials. Thus, airphotos can be used to identify soil and rock textures, to bound areas of similar materials, to evaluate and select better construction sites, and to identify and locate materials for engineering construction.

The procedures followed in identifying patterns are relatively simple and straightforward. After the aerial photographs have been processed, they are studied by a trained observer. He will find patterns—particularly in new and unexplored regions—with

* Numbers in parenthesis refer to bibliography and page number in the reference.

which he is unfamiliar, or patterns which he will wish to check in the field. He then takes the airphotos and, by studying exposures or by observing drill-hole records, determines the materials that develop the specific airphoto pattern in question. He will pay particular attention to such items as type of vegetation, erosional features, various topographic expressions, and the range in soil and rock textures within the limits of the photograph. After all the detailed patterns have been worked out in the field and the soil transportation and soil profile development processes of the region in question have been studied, the observer can be certain that similar patterns on aerial photographs taken from other regions will yield similar materials and similar engineering situations.

For successful use of aerial photographs for soil interpretation purposes, it is important that the observer be familiar with certain of the natural processes, particularly geologic and pedologic. Obviously he should familiarize himself with all of the available literature of the region in question. It will be found that there are limitations to the use of aerial photographs in soils work. There is an optimum photographic scale which should be obtained; stereo-pairs of airphotos are indispensable. Weather conditions and the time of year of the flight will have marked influence on the photo pattern obtained because of vegetative-color variations. A dense forest cover will present some difficulty to the interpreter since much of the soil pattern is obliterated. Frequently it becomes necessary for the interpreter to use inference in developing information on the subsurface conditions of soils. This is particularly true in arctic and subarctic regions.

In a relatively undeveloped region, such as in the Territory of Alaska, aerial photographs can be used to great advantage—particularly since the Territory is not adequately mapped for military or civilian use in locating airports, highways, railroads, bases, etc. When it is known that some engineering structure is to be built in a particular region, the airphotos of the region should be studied and, in a few hours' time, a general engineering soil map can be produced which will show the good, poor, and intermediate soil areas evaluated on the basis of anticipated performance of engineering structures. Thus, the poor soil areas can be eliminated almost entirely by study of the aerial photographs and the field investigation can be concentrated on those areas best suited to construction.

In a military sense, this method has particular application in planning operations in a territory held by hostile forces. Possession of adequate photography will permit advance planning of airfields and structures with the certainty that the least desirable locations are avoided and adequate construction areas are utilized.

In Alaska one of the primary problems of construction is permafrost. Although the complete details of the permafrost patterns have not been worked out, sufficient data are available at present (summarized and presented in this report) to indicate that the extremely poor and the very good areas can be identified by means of aerial photographs. Extensive field work with airphotos in hand has shown that detrimental and non-detrimental permafrost can be identified from aerial photographs. Soil polygons containing ice wedges and reflecting the most detrimental type of permafrost are readily identifiable in the aerial photograph, even in areas where they are relatively difficult to observe in the field.

With the completion of this program, it is believed that most of the major soil patterns in the Territory of Alaska will have been worked out in detail from field inspections. With this phase of the program successfully completed, it will be possible to develop engineering information on soil textures and permafrost from aerial photographs alone, not only for the Territory of Alaska but also in regions throughout the world where arctic and subarctic conditions prevail.

L. G. YODER
Colonel, Corps of Engineers
District Engineer
St. Paul District

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INTRODUCTION

THIS is a summary and a statement of the interpretation technique for identification of soil and permafrost conditions of arctic and subarctic regions from aerial photographs as developed largely from data collected by small field crews during five summers spent in the Territory of Alaska. The field investigations and airphoto analyses are being done under terms of War Department Contract W21-018-eng-336 between the United States Government and the Engineering Experiment Station, Purdue University. This program is a part of the comprehensive permafrost research studies being conducted by the St. Paul District, Corps of Engineers.

Purpose

The purpose of the permafrost study being conducted at Purdue University is as follows:

(1) To develop a method of interpreting soils and permafrost conditions in arctic and subarctic regions for engineering use from aerial photographs.

(2) To set forth the techniques and procedures involved in a manual form. This report is a comprehensive report which is to be used as a reference text for the manual. The procedures can be used by those who are actually faced with engineering problems associated with site selection, design, construction, location of materials, or soil survey in permafrost regions. The procedures can also be used by those civilian or military personnel who are engaged in planning and development of arctic and subarctic regions.

(3) To develop an engineering soils map of the Territory of Alaska which can serve as a guide in studies relating to development and planning in the Territory particularly if such studies are to be based in part on airphoto interpretation.

Scope

The scope of this study has been limited by geography, field operations, literature survey, and the type of audience for which the resulting manual is intended.

Geographically this study has been limited to the Territory of Alaska for reasons of accessibility, availability of literature, and ease of obtaining aerial photographic coverage of all parts of the land by the Air Forces. Field investigations were often limited to a reconnaissance nature both on the ground and in the air because of the vast amount of area to be covered and because of the extremely short seasons during which field work was practical. Field investigations were limited also by the type and practicability of transportation. Since time did not permit conducting extensive overland expeditions an area had to be accessible either by car, boat, small aircraft, or foot travel. Areas for field study were also limited by existing, available, and potentially available aerial photography. As far as the literature is concerned the study has been limited to existing investigational reports of others particularly those by American investigators. Quite often these reports discuss work of a reconnaissance nature.

With the above in mind the scope of this report has been limited to a presentation of the natural conditions of the Territory and the associated airphoto patterns expressed largely in engineering terminology. Since the report is designed primarily for Engineer and Air Force officers or other personnel who are technically trained and who must use the principles set forth in the field, perhaps under adverse conditions, the report avoids scientific theory, controversial issues, and scientific language. The understanding of the geography of Alaska, a few basic principles of geology, and the correlation of permafrost with vegetation, soil textures, topographic position and certain surface features will make possible the effective use of this report. The report is presented as a statement of interpretation techniques and has been prepared with the hope that the user will be able to place an engineering valuation on the permafrost conditions of a given area by utilizing the examples and data described herein.

Procedures

The procedures followed in conducting this survey can be divided into: field survey, literature survey, and study of existing aerial photographs.

FIELD SURVEY. Five summers have been spent in the Territory of Alaska by various members of the Engineering Experiment Station for the purpose of gathering data which would be of assistance in developing the techniques required to interpret soils and permafrost conditions from airphotos. The studies were largely in regions where aerial photographs were available and where accessibility by some form of transportation was no particular problem. When possible, such studies were made by "on the spot" sampling with the aerial photographs in hand. In accomplishing the field study it was necessary to group the natural features into such items as vegetation, topography, drainage, erosion, depth to permafrost and any other miscellaneous physical features or conditions pertinent to the development of the airphoto pattern. Field investigation consisted of comparing actual ground conditions with conditions as represented on the aerial photographs. Several progress reports and special reports have been prepared and submitted to the District Engineer, St. Paul District, *(72 to 77 inclusive)*. During the summer of 1945 Prof. D. J. Belcher spent a six-week period in Alaska to determine the feasibility of conducting an extensive airphoto interpretation program. The writer was the University representative in charge of the subsequent field operations. Other University representatives who assisted in field operations were Mr. Jean E. Hittle, Mr. Charles R. McCullough, Mr. Wm. S. Pollard, Mr. James R. Shepard, Professor Olin W. Mintzer, and Prof. K. B. Woods.

During each of the field seasons the Purdue parties were accompanied by Mr. Ernest G. Stoeckeler, soils engineer and forester for the Permafrost Branch, Corps of Engineers, not only to assist in the field operations but to conduct a study of arctic and subarctic vegetation. As a result of the three summers spent in the field on the airphoto survey Mr. Stoeckeler has prepared a report on the airphoto interpretation of arctic and subarctic vegetation *(78)*.

LITERATURE SURVEY. The literature survey has provided background material necessary to the field operations and has, in many instances, provided a means of substantiating certain predictions made from airphotos pertinent to soils and permafrost in areas not visited by the field parties. The writer has drawn heavily on the literature and throughout the report the sources of literature are indicated. In many instances the more general observations or findings of others have been summarized and the author and source have been indicated. In other instances, where an important observation has been made by a previous investigator and it is felt that the observation adds materially to the present study, particularly as written or expressed by the observer, then direct quotations are included. In such instances, again the author, source, and page are indicated. All reference material appears in the bibliography in the appendix to this report.

By far the greatest source of literature on Alaska is from the writings of the members of the United States Geological Survey which organization has spent some 50 years engaged in field studies in the Territory. Other agencies, both federal and private, have from time to time conducted surveys in the Territory the results of which have been published in bulletin or pamphlet form. The St. Paul District, Corps of Engineers, supplied translations of some of the Russian writings for use in connection with this survey. A considerable amount of engineering information was obtained from the engineering periodicals. Lastly, many popular articles both in periodical form and in book form were reviewed. The latter provided the field parties with valuable information concerning everyday life in Alaska, economic conditions, and other items so necessary to those assigned to the field in Alaska.

AIRPHOTOS. Prior to field operations a search was conducted to locate and evaluate existing photography which could be used in connection with this study. Early in 1946 it was learned that photography of the type necessary for the development of the soil interpretation method did not exist other than scattered photography made in connection with mosaics of four or five military bases. These were secured for the survey. For the most part the existing photography of Alaska at that time consisted of miscellaneous high altitude tri-metrogon strips.

In 1946 a project was initiated whereby vertical photography of the K-18 type and tri-metrogon photography were to be obtained of some areas in the tundra regions.

During the summer of 1947 two types of photography were obtained of several widely scattered areas in Alaska. Tri-metrogon photography was obtained of a limited area around Bettles, McGrath, and Yukon-Beaver-Circle. These photos were taken so that the scale of the center, or vertical photos would be 1:20,000; flight lines were generally 5 to 10 miles apart. The purposes of the tri-metrogon photography were to (a) determine the areal extent of certain soil patterns and (b) to determine the feasibility of using tri-metrogon photography for engineering soils and permafrost use.

Also during the 1947 photo season miscellaneous strips of single-lens vertical photographs were obtained of several areas at a scale value of 1:10,000. Photography of this type was obtained at Umiat, Bettles, Bethel, Ft. Yukon, and McGrath. Photography was also obtained of selected areas along the Alaska Railroad, the Steese Highway, and the Richardson Highway.

During the summer of 1948 the aerial photography program was expanded considerably and consisted for the most part of obtaining miscellaneous tri-metrogon strips and obtaining a series of single-lens photographs for research use. Tri-metrogon photos were taken in the Kuskokwim Valley, the Pt. Hope-Kotzebue area, the Koyukuk area, and the Sagavanirktok Valley. The research photography was taken in four areas of different engineering soil types.

The Report

The report is divided into eight chapters, an appendix, a bibliography, and a series of maps. In general, the first chapter discusses the natural setting of the Territory; it serves to provide necessary background material about the Territory, particularly about arctic and subarctic conditions in general.

The second chapter is concerned chiefly with permafrost; such items as definitions, distribution, mode of occurrence, and engineering significance are discussed. Information contained in this chapter is from field information, literature survey, and detailed airphoto study.

Chapter III is entitled "The Technique of Airphoto Interpretation of Engineering Soils". This chapter sets forth the limitations of the airphoto method; the principles of soils evaluation; the procedures to be followed both in making a survey of a known or accessible area and the procedures to be followed in making a survey of an unknown or inaccessible area; and the influence of permafrost on the photo pattern elements. Basically, this chapter is a review of the procedures and the techniques as taught to graduate students at Purdue University in connection with graduate studies in Civil Engineering. The information presented is from the unpublished lecture notes and miscellaneous pamphlets on airphoto interpretation and is not limited to Alaska.

Chapters IV, V, VI, and VII present the airphoto patterns of the various soil groups in Alaska as follows: Water-deposited Materials; Aeolian Materials; Ice-deposited Materials; and Rocks and Rock-Soil Materials. Each chapter is illustrated with airphotos and ground views. In addition to the airphoto interpretation techniques presented some discussion is given to the related engineering problems of each soil situation. Information for each chapter has been obtained largely from aerial photographs supplemented with field data.

The last chapter, entitled "Summary and Example of Interpretation", presents a typical airphoto analysis of the soils and permafrost conditions of two areas as an illustration of the method.

The appendix to this report is in three parts as follows: Part I, Climatic Data; Part II, Engineering Soil Test Data; and Part III, Criteria for Site Report. The climatic data are from existing reports such as: "Climate and Man" *(79)*, "Climatic Atlas for Alaska" *(80)*, and "Atlas of Climatic Types in the United States" *(81)*. Certain tables are reproduced for the convenience of the reader. Engineering soils test data are from test results obtained both at the Purdue Highway Research Laboratories and at the Soil Laboratory of the Permafrost Branch, Corps of Engineers, Ladd Air Force Base.

The bibliography lists chronologically the reference material as it appears in the report. The bibliography accompanying this report is by no means complete for Alaska.

The maps included with this report include the following:

(1) "Physiographic Map of Alaska," drawn by Mr. William Nunez, student in civil engineering and was prepared under the supervision of Mr. Jean E. Hittle.

(2) "Engineering Soils Map of Alaska", drawn by Mr. William Nunez assisted by Mr. Norman D. Wilhelm also a Purdue student. This map was prepared largely from data obtained from a literature search under the direction of Mr. John C. Stevens.

(3) "Distribution of Vegetative Cover," drawn by Mr. William Nunez. The information for this map is largely from existing maps of Alaskan vegetation. Mr. Hittle and Mr. Stoeckeler supervised the transfer of boundary data.

(4) "Absolute Maximum Temperatures, July Ocean Winds and Prevailing Ocean Currents for North America," drawn by Mr. Glen L. Herstine, student, under the supervision of Mr. Jean E. Hittle.

(5) "Absolute Minimum Temperatures, January Ocean Winds and Prevailing Ocean Currents for North America," drawn by Mr. Herstine under the supervision of Mr. Jean E. Hittle.

(6) "Mean Annual Number of Days of Freezing Temperatures," drawn by Mr. Herstine under the supervision of Mr. Jean E. Hittle.

(7) "Mean Annual Percipitation," drawn by Mr. Herstine under the supervision of Mr. Jean E. Hittle.

(8) "Mean Annual Temperature," drawn by Mr. Herstine under the supervision of Mr. Jean E. Hittle.

Information sources for each of the climatic maps are shown in the title block of each map.

Summary of Results and Conclusions

On the basis of the field and laboratory work performed to date in connection with the research program designed to develop means of locating various degrees of permafrost in arctic and subarctic regions, it may be concluded that aerial photographs can be used to distinguish good materials and good site areas from detrimentally frozen materials and unsatisfactory site areas.

In the hands of a trained observer the study of aerial photographs will assist greatly in site selection by eliminating the poor soil areas, by selecting the good sites, and by concentrating the field investigation on those areas best suited to construction and the overall tactical and logistical situation.

The results and conclusions of this investigation fall into two groups: The Engineering Significance and the Photographic Requirements.

Engineering Significance. In using the aerial photograph to analyze the engineering aspects of frozen soil areas, there are many elements which must be evaluated. The most important of these are topographic position, surface features, textures of the soil or rock-soil materials, and vegetation.

I. Topographic Position: Since water must be available for the formation of ice wedges, ice lenses, and detrimental permafrost and since surface runoff and other drainage features are controlled in part by topography, it follows that an analysis of the topography of a given area is of primary importance in evaluating permafrost conditions.

II. Surface Features: Aerial photographs record a multitude of surface features, some of which are unimportant in relationship to permafrost and some of which are very important. Many of these features have been evaluated by in-field inspections with airphotos in hand. In arctic and subarctic regions the most obvious surface feature markings on aerial photographs which can be correlated with detrimental permafrost in practically all instances, are those of polygons. Two types occur which include: (a) those with raised centers and depressed perimeters and (b) those with depressed centers and raised perimeters. The size of polygons vary from a few feet to as much as 200 feet across.

Other surface features which often appear on the aerial photographs and which are important in evaluating permafrost include drainage pattern, gully shapes and gradients, the presence or absence of muskegs and other swamp-like situations, vegetation, slope and exposure, and any other surface marking which may be peculiar to a particular type of deposit.

III. Vegetation: Available field information indicates that vegetation alone cannot be used with safety as an indicator of permafrost conditions; however, vegetation, when analyzed in conjunction with other elements of the airphoto pattern, is important. Natural changes in vegetative cover indicate, in part, a change in the environmental factors of the vegetal cover. One serious difficulty in connection with vegetation is burned over areas which change the vegetation balance and thus vitiate the corresponding airphoto pattern.

IV. Soil Texture: Since a general relationship exists between the various degrees of permafrost and soil textures, it follows that the airphoto techniques used for identifying soils become highly important. The process for identifying and evaluating frozen soils is indirect—the determination is made by inference, logic, and reason rather than by direct reading. An understanding of the natural soil-forming processes and the reflected or related earth features is of great importance. Field examinations of similar situations are always helpful and in some instances field work is indispensable. The areal extent, topographic position, surface features or general land form and the relationship of a deposit to the surrounding area are clues to the origin or depositional aspect of the deposits; these factors limit the type of material to be expected. Detailed analysis of the areal drainage pattern suggests the method of drainage—whether it is surface or internal. Detailed study of gully shape and gradient makes it possible to predict soil textures, since the gully characteristics are related to soil textures. Finally, study of vegetation lends supporting evidence to previous predictions. The presence or absence of permafrost, when polygons do not appear as surface markings, is largely determined by inference, logic, and reasoning from the collective evaluation of all pattern elements. In permafrost areas, variations or deviations from the normal, are striking when comparing the frozen and unfrozen conditions of similar soil materials or soil-rock mixtures.

PHOTOGRAPHIC REQUIREMENTS. From the results of this survey as well as from results of previous surveys in which airphotos provided the medium of survey it is believed that the best photography is of the single-lens type where complete stereo-coverage is obtained of an area such as that obtained by ordinary mapping procedures. For aerial photographs to be of optimum use, they must be obtained in stereo-pairs so that the relief of the major topographic features can be studied and outlined; this is the first step in analyzing permafrost or any situation from airphotos. Furthermore, airphoto coverage of large areas surrounding a specific situation in question is essential for establishing the overall conditions. Photographs should be taken to a scale value of between 1:15,000 and 1:22,000 for optimum engineering use. This is too small a scale for specific vegetation identification; however, since vegetation, as a soil indicator is in the minority, the smaller scales will suffice. It is believed any high speed aeropanchromatic film will provide good rendition of tones, shades, and contrasts, particularly when corrected with some type of haze filter.

As far as climate and season are concerned, in arctic and subarctic regions photography should be obtained any time during the summer after the snow has gone. Photography taken in the fall, particularly when the decidious foliage has changed color, makes it possible to separate trees of that class from trees of the conifer class. This is particularly important in soil determination of dry, unfrozen, well-drained soils when such soils are surrounded by poorly drained, wet, and frozen soils. However, in most instances the vegetation is one of many elements and is often supplementary for soil identification. Winter photography is practically useless for engineering soil determination since the deep snow, both on the flats and in deep drifts, destroys all pattern elements but those indicating topography and major drainage. In timbered areas, photography obtained immediately following a light snow brings out often unobserved soil polygons. However, there are usually other indications of permafrost in such areas, even though polygons may be obscured by the dense summer foliage.

As far as use in engineering soil analysis is concerned, tri-metrogon photography, at best, provides a means of making a preliminary survey of a large area in a relatively short time. For engineering soils and permafrost determinations tri-metrogon photography should be limited in use to coverage of a large area in which a development is to be considered and where time, cost, or facilities are not available to completely cover the area with vertical-mapping photography of the single-lens type. Photography for optimum use should be flown such that the scale of the center photo of the series (right, vertical, left) has a scale value of between 1:15,000 and 1:22,000. Flight lines should be approximately 7 to 10 miles apart. Study of this type of photography, at best, will make it possible to obtain an overall perspective of the physiography, geology, vegetation, and general soil types. Major land forms can be outlined and traced continuously from one flight group to another. Such a study or procedure will make it possible to locate areas believed to be most feasible for engineering consideration and hence requiring vertical-mapping-single-lens type photo coverage and/or ground survey. It is possible to obtain accurate soil and permafrost determinations only from the vertical photos of a tri-metrogon series.

CHAPTER I

NATURAL SETTING

THIS report presents certain details of a study of permafrost and the airphoto patterns of permanently frozen soils of arctic and subarctic regions found in Alaska. The purpose of this chapter is to discuss the natural setting of Alaska in order that the reader may become acquainted with the geography, physiography, geology, climate, and vegetation. The information has been obtained from other publications of agencies, societies, or individuals who have recorded their findings about the Territory.

GEOGRAPHY

Alaska has an area about one-fifth that of the continental United States, or about 586,000 square miles *(82, p. 15)*. Its 26,000 mile coast line is longer than that of the continental United States *(83)*. See Figure 1-1. It is bounded on the north by the Arctic Ocean, on the west by the Bering Sea, and on the south by the Pacific Ocean. The eastern border lies along meridian 141°00′W while the southeastern border is common with that of Yukon Territory and British Columbia in Canada. The northernmost point of the Territory is Pt. Barrow with a latitude of slightly over 71°30′N. The southernmost point is about 54°N latitude. The westernmost point on the mainland is Cape Wales on the Seward Peninsula which has a longitude of about 168°W. The tip of the Aleutian Islands is approximately 173°E longitude which is across the International Date Line. Approximately one-third of the area is north of the Arctic Circle.

Coastal Features

Study of the map of Alaska shows the shape to be that of a crown. There are three major peninsulas to break up the regularity of the mainland coast line. The Seward Peninsula, lying below the Arctic Circle and extending westward from the mainland, is the largest. This peninsula extends to within 60 miles of Asia. The Alaska Peninsula extends southwest from the mainland forming with the Aleutian Chain the barrier between the Pacific Ocean and the Bering Sea. The Kenai Peninsula extends south-southwest from the central part of the mainland. It is bounded on the northwest by Cook Inlet and on the southeast by the Gulf of Alaska.

The most regular and nearly unbroken coast line extends from Pt. Barrow to Bristol Bay. This is broken by the delta features of the Kobuk-Noatak and the Yukon-Kuskokwim rivers. Otherwise the coast features of this part are regular in shape with an occasional off-shore bar or barrier beach. The most important spits or barrier beaches occur at Pt. Spencer, Pt. Hope, Icy Cape, and Pt. Barrow. In places the shore line is marked by high cliffs. The "Panhandle", or southeastern Alaska, consists of a narrow mountainous band of mainland and a group of rugged islands extending southeast almost to the fifty-fourth parallel. The southeastern coast line is extremely irregular and contains many passages, inlets, islands, and fiords. Natural harbors are plentiful.

The Arctic Coast from Pt. Barrow east to the Canadian Border is quite irregular. It is characterized by numerous reefs, bars, inlets, shallow lagoons, deltas, and low cliffs; there are no natural harbors for ocean-going ships.

The Natural and Political Divisions

Colby *(83)* divides Alaska into six geographic units, as shown in Figure 1-1, part b, which he calls "The Six Alaskas." These divisions, or units, result in part from differences in geography, physiography, and natural resources. These are: (1) Southeastern Alaska or the "Panhandle", (2) South Central Alaska, (3) Southwestern Alaska, (4) Interior Alaska, (5) the Seward Peninsula, and (6) the Arctic Slope.

Politically, Alaska is divided into four political or judicial districts *(84)* as shown in Figure 1-1, part c. The First Judicial District comprises the area in the southeastern or "Panhandle" region. The principal cities of this area are Juneau, the territorial capitol, Ketchikan, Sitka and Skagway. The Second Judicial District covers nearly all of northwestern Alaska including the drainage basins of the Colville, the Noatak, the Kobuk, and the extreme lower part of the Yukon rivers together with the entire Seward Peninsula. The principal cities and settlements in this area are Nome (headquarters), Kotzebue, and Barrow. The Third Judicial District comprises nearly all the area north of the Alaska Range and west of the one hundred and forty-first meridian W. Its principal cities are Anchorage, Seward, Palmer, Cordova, and Valdez (headquarters). The Fourth Judicial District covers the largest area and contains the remainder of the Territory. Roughly it includes the watershed of the major part of the Yukon, Kuskokwim, Tanana, and Koyukuk rivers as well as a small part of the Territory north of the Brooks Range between the Canadian border and the Sagavanirktok River. The principal cities and settlements are Fairbanks (headquarters), Bethel, McGrath, Nenana, Circle, and Ft. Yukon.

There are several sources of information on present-day Alaska which cover its history, resources, religion, and other social aspects. One description of all the settlements, tourist facilities, transportation, and industry is presented in Colby's "Guide to Alaska" *(83)*. A similar publication to which the reader is referred is Pilgrim's "Alaska" *(85)*. One of the most representative books on conditions in Alaska today is Hilscher's "Alaska Now" *(86)*.

PHYSIOGRAPHY

An understanding of the arrangement of the physical features or physiography of Alaska is important in correlating the areal distribution of soils and permafrost and in studying potential engineering problems. Broadly speaking, Alaska is divided into four general physiographic provinces *(82, p. 16)* as shown in Figure 1-1, part c. From north to south these are: the Arctic Slope, the Brooks Range, the Central Plateaus, and the Pacific Mountain System. Brooks *(82, p. 16)* states that these are believed to be continuations of the major physiographic provinces of the western part of the United States and the western part of Canada. The physiographic map included in this report (in pocket) gives a graphic representation of the general physical arrangement and will be helpful in assisting the reader to understand the various land form relationships. The major physiographic units have been subdivided further into appropriate units such as plains, plateaus, basins, valleys, flats, and other local physiographic arrangements. A brief description of the more important of these follows.

The Arctic Slope

The Arctic Slope consists of two physiographic units, the Arctic Coastal Plain and the Arctic Plateau or Arctic Piedmont as it is often called. It is a continuation of the great plains of Canada and the United States. The Arctic Slope is a broad, gently-sloping land unit, bounded on the north by the Arctic Ocean and on the south by the mountainous topography of the Brooks Range. The Arctic Slope extends from the Canadian border to the northwest coast of Alaska, terminating at approximately Cape Lisburne. At its widest part, on the meridian of Pt. Barrow, this province is approximately 200 miles wide.

ARCTIC PLATEAU. The southern part of the Arctic Slope adjacent to the mountains is a high rolling piedmont, or plateau, which is commonly called the Arctic Plateau. Figure 1-2 shows topographic types on the Arctic Plateau. Smith and Mertie *(87, p. 41)* describe the plateau as being characterized by smooth uplands with gently rolling hills and moderately flaring valleys. The entire plateau is underlain by rather soft, weak sandstones and shales. The sandstones and shales lie nearly flat in the northern part and are gradually tilted upward, becoming tilted progressively steeper to the south. Adjacent to the mountains, the rocks in many instances stand nearly vertical thus presenting strong relief to the plateau. According to Brooks *(82)* the general ground slope of the plateau is downward from an elevation of about 3,000 to 3,500 feet on the south, to an elevation of about 400 to 600 feet on the north.

The general direction of all streams is north to the Arctic Ocean from the mountains across the Arctic Plateau and the Arctic Coastal Plain. Nearly all of the streams flowing northward from the Brooks Range have the major part of their length in the Arctic Plateau province. The most important stream of the area is the Colville River. Other streams, most of which rise directly in the mountains and flow across the plateau, are the Ikpikpuk, Kokolik, Utukok, Kukpowruk, Anaktuvuk, Sagavanirktok, Canning, and several tributaries of the Meade and Kuk rivers.

The extreme western part of the plateau ends abruptly at the Arctic Ocean in great bluffs which at Cape Sabine are about four hundred feet high *(87, p. 47)*. Some distance south of Wainwright along the coast the plateau borders the ocean in a series of much lower bluffs.

ARCTIC COASTAL PLAIN. The northern part of the Arctic Slope is the Arctic Coastal Plain. This province extends from the Canadian border, where it is very narrow, to the northwest coast at Cape Beaufort. At its widest part which is on the meridian of Pt. Barrow, the plain is about 80 miles wide *(87, p. 47)*. The Coastal Plain consists of unconsolidated marine sediments which are recent in age. Topographically, the plain is a monotonously flat surface broken only by an occasional beach ridge or sand dune and by numerous elongated lakes and lakebeds. Figure 1-3 illustrates topographic features of the Arctic Coastal Plain.

The shore line of the Coastal Plain is characterized by low cliffs on the mainland and numerous islands, reefs, and bars off the shore. Shallow lagoons are numerous. The Arctic Coast suffers little from the effect of tide since the tide in this region is only a few inches in height. (This information was obtained from communications with members of the Coast and Geodetic Survey stationed at Barter Island and Pt. Barrow).

The area is poorly drained because the general relief is low, the ground slope is almost imperceptible, and because of the permanently frozen ground. All of the streams which rise in the

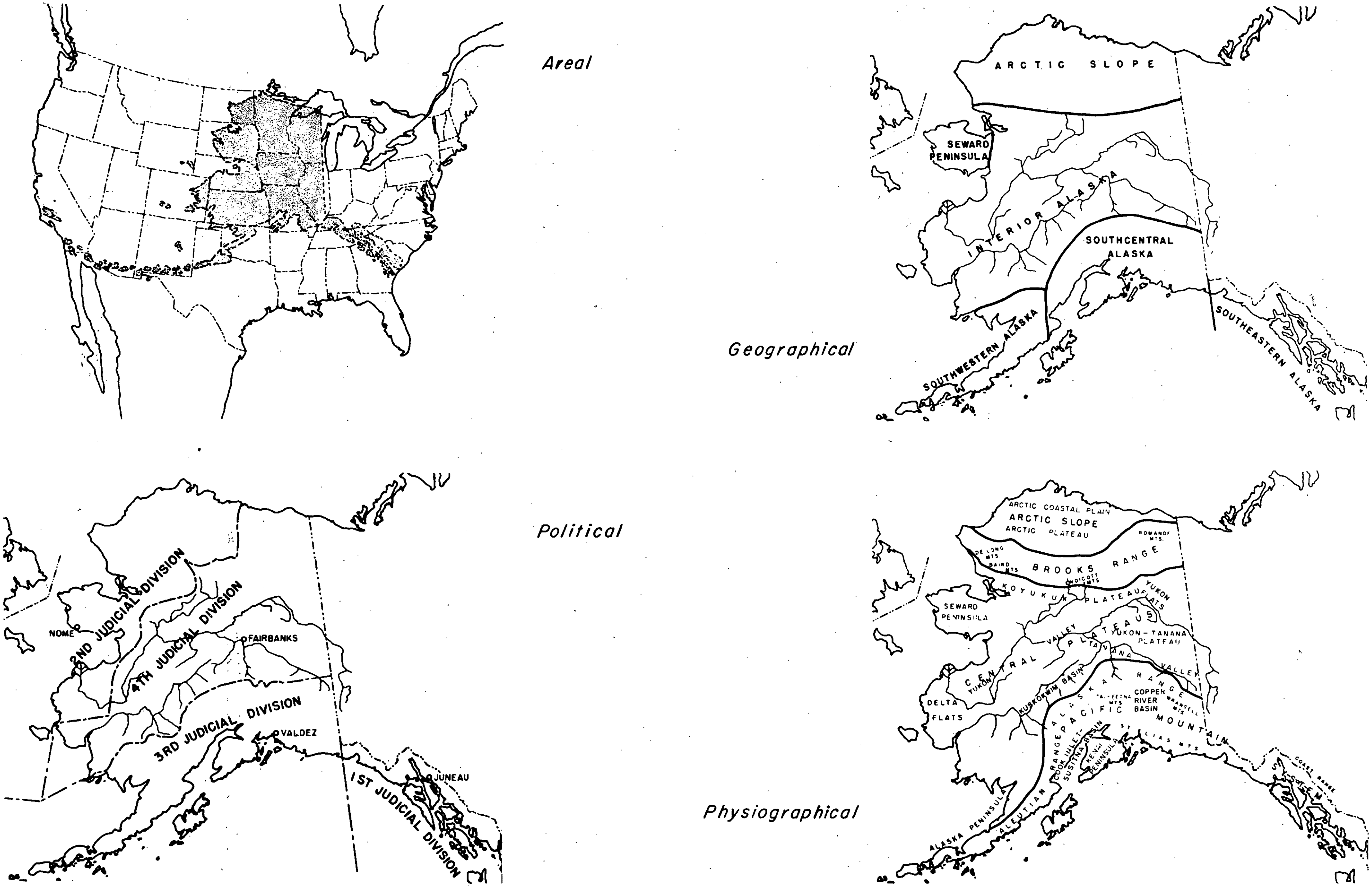


Fig. I–I THE NATURAL AND POLITICAL DIVISIONS OF ALASKA

13519
13192

13528
13704

(a) Uplifted rocks near the Brooks Range

(b) Uplifted rocks near the Brooks Range

(c) Gently rolling topography, near Umiat

(d) Gently rolling topography, near Umiat

Fig. 1-2 TOPOGRAPHIC TYPES IN THE ARCTIC PLATEAU

16074
16081

16076
16160

(a) Outer Coastal Plain, Ikpikpuk River

(b) Outer Coastal Plain, Ikpikpuk Delta area

(c) Inner and outer coastal plain transition, Ikpikpuk River

(d) Inner Coastal Plain near the Topogorak River

Fig. 1-3 TOPOGRAPHIC FEATURES OF THE ARCTIC COASTAL PLAIN mountains and flow northward across the Arctic Plateau also cross the Arctic Coastal Plain. Their course, however, in the Coastal Plain is vastly different from that in the Plateau province. Many of the streams in the Plateau are deeply incised in the upland surface and they flow in rocky valleys. In crossing the Arctic Coastal Plain the streams follow very circuitous meandering channels. The flood plains are broad and often merge imperceptibly into the surrounding coastal plain surface. A few streams are almost entirely contained in the Coastal Plain Province. These are the Meade, the Topogorak, and the Inaru. The line of demarcation between the Coastal Plain and the Plateau is sharp and is easily detected either from the ground, from the air, or from airphotos. A marked change occurs in stream characteristics, topography, surface markings, and soils. One outstanding feature of the Coastal Plain is the presence of numerous elongated lakes most of which are oriented so that the major axis of each is a few degrees west of north. Some of these lakes are rather deeply incised into the coastal plain and often form local bluffs as high as forty or fifty feet. Frequently a series of elongated beach ridges occur at right angles to the major axis of the lakes. These lakes and ridges are often the only reliable navigational aid for pilots or Eskimos, particularly in foul weather. The outer Coastal Plain is also characterized by numerous earthen mounds commonly called "pingos." These, when viewed from the ground, are the only visible land marks for miles around. They vary in size from only a few feet to over two hundred feet in height.

The Brooks Range

The Brooks Range in Alaska is a northward extension of the Rocky Mountain System of the continent. It forms a crescent-shaped mountain belt across northern Alaska roughly paralleling the Arctic Ocean. It extends from the Canadian border to the northwest coast ending in very high bluffs at Cape Lisburne. At its widest part the Brooks Range is approximately 150 miles in width. Its axis is roughly the 68th parallel.

Smith and Mertie *(87, p. 32)* describe the area as consisting of a number of individual mountain groups. These include the DeLong Mountains, the Baird Mountains, the Mulgrave Hills, the Lisburne Hills, and the Igichuk Hills in the western part; the Schwatka and Endicott Mountains in the central part; and the Romanzof, Richardson, and Davidson mountains in the eastern part. In general, the mountains in the western part are much lower in elevation than those in the east along the Canadian border. Peaks in the western part rarely exceed 4,500 to 5,000 feet. Many in the eastern part exceed 7,000 feet, with a few approaching 10,000 feet in elevation *(88)*. In general, the topography of the Brooks Range is extremely rugged even though the mountains themselves are not extremely high. Glaciation has played an important part in shaping many of the mountain features. At the present time glaciation is of minor importance, with glaciers being confined to sections of the eastern part of the province. Fig. 1-4 illustrates topographic features of the Brooks Range.

Some of the great rivers of the Territory have their headwaters in the Brooks Range. In addition to those mentioned which flow northward across the Arctic Slope, there are such rivers as the Koyukuk, which rises in the Endicott Mountains and flows generally southwestward to form part of the Yukon watershed; the Chandalar, which rises in the Davidson and Romanzof mountains and flows southward to join the Yukon; the Sheenjek and the Coleen, which rise in the Davidson Mountains and flow south to join the Porcupine and the Yukon watershed; the Kobuk, which rises in the southern part of the Endicott Mountains and flows westward to Kotzebue Sound; and the Noatak, which rises in the central part of the Endicott Mountains and flows west to Kotzebue Sound. The Noatak River is the only river of any size which is contained entirely in the Brooks Range Province. It forms a barrier between the Delong Mountains and the Baird Mountains.

The Central Plateau

The largest physiographic province of Alaska is, in reality, a group of many physiographic units which collectively are termed the Central Plateaus. It is a continuation of the Great Basin between the Rocky Mountains and the Coast Range. Generally speaking, this province includes all of the area between the Brooks Range on the north, the Alaska Range on the south, the Canadian border on the east, and the Bering Sea on the west. Its broad area roughly includes the watershed formed by the combined Yukon-Kuskokwim river system. Atwood *(89, p. 418)* calls this region the Yukon Plateau and describes it as a broad upland surface with a gently rolling topography. The nomenclature used by Brooks—the Central Plateaus—is widely accepted and will be used in this report. Brooks describes the area by saying *(82, p. 17)*: ". . . the term 'plateau' can be assigned to only a portion of this province, and even that is not a plateau in strict senses. For the most part this region is a gently rolling upland, in which the rivers have trenched broad channels, and which is of low relief compared with the adjacent mountain ranges. The interstream areas are the remnants of a former plateau surface, which has been dissected by erosion, and whose rolling surface slopes gently to the north and west. The continuity of this plateau is broken by a number of mountains and mountain groups which rise above the general level, but these are of much less extent and relief than the similar features of the plateau region of the western United States and Canada."

In the physiographic sense the Central Plateaus consist of delta flats, valleys, basins, plateaus, minor coastal plains, and low mountain ranges. The most important physiographic units are the following: The Yukon-Tanana Plateau, the Yukon Flats, the Tanana Valley, the Koyukuk Valley, the Koyukuk Plateau, the Kuskokwim Mountains, the Kuskokwim Flats, the Kilbuck Mountains, the Delta Flats, the Yukon Valley and the Seward Peninsula. Many of these have been subdivided further. Among the many physiographic provinces which make up the Central Plateaus are several of smal areal extent and of minor importance. It would appear that the physiography generally west of the 150th parallel has not been completely worked out and the names have not been standardized. The physiographic names are confusing, areas often overlap, and it is difficult to bound accurately the various units. Often such terms as basin, lowland, and valley are used interchangeably by various writers when speaking about the same general area.

THE YUKON-TANANA PLATEAU. The Yukon-Tanana Plateau is a highland region between the Yukon and Tanana rivers and the international border. Figure 1-5 illustrates topographic features in this part of the Central Plateaus. The Yukon-Tanana Plateau is shown in parts a and b. Mertie *(90, p. 23)* describes the province as a rolling upland characterized by discontinuous groups of higher mountains which add diversity to the sky line. The valleys lack uniformity; some of the streams flow in wide valleys which are large in comparison with the associated streams.

The wide variety of materials and the complex geologic history of Yukon-Tanana Plateau account for the diversity of land forms. The area consists largely of metamorphic rocks which have been intruded with igneous rocks. The irregularly rounded hills of schists, granite, and altered sedimentary rocks have an elevation of about 5,000 feet *(91, p. 11)*. In general, where harder materials intrude, they form ridges and produce local peaks of higher elevation. The main streams and rivers of this area are Tolavana, Chatanika, Chena, Salcha, and the Goodpaster, all of which flow south into the Tanana. The principal streams flowing north into the Yukon are Fortymile River, Birch Creek, Charlie River, Preacher Creek, and Beaver Creek.

THE YUKON FLATS. The Yukon Flats is an extensive alluvial lowland area formed chiefly by the valleys of the Yukon and Porcupine rivers. Through these gravel- and silt-filled "flats", the two rivers meander circuitously with intricately braided channels. The area is roughly triangular in shape and is a vast interior basin bounded on the north and west by outwash materials from the Brooks Range and on the south by the highlands of the Yukon-Tanana Plateau. Parts c and d of Figure 1-6 illustrate the Yukon Flats.

Mertie describes the Yukon Flats as follows *(90, p. 14)*: "The Yukon Flats constitute a great alluvial basin in which the Yukon River flows from Circle to Fort Hamlin, an air-line distance through Fort Yukon of about 180 miles. The greatest width of this basin, from north to south, in the vicinity of Fort Yukon, is about 75 miles, and the area is estimated to be at least 7,500 square miles. Within this stretch of the Yukon all the tributary streams on both sides are similarly aggraded in their lower courses, and in the Porcupine Valley these flats extend upstream from Fort Yukon for 80 miles in an air line . . . The name Yukon Flats is somewhat misleading, for the valley floor though devoid of relief, is far from approaching a horizontal plane. In fact, the fall of the river from Circle to Fort Hamlin is about 200 feet, or nearly 1 foot to the mile, and these "flats" are therefore a tilted alluvial surface, across which the river flows swiftly through a system of shallow braided channels."

Adjacent to the major streams the terrain is marked with a maze of meander scars, cutoffs, and abandoned sloughs. Some distance inland from the major streams the characteristic circular shape of abandoned stream meanders gives way to numerous irregularly-shaped lakes. General marsh or swamp conditions prevail throughout. Numerous channels make up the Yukon and the Porcupine rivers. It is difficult to trace the main channel of either and to locate the junction of tributary streams *(92, p. 229)*. The Chandalar River is the other major tributary to the Yukon which together with the Porcupine has contributed materially in creating the Yukon Flats. Mertie *(93, p. 95)* describes the junction of the Porcupine and Yukon rivers as a series of numerous channels which have created a maze of islands for 50 miles below Ft. Yukon Village. The eastern part of the Yukon Flats extends up the Porcupine almost to the mouth of the Coleen; also included are parts of the Black, Little Black, and Sheenjek rivers.

HODZANA HIGHLAND. The Hodzana Highland is one of the smaller physiographic provinces which are included in the Central Plateaus. This highland lies chiefly in the Yukon watershed and is bounded on the south by the Yukon Flats, on the north by the Endicott Mountains, and on the west by the Koyukuk Flats. Maddren *(94, p. 13)* describes the Hodzana Highland as an undulating upland area having even-topped ridges above which rise some rugged isolated mountain masses. The northern part *(Maddren 94, p. 13)* consists of a large basin or trough bounded by strong mountain slopes. The important streams in the Hodzana Highland are the Chandalar River in the east; the Hadweenzic River, the Orenzik

16212
15816

16217
13591

(a) Eastern part of the Brooks Range

(b) Glacially carved eastern part of the Brooks Range

(c) Western end of the Brooks Range, Cape Lisburne

(d) Brooks Range from the North, Sagavanirktok River

Fig. 1-4 TOPOGRAPHIC FEATURES OF THE BROOKS RANGE

10012
16347

12749
16393

(a) Yukon-Tanana Plateau, near Fairbanks

(b) Yukon-Tanana Plateau, near Circle

(c) Yukon Flats, near Beaver Creek

(d) Yukon Flats, lower Chandalar River

Fig. 1-5 TOPOGRAPHIC TYPES IN THE CENTRAL PLATEAUS

15893
10172

10425
16568

(a) Hodzana Highland, near Dall

(b) Tanana Valley, near Northway

(c) Tanana Valley, near Fairbanks

(d) Tanana Valley, near Nenana

Fig. 1-6 TOPOGRAPHIC TYPES IN PARTS OF THE CENTRAL PLATEAUS

River and the Hodzana River in the east-central part; and the Dall River in the south-central part. These streams join the Yukon River. Along the northwest part of the highland the streams flow into the Koyukuk River. Chief among these are the Mosquito River, the Jim River, the South Fork River, and the Kanuti River. Part a, of Figure 1-6 illustrates topography typical of part of the Hodzana Highland.

THE TANANA VALLEY. The Tanana Valley lies between the Yukon-Tanana Plateau on the north and the Alaska Range on the south. It extends from the Canadian border, where it is formed by the confluence of the Chisana and Nabesna rivers, to its confluence with the Yukon at the village of Tanana. Figure 1-6, parts b, c, and d and Figure 1-7, part a, illustrate topography of the Tanana Valley. The major tributaries to the Tanana enter from the south. Most of these are glacial streams which drain the north slopes of the Alaska Range *(90, p. 20)*. The most important streams entering the Tanana from the south are the Kantishna, Nenana, Hood, Delta, Gerstle, Johnson, Robertson, Chisana, and the Tok rivers. In contrast, very few streams enter the Tanana from the north. As mentioned previously, these are the Chatinika, Chena, Salcha, Goodpaster, and the Tolavana. Since all the larger tributaries of the Tanana are glacial streams, the Tanana is silt-laden along its entire flood plain.

The Tanana Valley is known by other names such as "Tanana Flats", "Tanana Lowlands", and "Tanana Basin". Good descriptions of this area are given by Brooks *(82. p. 83), (95)*, Capps *(96, p. 13)*, and Mertie *(90, p. 21)*. The area is of irregular width from north to south, its greatest width being 60 miles near Kantishna. The area has been formed by a vast alluvial valley-filling action. The lowland is dotted with numerous lakes, muskegs, and other basins. It is rather flat but slopes gently northward from the base of the foothills to the Tanana River. The Tanana Basin or Flats merges into the Kuskokwim Basin on the west.

The upper part of the Tanana Valley consists of a group of basins *(95, p. 450)* which is caused in part by the combination of valley-filling and pre-existing bedrock topography which has resulted in a series of constrictions in the valley. Like the Yukon Flats, the Tanana Flats in many places consists of many shallow channels, islands, bars, and levees which have been built by the river as it meanders tortuously over the valley floor.

PIEDMONT PLATEAU. The north and west slope of the Alaska Range, generally between the Toklat River and the West Fork Kuskokwim River, forms a rather high piedmont plateau. Figure 1-8, parts a and b illustrate topographic features in the Piedmont Plateau. The plateau extends from the Alaska Mountains to the flats formed by the Kuskokwim in the western portion and to the flats formed by the Kantishna in the eastern portion. Brooks *(97, p 46-47)* describes the plateau as having a remarkably even surface which slopes from the mountains to the timbered lowland of the Kuskokwim Basin. The Piedmont Plateau is crossed by such streams as the McKinley River, Birch Creek, the Swift River, the Tongona River, the South Fork Kuskokwim, the Middle Fork Kuskokwim, the West Fork Kuskokwim, the Stony River, and the headwaters of the Hoholitna.

KUSKOKWIM LOWLAND. Immediately northwest of the Piedmont Plateau and south of the highlands between the Yukon and Kuskokwim valleys is a broad basin which has a variety of names such as the Kuskokwim Lowlands, the Kuskokwim Flats, the Kuskokwim Valley, and the Kuskokwim Basin. See Figure 1-9. The area parallels the Alaska Range and is located generally between McGrath and Georgetown on the west and the Kantishna Basin on the east. Brooks *(97, p. 47)* describes the lowland as a broad, level-floored basin bounded by the Piedmont Plateau on the east and an unexplored highland on the west. The basin in the vicinity of McGrath is about 100 miles wide *(98, p. 28)*.

This lowland is deeply filled with outwash sediments largely from the glacial outwash of the north slopes of the Alaska Range. The general topography is extremely flat and broken only by an occasional rock monadnock rising above the valley floor. There are three major rock knobs between Minchumina and McGrath which create the appearance of older mountain masses. These are gradually being buried by outwash and valley-filling processes.

The basin is characterized by numerous lakes, muskegs, abandoned-stream meanders, and swampy areas. The major streams in this basin are, for the most part, tributaries to either the Kuskokwim or the Tanana. Those flowing generally northwest into the Kuskokwim from the mountain range are the West Fork Kuskokwim, Middle Fork Kuskokwim, South Fork Kuskokwim, Tonzana and the Swift rivers. Those flowing generally north into the Tanana watershed are the McKinley River, Birch Creek and the streams which make up the Kantishna River. Many of these do not appear to be named. Lake Minchumina is situated in the northern part of this basin and is drained by the Kantishna River *(82, p. 86)*. The divide between the Tanana and Kuskokwim watershed is approximately midway between the Swift River and the Birch Creek system. The northern part, near McGrath, occupies a basin formed by the Nixon Fork. This basin is flat, swampy, dotted with peat mounds, and is surrounded by the Kuskokwim Mountains. Other basins are also included in the Kuskokwim Basin. Some of these are *(98, p. 27-33)* Holitna Basin, Stony Basin, and George Basin. The Stony Basin is described by

Capps *(99, p. 21)* as: ". . . a broad area of low relief broken by groups of isolated hills".

KUSKOKWIM MOUNTAINS. The Kuskokwim Mountains form the more or less continuous chain of low-lying hills between the Yukon and the Kuskokwim rivers. See Figure 1-10. As nearly as can be determined, they include the area between the Aniak River and the Iditarod River on the west, and the Nowitna River on the east. Included in this province are such local mountains as Lookout Mountain, Camelback Mountain, Crater Mountain, Beaver Mountain, Cloudy Mountain, Barometer Mountain, and Von Frank Mountain. Many important streams rise in the Kuskokwim Mountains. These include the Takotna, Iditarod, Innoko, Dishna, Nixon Fork, Susulatna, Nowitna, Sulukna, and Titna rivers. The Zitziana River, Cosna Creek, and the Chitanana River rise in the low foot hills of the far eastern portion of this province.

In general, the mountains consist of sedimentary rocks which have been tilted and metamorphosed in places. In some instances local intrustions of igneous rocks occur. The sedimentary rocks and some of the partly metamorphosed rocks, when viewed from a distance, appear to form a plateau surface. Within the mountains the relatively soft shales weather to produce a sharply rounded topographic feature in which most of the hills show lineal arrangement due to the strong tilt. In general, the direction of this arrangement is northeast-southwest. This arrangement controls the major drainage and drainage divides. Mertie *(100, p. 122)* discusses the parallelism of the drainage of the region and says that it is controlled by the structure of the country rock. Where intrusions of igneous materials occur, the lineal arrangement is absent and the hills are more rugged. The mountains which flank the Nixon Fork are quite rugged and in places rise to 3,000 to 4,000 feet *(101, p. 100)*. Those in the Nowitna River area are of moderate altitude and have a rolling surface.

KOYUKUK PLATEAU. In general, the Koyukuk Plateau includes the area paralleling the Brooks Range, lying south of the Baird Mountains and the Endicott Mountains and north of the divide between the Yukon and Koyukuk rivers. The western part of the Plateau includes an area known as the Lockwood Hills. The best description of this plateau is given by Smith and Mertie *(87, p. 31)* who state that even though the area is a plateau there are relatively few upland areas which remain undissected. The plateau features are evident when seen from a distance.

KOYUKUK FLATS. The upper part of the Koyukuk Valley, which is located chiefly between the Endicott Mountains on the north, the Ray Mountains on the south, the Hodzana Highland on the east, and the Highlands west of the Koyukuk River on the west, is a broad lowland basin sometimes called the Koyukuk Flats. Parts c and d of Figure 1-11 illustrate the Koyukuk Flats. Maddren describes this flat area as follows *(94, p. 14)*: "The main river hugs the northwest side of the basin and leaves it through a comparatively narrow valley entrenched into a highland which forms its rim in this direction. This valley is comparable in a general way with that of the Yukon below the Yukon Flats, but differs in not being so deeply cut."

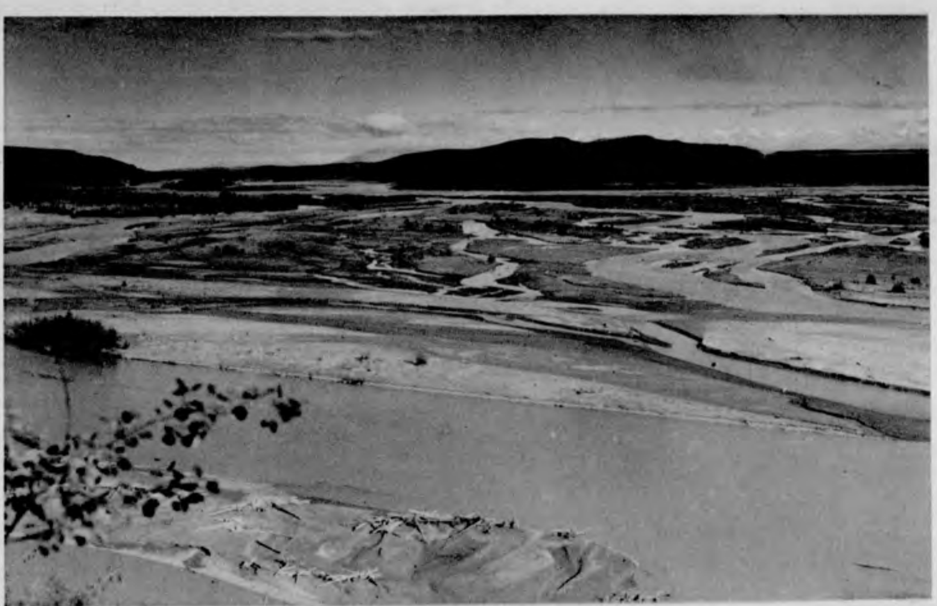
KOBUK-NOATAK-SELAWIK-DELTA. The southwestern part of the Brooks Range is drained largely by the Kobuk, Noatak, and Selawik rivers. These three rivers flow westward paralleling the axis of the range and empty into Hotham Inlet which is a part of Kotzebue Sound. Figure 1-12 illustrates the topography of parts of the Kobuk-Noatak-Selawik-Delta. Each of these rivers creates separate deltas which, when combined, form a very large delta region. Each delta is characterized by flat topography, with many lakes, swamps, cut-off meanders, and numerous channels. The Selawik Delta contains a large lake known as Selawik Lake which owes its origin to the building-out of the Kobuk Delta *(82, p. 96)*. Brooks describes the delta of the Kobuk by saying *(82, p. 98)* that it ". . . is traversed by a maze of intricate waterways, with numerous lakes and lagoons, is being rapidly extended seaward, and is constantly encroaching on the shallow waters of Hotham Inlet." The delta of the Noatak forms the northern shore of Hotham Inlet and appears to have much less areal extent than that of the Kobuk Delta *(82, p. 99)*.

THE LOWER YUKON BASIN. The lower Yukon Valley consists roughly of that portion of the Yukon River between the gorge at Rampart and the delta flats on the Bering Sea *(82, p. 79)*. This section of the Yukon Valley consists of a series of lowland basins. These basins are illustrated in Figure 1-13. The first of these is at the confluence of the Yukon and the Tanana where the Tanana Flats merge imperceptibly into the Yukon Valley. Some of the other large basins in the Yukon Valley are as follows: the junction of the Nowitna and the Yukon; the junction of the Koyukuk and the Yukon; and the basin formed by the Innoko-Iditarod system at its confluence with the Yukon. The extreme lower part of the Yukon constitutes a part of the Delta Flats.

DELTA FLATS. The largest delta in the Territory of Alaska is that formed by the combined Yukon-Kuskokwim system. The delta has a long and very irregular coastal line which extends from the southern part of Norton Sound to Kuskokwim Bay. Bethel, on the Kuskokwim, is the only town of any size in this flat area. The topography is monotonously flat over the major portion of the delta, however in the vicinity of Baird Inlet there is a series of highlands which rise above the alluvial delta

11973
20482

20167
20508



(a) Tanana Valley, near Richardson

(b) Tanana Valley, near Nenana

(c) Tanana Valley, near Big Delta

(d) Terrace, near Nenana

Fig. 1-7 TOPOGRAPHIC TYPES IN PARTS OF THE CENTRAL PLATEAU

16690
16737

16627
16793

(a) Piedmont Plateau, Farewell

(b) Piedmont Plateau, McKinley River Area

(c) Kuskokwim Basin, near McGrath

(d) Kuskokwim Basin, McGrath

Fig. 1-8 TOPOGRAPHIC TYPES OF THE PIEDMONT PLATEAU AND THE KUSKOKWIM LOWLAND

16799
16765

16815
16810

(a) Kuskokwim Lowland, near Medfra

(b) Kuskokwim Lowland, near Minchumina

(c) Nixon Fork Basin, near McGrath

(d) Kantishna Basin, Toklat-Kantishna Area

Fig. I-9 TOPOGRAPHIC TYPES IN THE KUSKOKWIM LOWLAND

20121
16779

20122
16784

(a) The Hoholitna Basin

(b) The Stony Basin

(c) The Kuskokwim Mountains

(d) The Kuskokwim Mountains

Fig. 1-10 TOPOGRAPHIC FEATURES OF PARTS OF THE CENTRAL PLATEAUS

15641
10905

10903
10906

(a) The Koyukuk Plateau, west of Shungnak

(b) The Koyukuk Plateau

(c) The Koyukuk Flats

(d) The Koyukuk Flats

Fig. I-11 TOPOGRAPHIC FEATURES OF PARTS OF THE CENTRAL PLATEAUS

15668
15683

15667
15705

(a) Kobuk Delta

(b) Kobuk Delta

(c) Noatak Delta

(d) Noatak Delta

Fig. 1-12 TOPOGRAPHIC FORMS TYPICAL OF THE DELTA FORMED BY THE KOBUK AND NOATAK RIVERS

16887
17142

16939
17135

(a) Yukon Basin, near Galena

(b) Yukon Basin, near Nulato

(c) Innoko Flats

(d) Yukon Basin, near Tanana

Fig. I-13 TOPOGRAPHIC FEATURES IN THE LOWER YUKON BASIN surface. Figure 1-14 illustrates the topography of the Yukon-Kuskokwim Delta. Those highlands to the north of Baird Inlet consists of a series of rocky volcanic cones and craters many of which are being buried by delta action.

The extreme breadth of the delta flats is about 200 miles *(82, p. 81)*. It is a flat just slightly above sea elevation and drained by sluggish streams. At low tide the mud flats extend many miles out to sea.

KAIYUH HILLS. One of the smaller and less important physiographic units of the Central Plateaus, known as the Kaiyuh Hills, is an isolated group of hills in west-central Alaska generally between the Yukon and Kuskokwim Rivers, and between Nulato and Ruby. The following description of this province is from the writings of Mertie *(102, p. 147)*. He describes the Kaiyuh Hills as being about 75 miles long, about 15 miles wide and surrounded sharply by alluvial flats on all sides. The Kaiyuh Hills are separated from the hills to the north by a great swampy lowland which is about 30 miles wide. The wide valley of the Yukon River separates the Kaiyuh Hills and the Ruby District. The Kaiyuh Hills to the south end abruptly at a valley occupied by a fork of the Mud River which is a tributary of the Innoko.

SEWARD PENINSULA. One of the largest single physiographic units in the Central Plateau is the group of smaller provinces which collectively make up the Seward Peninsula. (See Figure 1-15.) The total area is approximately 20,000 square miles *(103, p. 41)*. The Seward Peninsula is situated in far western Alaska and extends outward from the mainland, lying chiefly between 64°30'N. latitude and 66°30' N. latitude. It is bounded by Kotzebue Sound and the Arctic Ocean on the north, Norton Sound on the south, and the Bering Sea on the southwest. The peninsula is drained by the following rivers: the Buckland, Kiwalik, and Koyuk in the far east; the Goodhope and Inmachuk in the north central part; the Serpentine, Nuluk and Pinguk rivers in the northwest; the Sinuk, Snake, Nome, Eldorado, Fish, and Kwiniuk rivers in the south; and the Noxapaga, Kougarok, and Kuzitrin system in the interior. Most of the rivers flowing into the ocean empty into large basins or lagoons and form delta flats.

Politically, the Seward Peninsula is divided into several precincts. Most of the information pertinent to the natural features is contained in geological reports of various precinct areas. The precincts are as follows *(104, p. 11)*: Goodhope, Pt. Clarence, Cape Nome, Kugruk, Fairhaven, Council, and Koyuk.

As to physiography, the peninsula is divided into a series including mountains, highlands, plateaus, coastal plains, and interior basins and valleys. Brooks *(82, p. 37)* states that the peninsula falls into the Plateau Province even though plateau features are not strongly emphazised. Topographic types include rounded hills and ridges 800 to 2,000 feet high which are broken by broad valleys, basins, and some mountain masses.

The Seward Peninsula contains four major physiographic types, including uplands, lowlands, mountains and terraces *(103, p. 44)*. The lowlands embrace three types. These are the coastal plains, which nearly everywhere border the shore; the extensive basin lowlands, which are nearly surrounded by uplands and drained through relatively narrow valleys; and the inland valleys, which are characteristically flat floored and have a generally sloping wall. The mountainous part of the peninsula consists of a range which has been divided into the Kigluaik, Bendeleben, York, and Darby mountains. These mountains are rugged and have sharply cut valleys which include many glacial features. The highest peaks as reported by Collier, Hess and others *(103, p. 45)* reach an altitude of about 5,000 feet in the Kigluaik Mountains, 3,700 feet in the Bendeleben Mountains, and 2,500 feet in the Darby Mountains. The Kigluaik and Bendeleben mountains are separated from the upland plateaus of the north by a series of lowlands, the largest of which is the Kuzitrin Basin.

The southern part of the peninsula, between Norton Sound and the mountains, can be divided into three physiographic units, including mountains, uplands, and coastal plain. The mountains are rugged and join the upland abruptly at an elevation of about 2,500 feet *(103, p. 146)*. The uplands stretch toward the coast with a constantly decreasing altitude and merge into the Coastal Plain. The Coastal Plain as described by Collier and Hess *(103, p. 146)* is broken by a series of benches or beach terraces. Smith *(105, p. 31-32)* describes the Seward Peninsula Coastal Plain as being very flat with a gentle rise of about 100 feet to the mile from the ocean inward. There are many off shore bars, spits, and reefs which inclose lagoons along the coast line. At one location, the outer part of the York Mountains is a series of high limestone terraces or benches (Port Clarence Limestone) which have been cut by wave action *(106, p. 35)*.

The physiographic divisions in the remainder of Seward Peninsula are divided into individual units as follows *(107, p. 34-44)*: the Nuluk Plateau, the Kugruk Plateau, the York Plateau, the Lowland Plains, and the Valley Lowlands. Rather than being distinct physiographic units, the three plateau surfaces are remnants of the base level of erosion of three distinct periods in geologic history. They are used as keys to date events of the geological past. The most recent of these is the base level represented by the coastal plain of the peninsula *(103, p. 47-48)*.

The Nuluk Plateau represents the highest topographic surface in the northwestern part of the peninsula. The Nuluk Plateau roughly includes the highlands of the Nuluk River along the coast north of the York Mountains. Collier says that the Kugruk Plateau forms a surface which extends roughly from the Midnight Mountain area westward to Cape Wales, and that it is characterized by deeply cut canyons which are somewhat rounded and terraced. The southern part slopes toward the Kuzitrin Basin. Moffit *(104, p. 43)*, in his description of the Fairhaven Gold Precinct, bounds the Kugruk Plateau on the east by the Buckland River. He further states that the upland surface of the plain slopes gently to the north, and that it is interrupted by broad, flat valleys occupied by major streams. Hence, the Kugruk Plateau includes the watersheds of the Buckland, the Kiwalik, the Goodhope, the Inmachuk, and the Kugruk rivers. The Buckland River, in the far eastern part of the peninsula, has built up a large delta at its mouth in Eschscholtz Bay. The Buckland River meanders considerably not only in the delta but in the mid-part of its long valley. As is typical of all deltas in this region, the delta is very low in relief and contains numerous marshes, lakes and other delta expressions. In places, it merges imperceptibly into the delta formed by the Kiwalik River on the west. Inland, these two rivers are separated by a highland consisting chiefly of lava flows. Figure 1-16 illustrates some of the deltas of the Seward Peninsula rivers.

The Kiwalik River, in its headwaters and middle portion, contains a broad inland basin which is also flat and swampy. The Kiwalik Delta roughly extends from the vicinity of Candle northwest to Eschscholtz Bay. The Kugruk River rises in the lava-flow area in the interior of the peninsula, near Imuruk Lake. It empties into Kotzebue Sound and, together with the mouth of the Inmachuk, forms a delta in the vicinity of Deering. The Goodhope River rises in the northeastern part of the vast lava flow in the interior of the peninsula. Its main headwaters are the Right Fork and the Cottonwood. They are deeply incised into the basaltic lava plateau. The outward portion of the Goodhope has also built up delta features.

The York Plateau is essentially a high-bench region partially surrounding the York Mountains *(107, p. 36-39)*. This plateau surface, or bench surface, is said to vary in width up to fifteen miles and consists mostly of rock. The Lowland Plains, as described by Collier, consists mostly of coastal-plain sediments surrounding the interior highland mass. The coastal plain of this region borders the Arctic Ocean and extends from Cape Wales to Cape Espenberg. The coastal plain varies in width from about five miles near Wales to about 30 miles at Shishmaref. A similar but smaller coastal plain partly surrounds the Port Clarence area. The rivers and streams flowing across the coastal plain are deeply entrenched in the coastal materials.

The Valley Lowlands, as described by Collier *(107, p. 40)*, consist of a series of low-lying plains which surround the Imuruk Basin and extend inland to include basins of the Agiapuk and Kuzitrin rivers. The Imuruk Basin is characterized by a series of flat-topped plains or table lands which appear to be correlated with the coastal-plain sediments along the coast outside of Imuruk Basin. The drainage from the interior of the peninsula finds its way to Bering Sea at Grantly Harbor through the Tusksuk Channel situated at the western end of Imuruk Lake. The Kuzitrin Flats include the flat-basin topography formed by the Kuzitrin River and its principal tributaries, the Noxapaga and the Kougarok. The Kuzitrin Flats are characterized by numerous meandering channels, abandoned cut-off lakes, extensive marshes, muskegs, and otherwise swampy areas. A series of small mounds dot the basin topography. Collier *(107, p. 41-42)* states that the small isolated buttes are composed of gravel and are remnants of the same high plain that is shown in the benches which are situated on the western, northern and eastern side of the lowland.

The Pacific Mountain System

The Pacific Mountain System consists of a broad belt of high mountain ranges that follow the general contour of the coast, from the "Panhandle" in southeastern Alaska to the Aleutian Islands in southwestern Alaska. The Pacific Mountain system contains several important mountain groups which, in some instances, have been subdivided further into various mountain units. It is a continuation of the Coast Range farther south. The most important mountain groups are the Coastal Range, the St. Elias Range, the Chugach Mountains, the Wrangell Mountains, the Alaska Range, the Talkeetna Mountains, the Chigmit Mountains, the Kenai Mountains, and the mountains which make up the Aleutian Range. The loftiest peaks of the continent are situated in the Pacific Mountain System. As a matter of interest there are eleven peaks in Alaska which are higher than Mt. Whitney, the highest (14,501 ft.) in the United States *(85, p. 190)*. These eleven peaks include McKinley, the highest with an elevation of 20,300 feet, St. Elias, Foraker, Bona, Sandford, Blackburn, Vancouver, Fairweather, Hunter, Hubbard, and Bear. Some of the mountains in the Pacific Mountain System are shown in Figures 1-17 and 1-18.

The geographic position of these mountain ranges with respect to the warm ocean currents and prevailing winds, provides this region with a heavy snowfall which results in numerous mountain glaciers throughout the province. See Figures 1-19 and 1-20. Everywhere the topography shows the results of glacial activity, either by the presence of existing glaciers or by evidence of glacial activity, such as

12275
12283

12285
21766

(a) Yukon delta flats

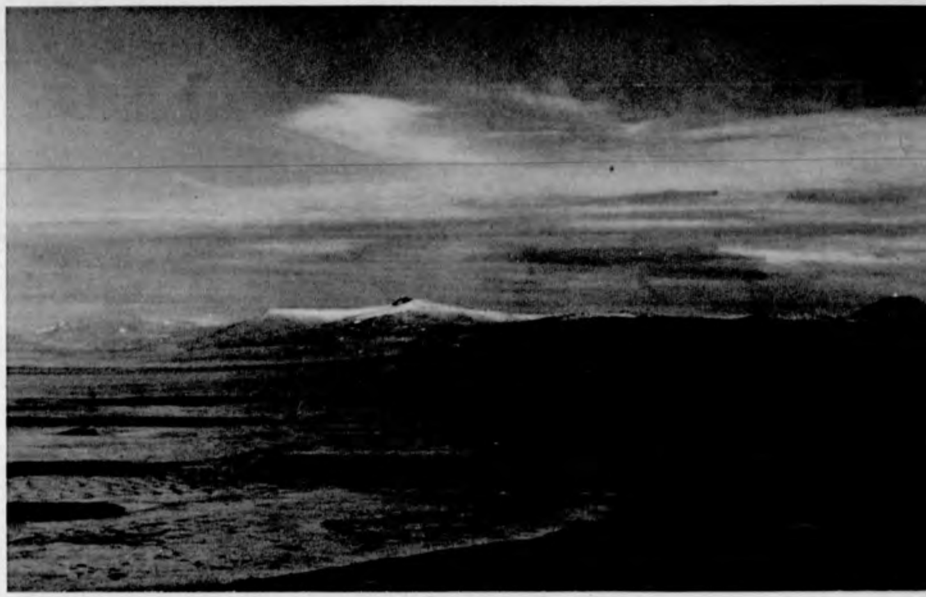
(b) Kuskokwim delta flats, west of Bethel

(c) Lakes in the delta flats

(d) Outer Kuskokwim delta

Fig. 1-14 TOPOGRAPHIC FEATURES OF THE YUKON-KUSKOKWIM DELTA

(a) Kigluaik Mountains



(b) Interior basin, Kuzitrin Valley

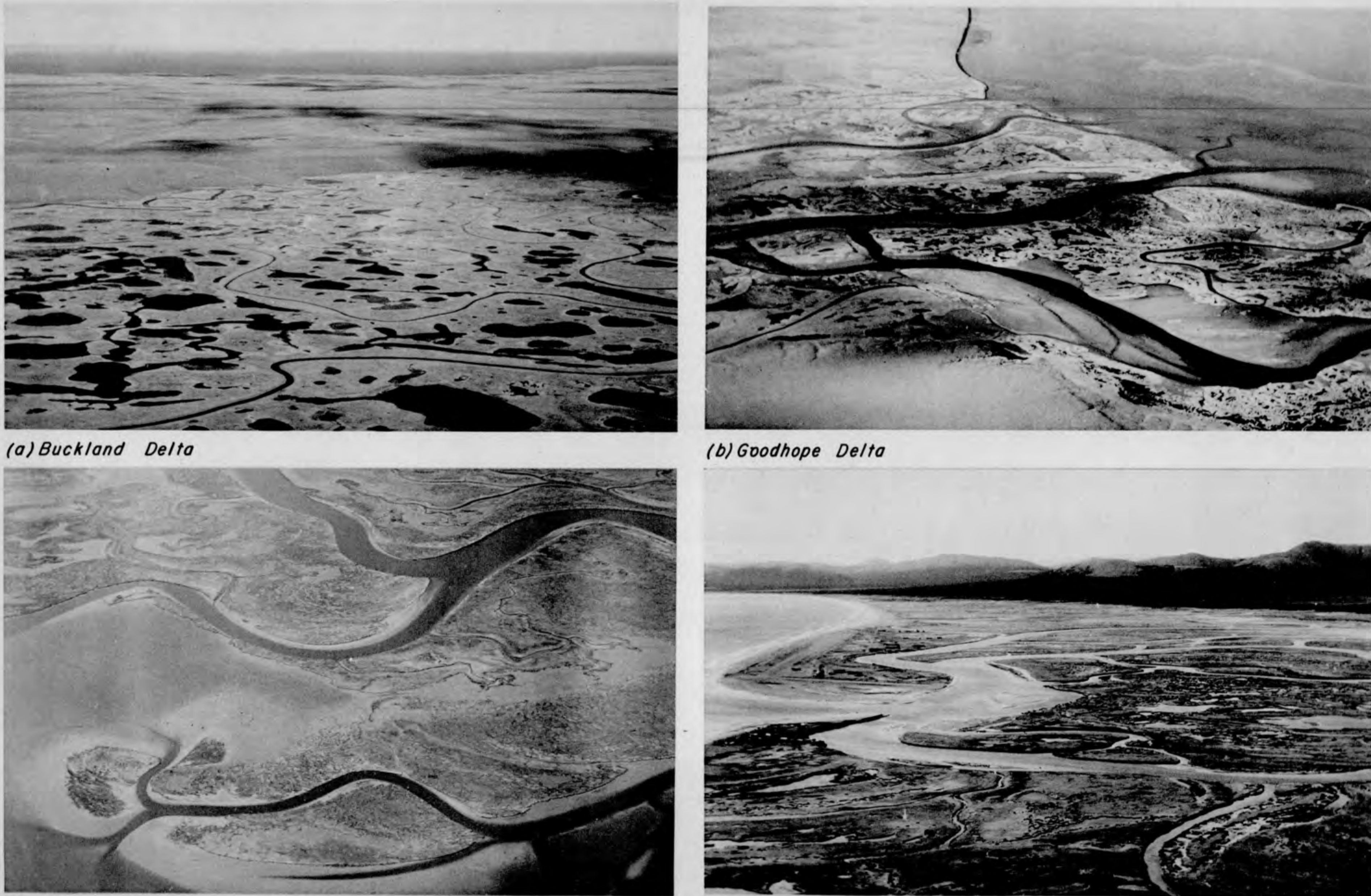
(c) Bering Sea Coastal Plain

(d) Interior highlands

Fig. 1-15 PHYSIOGRAPHIC TYPES OF THE SEWARD PENINSULA

17066
15548

10866
17030



(a) Buckland Delta

(b) Goodhope Delta

(c) Koyuk Delta

(d) Kowiniuk Delta, Moses Point

Fig. 1-16 DELTAS OF THE SEWARD PENINSULA

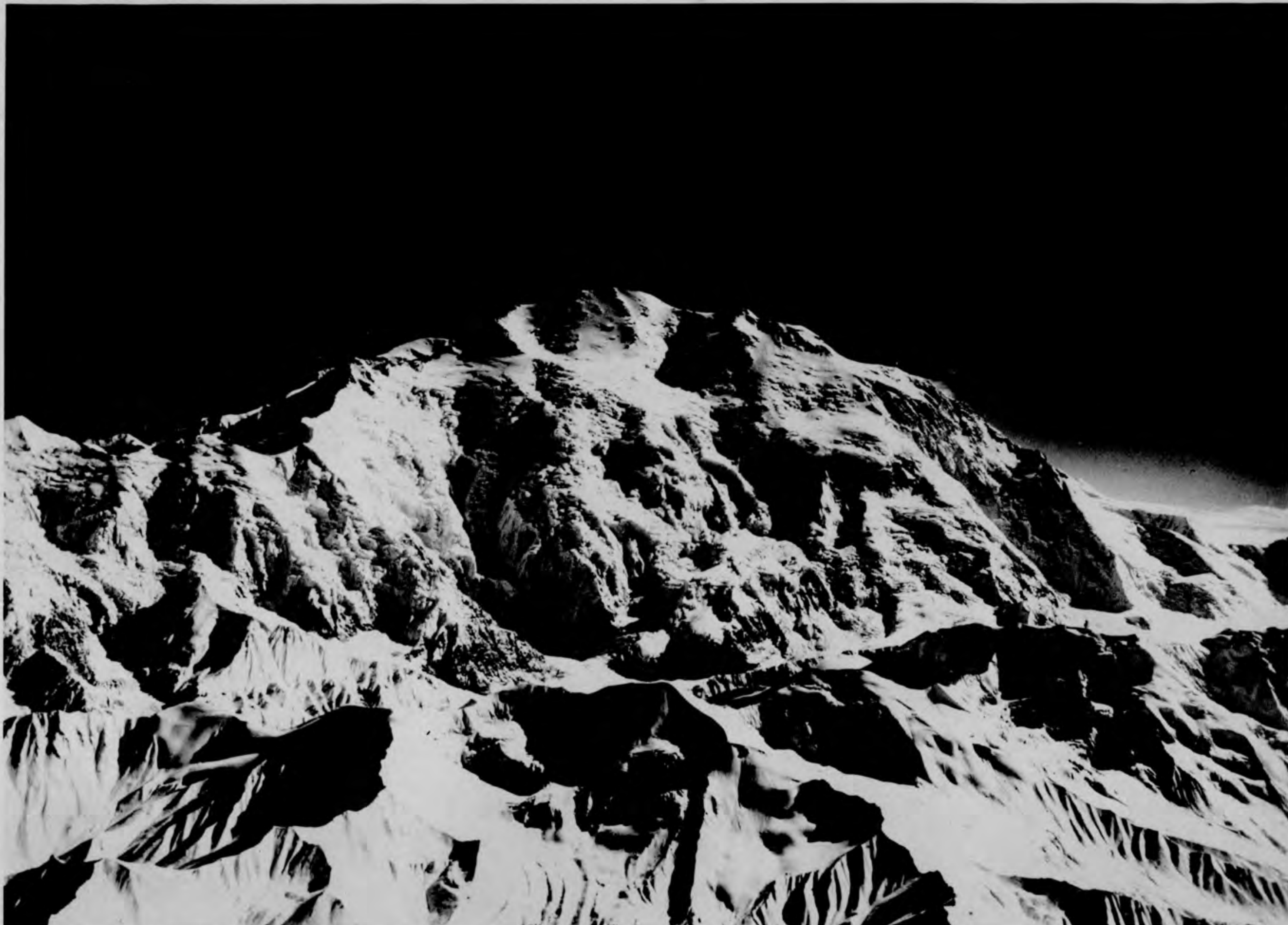


Fig. 1-17 MT. McKINLEY, THE HIGHEST PEAK ON THE CONTINENT (20,300 FT.)

12053
17333

16698
16649

(a) The Chugach Mountains, near Sheep Mountain

(b) The Alaska Range, near Farewell

(c) The Alaska Range

(d) The Alaska Range

Fig. 1-18 THE PACIFIC MOUNTAIN SYSTEM

17430
17293

17427
17301

(a) Black Glacier

(b) Glacier near Mt. Hayes

(c) Glacier in the Skweetna Valley

(d) Ruth Glacier

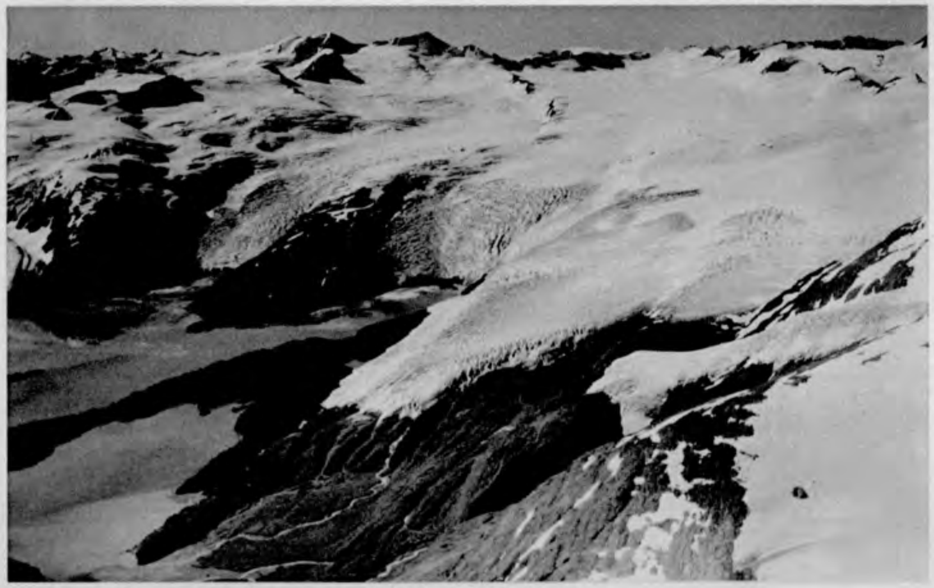
Fig. I-19 GLACIERS IN THE ALASKA RANGE

17386
20601

17406
20604

(a) Between Portage and Whittier

(b) Columbia Glacier



(c) Harding Ice Cap

(d) Kenai Peninsula

Fig. 1-20 GLACIERS ALONG THE ALASKA COAST cirques or glacial markings, glacial deposits, and other related features.

Many of these glaciers empty directly into the Gulf of Alaska and are responsible for the present-day coast line which is made up of numerous islands, inlets, and fiords. Brooks *(82, p. 18)* describes this southeastern coast as one of great irregularity consisting of deep embayments which penetrate the mainland, and many islands which are separated by a network of rocky straits. The coastal shelf is narrow and the sea bottom descends very rapidly to great depths; the land rises steeply from tide water.

COAST RANGE. The Coast Range between the State of Washington and the Alaskan border (141st. Meridian), follows the Alaska coast for about 900 miles. It is partly in the Territory and partly in British Columbia. It passes inland behind the St. Elias Range some distance north of Juneau where it merges into the Central Plateau. It varies in width from 50 to 100 miles *(82, p. 28)*.

ST. ELIAS RANGE. The St. Elias Range extends roughly from Glacier Bay northwest and west to the tip of the Kenai Peninsula. It includes such mountain groups as the Chugach Mountains, the Wrangell Mountains, the St. Elias Mountains, the Skolai Mountains, part of the Nutzotin Mountains, and the Kenai Mountains. The St. Elias Range is a rugged mountain mass *(82, p. 32)* which parallels the Pacific Coast from Cross Sound as far as the entrance to Cook Inlet. Some believe that the Chugach and the Kenai Mountains are of one mountain group *(108, p. 24)*.

THE ALEUTIAN RANGE. The Aleutian Range is the far-west extension of the coastal groups of the Pacific Mountain System. This range extends in a broad, sweeping arc from the mainland generally westward for about 900 miles from the mainland as a series of islands. The mainland portion is known as the Alaska Peninsula. The Aleutian Range of the mainland is about 80 miles wide near latitude 58° *(82 p. 33)*. Its relief is due, for the most part, to volcanic activity; it is made up of a series of volcanic peaks distributed at irregular intervals along the Alaska Peninsula and the Aleutian chain.

THE ALASKA RANGE. The Alaska Range is the northernmost group in the Pacific Mountain System and forms a great sweeping arc from Lake Clark to the Canadian border. It also forms the watershed divide between the Pacific Ocean and the Bering Sea. The northern border of this range rises abruptly out of the various inland basins which form the central part of the plateau. These low basins are the Tanana Valley and the Tanana Flats on the north and northeast, and the Kuskokwim Basin on the northwest. The average width of this mountain group is 50 to 60 miles. The mountain mass is exceedingly rugged; the topography is chiefly the result of uplift an subsequent alpine glaciation. Present day glaciation is more extensive on the southern than on the northern slopes. The Alaska Range is bounded on the south by Cook Inlet, the Susitna-Talkeetna Basin, the Cooper Basin, and the Mentasta Basin. A group of mountains, known as the Talkeetna Mountains, lies between the Alaska Range and the Chugach Mountains and belongs to neither system *(82, p. 30)*. The eastern end of the Alaska Range merges into the Nutzotin Mountains which are a part of the St. Elias Range. Capps *(108, p. 25)* describes the Talkeetna Mountains as consisting of "sawtoothed ridges and peaks".

THE SUSITNA BASIN. The Susitna Basin is the broad depression or basin formed by valleys of the Matanuska, Susitna, Yentna, and Skwentna rivers. Figure 1-22, part a and b, shows a variety of topographic features in the Susitna Basin. The Susitna Basin is bounded on the west by the Alaska Range and on the east by the Talkeetna and Chugach Mountains. The main river of the area is the Susitna. It has built a large delta extending outward into Cook Inlet *(97, p. 44)*. The topography of the Susitna Basin is flat, but is broken in places by high hills which create the appearance of mountains being buried by alluvial filling. Beluga Mountain and Susitna Mountain are examples of these hills. The basin is deeply filled with glacial sediments which were carried and deposited as outwash materials from the glaciers in the Alaska Range. The lower part of this region is marshy and is dotted with numerous lakes. In the upper part, the topography is more rolling and contains some glacial morainic features such as eskers, kames and various types of moraines *(109, p. 106)*. The basin extends around Knik Arm and includes at least 20 miles of the Matanuska Valley *(97, p. 44)*. In the lower Matanuska Valley, near Palmer, the topography is rolling as a result of the morainic deposits left by past glaciers. The glacier which was responsible for the present day topographic situation and the deposition of materials now in the Susitna Basin was believed to have filled the upper basin of Cook Inlet. It may have extended as far as the mouth of the Inlet *(99, p. 77)*.

THE COOK INLET LITTORAL. The southern extension of the Susitna Basin has been called by Brooks the Cook Inlet Littoral *(97, p. 43)*. This is the coastal region which lies on the east and west sides of Cook Inlet. This region is bounded on the west by the Chigmit Mountains and on the east by the Kenai Mountains which form the backbone of the Kenai Peninsula.

Bennett *(110, p. 32)* describes the western part of the Kenai Peninsula as being a vast lowland plain, composed of flats, low ridges, hillocks, and muskegs dotted with small lakes. He describes the shore along Cook Inlet as being precipitous with bluffs rising from 40 to 300 feet above the gravel beach. In some places there are low benches along the beach which are not more than 10 to 20 feet above high tide. The shore line of the western side of the inlet consists of long, sweeping curves with few conspicuous embayments or points. It is vastly different from the shore line on the southern and eastern sides of the inlet. The latter shore line is rugged, and has numerous bays or fiords. Physiographically the Kenai Lowland belongs with the other bench land areas which border the Inlet and extend up the major valleys *(110, p. 65)*. It consists of glacial materials which have been left in the form of terraces, benches, eskers, kames, outwash, and ground moraine.

THE COPPER BASIN. One of the major interior provinces in the Pacific Mountain System is the Copper Basin. It is bounded on the north by the Alaska Range, on the east by the Wrangell Mountains, on the south by the Chugach Mountains, and on the west by the Talkeetna Mountains. Figure 1-22 illustrates topography in the Copper Basin. The principal stream in this area is the Copper River; its major tributaries are the Gulkana, Gakona, Chistochena, and the Chitina rivers. Brooks *(82, p. 54)* says the basin floor has a monotonous lack of relief which in places is varied with hills and small groups of mountains. It contains many lakes. Mendenhall *(111, p. 19)*, who was probably the first to describe it, says that it is a crescent shaped swampy plain which in the spring is a water soaked morass. It is timbered below 3,500 feet.

COPPER-SUSITNA LOWLAND. The Copper-Susitna Lowland is a basin lying principally in the area between the Talkeetna Mountains and the Alaska Range. It is an extensive, broad gravel-filled depression which includes some of the Copper Basin and some of the Susitna Basin *(112, p. 48)*. It has an elevation of about 2,500 feet. The divide between the Susitna and Copper rivers is contained in the area; there is no topographic break in the watershed divide in this basin. Chapin *(112, p. 48)* says that he believes that the topographic continuity indicates that the one master stream which at one time drained the Copper Basin once flowed through this basin.

GEOLOGY

In addition to physiography one of the most important natural studies related to permafrost and engineering problems is geology. Although not foremost in importance in being directly related to permafrost, an understanding of the geological concept of an area, particularly the physical geology, will aid materially in knowing what to expect in an area as far as construction materials are concerned.

Geology is a study of the earth's history as interpreted from the rocks. The sequence of events which occur in the physical development of an area from the time of the original deposition of a formation to the present can be determined from detailed study of the rocks and of the existing land forms which the earth materials have. The existing land forms and topographic expressions are the result of a combination of influencing factors, the most important of which are the type of material from which a land mass is made, climatic influence, and erosional aspects.

The first step in deciphering the natural history of a region is necessarily the grouping of the materials or the rock masses into classes related to the original method of occurrence. Important groupings which the geologists use for this basic arrangements include: materials formed in place, those transported by water activity, those transported by wind, and those transported by ice. Of these four types, the first is of utmost importance to the geologist since proper identification of rocks, their lithological characteristics, physical features, and their topographic situation with respect to the surrounding area help to establish their relative age. The last three items refer to agents of transportation and removal of the detritus from the original rocks. The geologist has divided the rock materials into igneous, sedimentary, and metamorphic as the types. Through agents of decomposition, disintegration, crustal movements, and transportation, these rock materials are constantly being destroyed, giving way to various topographical expressions or physical features.

Physical and historical geology is defined by Schuchert and Dunbar *(113, p. 1)* as follows: "The first deals with the physical characters of the Earth and with the processes that operate to mold and change these features; the second attempts to follow in chronologic order the important changes through which the Earth has passed since its origin as a planet—not merely the changes in its physical features, but also the orderly appearance and evolution of life upon its surface".

The geology of Alaska is complex. The area of the Territory is large and the absence of a well-developed, ground transportation system has seriously hindered complete geologic mapping. Much of the area is inaccessible. Considerable mapping must be done by making detailed, painstaking, and time consuming expeditions on foot. The difficulties of mapping in the summer caused chiefly by the ever-present swamp or marshy conditions together with a short working season makes ground reconnaissance time consuming and costly. The severe winter temperatures, together with difficulties of supply, necessarily confine natural exploration to summer periods. The ever increasing use of the Alaskan bush pilot and his "knack" for gravel-bar landings and

17285
17378

17288
17278

(a) The Susitna River, near the Yentna River

(b) Glacial topography, upper Skwentna Valley

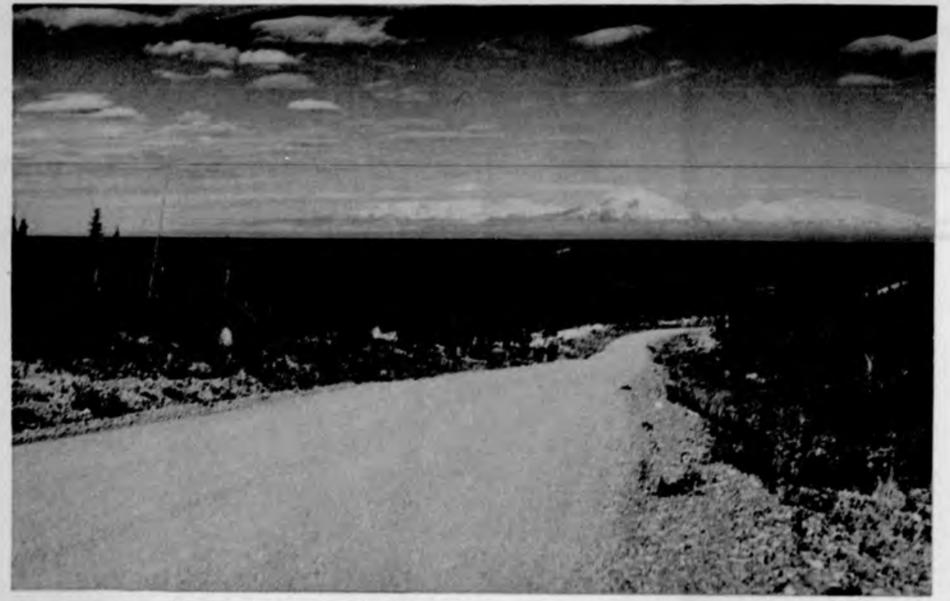
(c) Tidal flats, near Anchorage

(d) Delta and tidal flats of the Susitna River

Fig. 1-21 TOPOGRAPHIC FEATURES OF THE SUSITNA BASIN

17199
17524

17465
17780



(a) Copper Basin, near Gulkana

(b) Copper River, near the Sandford River

(c) Topography near Chistochina

(d) Copper Basin near Sourdough

Fig. I-22 TOPOGRAPHIC TYPES IN THE COPPER BASIN float use on small lakes or streams has greatly accelerated the mapping program by various agencies in the Territory. The use of weasels, helicopters, and "cat" equipment affords often the only feasible means of getting in and out of isolated or inaccessible areas.

Prior to the war, the basic geology of Alaska had been worked out by well-planned and well-organized overland expeditions. The agency directly responsible for the geologic mapping of the Territory is the United States Geological Survey, which agency has been actively engaged in the project for some 50 years. The findings of the Survey are made available to the general public in the form of bulletins, pamphlets, professional papers, and other miscellaneous types of publications. The earlier surveys of the Geological Survey were directed toward detail mapping and assembling facts and data in and about areas of mineral wealth. From time to time, reconnaissance surveys of a more general nature were made covering larger areas, so that the more general geologic aspects of the Territory could be understood better. In 1903 Alfred H. Brooks *(82)* compiled all of the available and existing geological information about the Territory into one publication.

In 1939, Philip S. Smith *(114)* brought the geology of Alaska up to date and compiled existing data into one publication which represented the overall views of the Survey on Alaskan geology at that time. In addition to the description of the general geology of the Territory, Smith presents a fairly complete listing of Geological Survey publications on Alaska. His report starts with a description of the oldest geologic rocks. Each succeeding age of rocks is discussed, those of the present day being discussed last. He describes the type and areal distribution of the rocks of each particular age and in doing so systematically covers the territory, starting, as he states, *(114, p. 3)* ". . . in the southeastern part of the Territory and proceeding in a generally orderly fashion to the extreme northwestern part."

For the purpose of this discussion of the geology of the Teritory of Alaska, the writings of Smith have been summarized and are briefly reviewed. It is believed that for the purpose of this review the data presented by Smith are the most complete and are the most easily understood. For greater detail those who are interested sufficiently are referred to reports on various areas as listed by Smith *(114)*, or as listed in the various bibliographies published by the United States Geological Survey.

Pre-Paleozoic Rocks *(114, p. 7-10)*

The oldest rocks of Alaska, Birch Creek schist, are highly metamorphosed from rocks of sedimentary origin which include quartzite schist, quartz mica schist and mica schist. The rocks have been subjected to mountain-building processes and have been intruded by igneous materials of many subsequent ages. Geologically, the area is complex, and the rocks do not exhibit any recognizable features of the original structure. Birch Creek schist occurs predominantly in the Yukon-Tanana Plateau. They also occur fairly widespread in the Seward Peninsula.

Paleozoic Rocks *(114, p. 10-34)*

All of the systems of the Paleozoic are represented in the Territory.

CAMBRIAN SYSTEM. It is believed that Cambrian rocks do not now form extensive surface rocks within the Territory. Rocks of the Cambrian system are present only in the extreme eastern part of the Territory in the area adjacent to the International border north of the Yukon River. They have been deformed and fractured by earth movement but on the whole have not been appreciably metamorphosed.

ORDOVICIAN SYSTEM *(114, p. 12-15)*. Rocks of the Ordovician System are widely represented in Alaska and occur in southeastern Alaska, the Yukon Region, the Kuskokwim Region, and in the Seward Peninsula. Ordovician rocks of Alaska generally consist of graywacke beds, slate, some volcanic rock, conglomerate, grit, limestone, black chert and quartzite. The most extensive areas of Ordovician rocks in Alaska occur in the Seward Peninsula (Port Clarence limestone) where there is an area with more than 2,000 square miles of Ordovician rocks exposed at the surface.

SILURIAN SYSTEM *(114, p. 15-18)*. Rocks of the Silurian System occur in southeastern Alaska, the Yukon Region, northern Alaska, and the Seward Peninsula. Silurian rocks of Alaska include four lithologic types which are: (1) indurated graywacke and black slate with a small amount of conglomerate and limey beds; (2) andesite and andesite porphyry lava flows, conglomerate, and some associated graywacke, tuff, breccia, and limestone; (3) thick-bedded dense limestone in which are intercalated locally thick beds of conglomerate, thin-layered limestone, nodular shaly argillaceous limestone, and sandstone (also included with this member are sandstone, shale and some other limestone); and (4) the uppermost member of the Silurian sequence (in southeastern Alaska) which consists of green-gray graywacke with sparse conglomerate beds interbedded with red, gray-green, and gray graywacke-like sandstones, and small amounts of shale.

DEVONIAN SYSTEM *(114, p. 18-25)*. Deposits formed during Devonian time have been found in all major regions except in the southcentral part of the Territory. In southeastern Alaska, the Devonian is represented by predominantly basic volcanic rocks, graywacke, tuffaceous sedimentary rocks, black slate, conglomerate, andesitic lava (in part with pillow structure), breccia, tuff, and local rhyolite lava. The upper Devonian beds consist of basalt, andesitic tuff, limestones, sandstone, slate, and conglomerate.

Devonian rocks occur in the Yukon River Area between the Tanana River and the International border in the vicinity of Hot Springs, Rampart, Tolovana, Preacher, Circle, Eagle, and Fortymile. Devonian rocks, consisting of blue to white limestone in a rather complex structure, occur along the northern flanks of the Alaska Range in the Kantishna-Kuskokwim-Nenana area. Devonian rocks which are closely folded and stand at high angles also occur in the Nenana Canyon. A large area of Devonian rocks consisting of thin-bedded limestones, interbedded with various types of shales occur in the Kuskokwim region near McGrath. In northern Alaska, Devonian rocks occur near Cape Lisburne and in the Canning River region. In the Lisburne district, the Devonian rocks are calcareous sandstones and calcareous slates, and they form sea cliffs for about 15 miles along the coast. The Devonian rocks in the Canning River region consist of black shale, and some sandstone.

CARBONIFEROUS SYSTEM *(114, p. 25-34)*. The Carboniferous System consists of three principal epochs namely: Permian (youngest), Pennsylvanian, and Mississippian (oldest). Of the three rock types, those of the Mississippian age are believed to be the most widespread in Alaska. In southeastern Alaska the Mississippian rocks include thin conglomerate beds; calcareous arkose, highly fossiliferous crystalline limestone; black, thin-layered chert; interbedded dense gray quartzite and cherty limestone with sparse sandstone, conglomerate, and limestone; and massive white limestone.

In the Copper River region the rocks of Mississippian and Permian ages are considerably folded and faulted, and many of the rocks have been altered into schists. The rocks include slate, altered limestone, tuffaceous beds, and basalt flows; while the younger rocks include lava flows, tuffs and volcanic breccia, shale, limestone, limey shale, sandstone, and conglomerate.

Carboniferous rocks in the Yukon-Tanana Plateau are known as the Rampart group and consist of an assemblage of sedimentary rocks and interbedded lava flows which are strongly folded, faulted, and brecciated. The limestone beds are overlain by the Calico Bluff formation, which consists of alternating beds of limestone and shale with some slate. Others in the same general area include the Nation River formation which consists of a thick sequence of clay shale, sandstone, and conglomerate (bituminous coal occurs). The beds are closely folded and are broken by faults.

In northern Alaska, carboniferous rocks have been found in the Brooks Range from the head of the John River westward to the Kivalina River; the western part of the Lisburne District; and the central and eastern part of the Canning District. Carboniferous rocks of the western part of the Brooks Range consist of rather massive sandstones and shales (Noatak formation) and limestones (Lisburne limestone). All of the units of the Noatak formation have been uplifted and faulted so that they are now greatly deformed. The Lisburne limestone, at Cape Lisburne, which is located a short distance north of Pt. Hope forms a prominent land mark with white cliffs rising more than a thousand feet above the sea level. Similar features occur at Cape Thompson and Cape Seppings.

In the Kuskokwim area, Carboniferous rocks have been found only near the mouth of the Aniak River and in Goodnews Bay. It is also believed that Carboniferous rocks occur on the north flank of the Alaska Range; in an area north of McGrath; in the highlands of the Georgetown district (the Lime Hills areas); and in the western headwaters of the Aniak River rise. The limestone of Goodnews Bay contains some red and black slates and nodular chert, all of which are overlain by argillite, sandstone, and graywacke.

Mesozoic Rocks *(114, p. 34-58)*

Mesozoic rocks are divided into the following systems: Triassic, Jurassic and Cretaceous and of these three systems, deposits belonging to the Jurassic and Cretaceous are widely distributed in the Territory. A very complete report on the Mesozoic stratigraphy of Alaska has been prepared by the U. S. Geological Survey. This volume presents detail of the Mesozoic Era and its formations *(115)*.

TRIASSIC SYSTEM *(114, p. 34-40)*. Triassic rocks occur in southeastern Alaska where they include conglomerate, sandstone, limestone, black slate, and andesitic rock, including breccia with limestone matrix and lava flow. Some sequence of Upper Triassic rocks occurs in the Copper River region in the Kuskokana and Nixiana districts. All of the Triassic rocks are considerably folded and faulting is common. The rocks here consist of limestone which rests on a series of lava flows (Permian), shale beds, thin layered limestone and alternating beds of shale, and almost uninterrupted shales consisting of black shale and argillite. Other localities where triassic rocks have also been identified include the Cook Inlet-Susitna region and the Chulitna District.

Triassic rocks occur in nearly all parts of northern Alaska extending from the Canning River westward to the vicinity of Cape Thompson. Rock types include calcareous sandstone, limestone, interlayered shale, and black shale. Those in the western part of northern Alaska have been highly deformed and faulted and they have been involved in great mountain-building deformations. They form part of the great structural feature in which the beds become progressively younger toward the north. Vertical dips and overturning of the beds are the rule rather than the exception.

JURASSIC SYSTEM *(114, p. 40-47).* Smith reports that the best development of the Jurassic column on the North American Continent is contained in the Territory. Jurassic outcrops are closely confined to the areas adjacent to the shores of the Pacific Ocean in the southern Copper River region, the Cook Inlet region, and the Alaska Peninsula. The Jurassic rocks of southeastern Alaska include: layered rocks formed mainly through volcanic activity and consists of schistose greenstone, mainly hornblende and less commonly augite porphyry, and breccia, with intercalated tuffs and flows, black slate, and graywacke; and a younger group which is predominantly sedimentary rock, consisting of graywacke, black slate, and conglomerate. Near the mouth of the Chitana River in the central part of the Copper Valley, Jurassic rocks consist of a massive conglomerate, tuffaceous beds, and dark fine-grained sandstone-like rocks. In the Chitana district the Jurassic rocks consist of sandstones, sandy shale, conglomerate, grit, arkose, some limestone beds, and gray-black and reddish argillaceous shale in which are some sandy and calcareous beds, and, rarely grit. The Jurassic rocks of the Matanuska, and Talkeetna districts include lava, breccia and tuff interbedded with sandstone and shale. The uppermost formation of the Jurassic in the Matanuska district consists of green sandy shale several hundred feet thick. In northern Alaska the only place where Jurassic rocks have been identified definitely is the central part of the Canning district where the formation consists of about 4,000 feet of black shale.

CRETACEOUS SYSTEM *(114, p. 47-58).* The Cretaceous Period was a time of varied geological activities including diastrophism, and the injection of igneous masses, which seem to have begun in the Jurassic Period and to have continued into the Cretaceous Period.

Rocks of the Cretaceous Period have been recognized in the Copper River region mainly in the central part of the Chitina Valley, especially in the valleys of the tributary streams that come in from the north. The beds of the Cretaceous deposits of the Chitina Valley are made up chiefly of black shale and sandstone, with subordinate amounts of conglomerate, grit, and gray sandy shale. These rocks are all less deformed by folding and faulting than the older rocks beneath them.

In the Cook Inlet-Susitna region the only sizable area of Cretaceous rocks is in the Matanuska district where the sedimentary beds in this area consist of conglomerate tuff and arkose about 200 feet thick which are overlain by several hundred feet of a massive, dark, fine-grained limestone, and shale with subordinate amounts of sandstone.

In the Gridwood Area of the Anchorage district the Cretaceous rocks consist of a thick sequence of argillites and graywackes which contain amounts of conglomerate, limestone, and partly indurated sandstone. The beds have been strongly deformed, tilted, and fractured. West of Cook Inlet, the Cretaceous sedimentary rocks consist mainly of black and gray slate phyllites and graywacke which also, have been strongly deformed and are much jointed. The Alaska Peninsula affords one of the most complete sections of Cretaceous rocks in the Territory. In general, the Cretaceous rocks in this region appears to be comprised of shale at the base, overlain in turn by limestone, shale with coal, and sandstone.

In the interior Cretaceous rocks are found in the Kuskokwim Basin (conglomerate, sandstones, and shales which are folded), in the area between the Yukon River and Norton Sound (folded sandstones and shales, with coal), and in the Woodchopper area (black shale, sandstone and conglomerate which have been folded).

Probably the most uninterrupted area of Cretaceous rocks in Alaska is the great plateau and plains region north of the Brooks Range in northern Alaska which has been called Arctic Plateau. Throughout this strip the rocks consist predominantly of sandstone with shale and lesser amounts of conglomerate and grit. At most places the beds have been folded and stand at inclinations of at least 45°. Near the mountains some of the folds appear to have been overthrown. The middle part of the Cretaceous System is composed predominantly of shale with subordinate amounts of sandstone. Varying degrees of deformation have affected these rocks in different parts of the region. Near the southern limit they are strongly folded. Farther north and near the coast the folding is less intense. Coal beds form an integral part of the upper Cretaceous rocks. Coal crops out at many localities along the Arctic Coast and along the north flowing streams.

Cenozoic Rocks (114, p. 58-70)

In terms of years the beginning of the Cenozoic Era was far in the past, having been estimated as occurring ten to sixty million years ago which means that there has been a long span during which many processes have been active in making new deposits and new land forms and in carving away and altering those features that were made during earlier ages. During the Cenozoic there were times of uplift, folding and faulting; however, it appears that, on the whole, the major features of the country, as it is now, had been established at the start of this era.

TERTIARY SYSTEM *(114, p. 58-66).* The Tertiary System which is the earliest of the Cenozoic Era includes such epochs as the Eocene, Miocene, Oligocene, and Pliocene. In southeastern Alaska, sedimentary rocks of Tertiary Age include lava and the accumulation of volcanic ejecta and tuffs, coarse sandstone with conglomerate, rhyolitic and andesitic beds cross-bedded sandstones, shales, and clays with some coal seams. In this region they are broadly tilted.

The Tertiary rocks of the Copper River region are also of volcanic origin, but there are minor accumulations of sedimentary beds. Tertiary rocks also occur in the Cook Inlet-Susitna region, but they are covered to a large extent with Quarternary deposits. The Tertiary beds consist of sandstone and shale. In the Matanuska district the Tertiary sediments include shales and sandstones with numerous beds of coal. The beds are considerably folded and faulted and some of them have been intruded by basic igneous rocks. In places a thick conglomerate bed overlies these rocks. In the Yukon region Tertiary rocks are found along the northern foot hills of the Alaska Range, in the Koyukuk-Dall River area, and in the Eagle-Fortymile District. The beds along the north flank of the Alaska Range are famous for the Healy Coal. The Nenana gravels occur in this area.

In northern Alaska there are three principal sites where Tertiary rocks have been identified definitely. These are near the Canning River Valley, the Colville River Valley, and in the Kobuk River Valley. The Tertiary rocks in the Canning River Valley are described as neutral-tinted soft shales associated with bands of harder sandy shales.

Tertiary rocks are found at a number of points in the Seward Peninsula, namely: in the valley of the Sinuk River, the Kugruk River, and the Koyuk River. In all these locations the beds are predominantly composed of sandstone and shale with some coal.

QUARTENARY SYSTEM *(114, p. 66-70).* The Quaternary System includes the pleistocene, or the great glacial age, and recent times. During the Quaternary Period, which may have embraced a million years or so, glaciation has occurred.

At the present time, glaciers cover an area roughly equivalent to less than four per cent of the area of the Territory. The glaciers range in size from small tongues of ice, extending only a short distance beyond the snow banks at their heads; to majestic streams, tens of miles long and a mile or more in width; or to stagnant piedmont fields, embracing, as in the Malaspina glacier, an area of ice roughly 50 by 25 miles. Many of the glaciers extend all the way to the coast and enter the ocean waters. The greatest glaciers are situated in the southern mountain areas, especially in the Coast, St. Elias, Chugach, Wrangell, and Kenai Ranges.

The second most extensive glacial area is in the Alaska Range. It extends from the vicinity of Mentasta Pass westward through the great arc that passes through Mt. McKinley, and then southwestward nearly to Lake Iliamna. A few small glaciers occur in the highlands of the Brooks Range. One great cause for the absence of glaciers north of the Alaska Range is the decrease in the amount of precipitation to the north.

In Alaska there was no continental glaciation as there was in Canada and in parts of the continental United States. The central area of Alaska, even though not over-ridden by the glaciers themselves, has been covered to varying depths with glacial debris chiefly in the form of outwash materials. Within the areas covered by glaciation the evidences of past glaciation are quite strong. This is shown by such features as glacially scoured valleys, morainic deposits, terraces, valley trains, and numerous glacial lakes. Much of the splendor of present-day Alaska scenery is directly due to the glacial history of the region. The deeply cut fiords of southeastern Alaska form the present network of waterways. Many of the present-day land forms have been produced through a combination of processes together with glaciation. The products of these agencies are common.

The exact correlation of glaciation in Alaska with the similar phenomena in Canada and in the United States is still inconclusive. Smith mentions that Capps believes that the period is contemporaneous with the Wisconsin stage of glaciation in northern United States. At present five ice advances are generally recognized in the States. These advances are separated by four interglacial stages in which the ice retreated and almost entirely disappeared. It is not known whether or not there were similar glacial advances or periods in Alaska, but there are some evidences which strongly suggest a possibility. Smith *(114, p. 70)* summarizes the present thinking (1939) on glaciation in Alaska by saying: "(1) Glaciation in Alaska was not restricted to the Pleistocene epoch but has been more or less continuous throughout the Quaternary period down to the present day. (2) Although there was a great expansion of ice in Pleistocene time, that expansion was by no means so surprising as the fact that so large a part of the region now lying within the arctic and subarctic portions of the Territory was ice free when such extensive areas in the temperate regions of the States were overwhelmed by an ice mass of continental dimensions. (3) In the main the present as well as the past glaciation has centered in the mountain areas, and the ice has moved outward from those highlands and occupied the already established lines of flow that had been carved by rivers and other agencies."

CLIMATE

The present-day climate of the Arctic and the Subarctic regions exerts a great influence on the presence of permafrost. A brief summary of the climatic conditions of Alaska is helpful in understanding some of the peculiarities of permafrost. Obviously the existence or even the presence of permafrost is not attributed entirely to climatic peculiarities. Rather, it is the result of a combination of natural causes, among which is "a cold climate".

Approximately one third of the land of Alaska lies north of the Arctic Circle. For this reason the popular conception of the climate is in terms of ice and snow. There are many popular misbeliefs about the Alaska climate. Many of these result from an improper analysis of weather and climatic information. Perhaps some of these misbeliefs result from a misunderstanding, or misuse, of the terms climate and weather. The following, taken from the "Arctic Manual", clearly presents the difference between climate and weather *(116, p. 21)*: "Weather is the total effect of temperature, precipitation, and wind over a short period of time. On the other hand, climate takes account of the average weather and its departures from the average over a long period. The weather at any particular place at a particular time may be quite different from the general climate."

Colby *(83, p. xliii)* in his GUIDE TO ALASKA, discusses what he calls "Popular Errors about Alaska". As examples, some of these are quoted: "The farther north you go the colder it gets". In discussing this, Colby says the Arctic Region is warmed by the heat from the Arctic Ocean. He points out that thousands of square miles of the interior are colder than Pt. Barrow. Others say: "Alaska is a frigid land of ice and snow". He points out that the average snowfall in the Arctic Lowland is less than the average snowfall in Virginia and that temperatures of as high as 100°F have been recorded in the interior. Another popular misconception is: "Alaska's many glaciers indicate a cold climate". Contrary to this belief is the fact that the glaciers are found in high mountainous regions along the coast where heavy precipitation occurs.

General Climate

Because of the geographical position of Alaska with respect to latitude, oceans, winds, and currents, together with extreme variations in elevation, the Territory has a diversified climate. Generalized climatic maps of the Territory are contained in the Appendix. A comparison of the maximum and minimum temperatures of Alaska with those of the North American continent shows that the range in temperature experienced in Alaska is not far different from that of the North Central States. To cite actual temperature ranges, the maximum temperature at Ft. Yukon has been as high as 100°F *(79, p. 1211)*. During the winter of 1946-47 it was reported that all time low temperatures for the continent of slightly lower than 80°F below zero was experienced at Snag in Yukon Territory, Canada. Such extreme temperatures are rare for Alaska, while in the continental United States a temperature of 100°F is a prevailing maximum in many areas. Yellowstone Park *(79, p. 1203)* has temperature extremes from —66°F to 97°F.

While these comparisons show that the range in temperature experienced in Alaska is somewhat similar to that of the continental United States, they are not indicative of the climate or average temperature, since such data do not take into consideration the duration of maximum and minimum temperatures. The temperature of 100°F at Ft. Yukon, for instance, was of short duration as compared with a long duration for similar temperatures in the United States. Likewise, the extremely cold minimum temperatures of Montana or Wyoming are for short durations, while those of 60° F or 70°F below zero in Alaska are for long durations.

A more representative indication of the relative severity of climate is obtained by considering the average number of days during the year with temperatures of zero or lower. In Alaska this ranges from less than one day a year for Juneau, to 132 days for the interior town of Ft. Yukon, and to 170 days per year at Pt. Barrow *(79, p. 1214)*.

It is equally interesting to note the number of days with a temperature below freezing. The following, from the Climatic Atlas for Alaska presents a more natural picture of Alaska *(80, p. 84-86)*. For example, at Anchorage there are 206 days of each year in which the temperature is below freezing, and at Juneau there are 107 days. Even though the climate of southeastern Alaska is rather mild for northern regions, Sitka reports 104 days out of the year with temperatures below freezing. Compare these with the record for Pt. Barrow which has 321 days out of each year with a temperature below freezing. Even in the warmest months of the year, which in the Arctic are June, July, and August, Pt. Barrow has, on the average, 23 days in June with temperatures below freezing, 13 days in July, and 16 days in August.

Study of the precipitation of the Territory is equally as interesting. The variations are comparable with those of the temperature. The rainfall along the southern coast is heavy, and, in many places, it is greater than anywhere in the United States *(79, p. 1215)*. In the southeastern part of the Territory the average annual rainfall is in excess of 150 inches and is considerably over 100 inches in some of the central-coast sections. Progressing inland from the coast the precipitation decreases rapidly, ranging from 7 to 14 inches in the Yukon-Tanana area to somewhat less than the five inches in the Arctic Coastal region.

The snowfall in Alaska is distributed similarly to the rainfall. It is heavy in the southeastern part and light along the Arctic Coast *(79, p. 1215)*. A few snow fall statistics from the Climatic Atlas of

Alaska *(80, p. 154-156)* illustrate the above. The highest snowfall for Alaska is 368 inches which occurred at Ft. Liscum near Valdez. The lowest amount of snowfall is along the Arctic Coast with Pt. Barrow reporting 33 inches.

Climatic data, including rainfall, snowfall, and temperature, for a few selected stations appear in the appendix of this report; these data have been taken from the Army's "Climatic Atlas for Alaska" *(80)*.

According to the generally accepted "World Climate" arrangement Alaska lies in the humid region *(81, Map, Plate 2)*. More specifically, Alaska can be divided into three climatic zones which are as follows: the Humid region; the Continental region; and the Arctic region *(80), (116, p. 1-2)*.

The Humid Region

The humid region corresponds roughly to the coastward side of the Pacific Mountain System. It begins with the islands of southeastern Alaska and extends in a crescent-shaped arc around the Gulf of Alaska westward to and including the Aleutian Islands. This area is extremely mountainous and is densely timbered up to elevations of 1,000 to 3,000 feet, with forests of spruce, hemlock, and cedar. Exceptions are the Alaska Peninsula and the Aleutian chain *(79, p. 1213)*. The Aleutian Mountains act as a barrier to the Japanese currents. The mountains separate the warm waters of the north Pacific from the cold waters of the Bering Sea *(117)*. This fact in combination with the high land masses of the Pacific Mountain System, gives the region abundant precipitation, mild summers, and mild winters. The rainfall and snowfall along the coast are extremely high while inland a few miles they are considerably less because of the influence of the surrounding mountains. Mean annual temperatures in the coastal region vary from 36°F to 46°F with extremes in temperatures varying from —10°F to 90°F. A few miles inland, at Talkeetna, the coldest temperature shown is —48°F. At Anchorage the highest temperature has been 92°F. In this region the precipitation is quite high, and in the higher elevations, the bulk of the precipitation comes as snow. It is this high precipitation, largely in the form of snow, which is responsible for the glaciers of southeastern Alaska.

The highest precipitation has been recorded at Little Port Walter in southeastern Alaska, which shows an annual mean of 230 inches. Other stations, as listed in the "Climatic Atlas" *(80)*, report as follows: Baranof, 163 inches and Cordova, 147 inches. At Seward, which is on the northern part of the Gulf of Alaska, the mean annual precipitation is 67 inches. At Anchorage, several miles inland and across the Kenai Mountains from Seward, the precipitation is only 14 inches. In addition to the 368 inches of snow at Ft. Liscum other areas of high snowfall are: Valdez with 265 inches, Annex Creek with 240 inches, Porcupine Creek with 165 inches, and Taku Pass with 196 inches.

The Continental Region

The Continental region corresponds roughly to the Central Plateaus and includes the area between the northern part of the Alaska Range and the southern part of the Brooks Range. It extends from the International border to the Bering Sea. The annual precipitation in this region varies from about 7 to 32 inches *(80, p. 1)*. In most of this region approximately one-fourth of the precipitation is in the form of snow, the amount of snowfall increasing with elevation. As was pointed out earlier, the highest and lowest temperatures on record occur in the Central Plateaus with a range of about 180°F between the maximum and minimum. It is of interest to note that at Ft. Yukon, for instance, the annual mean temperature is 20°F and the monthly means are below freezing for all months except May, June, July, August, and September. Temperatures such as these exert considerable influence on the permafrost. In the warmer months at Ft. Yukon the monthly means vary from 42°F to over 60°F. Thus, in the warmer months, sufficient heat is available to create a severe thaw when other natural conditions, such as insulation, are disturbed.

Of more significance in evaluating climate of the interior are the monthly and annual "number of days with freezing temperature" and the monthly and annual "number of days with temperatures below zero." For instance, at Ft. Yukon, which is in the heart of this area, there are 244 days with temperature below freezing. When considered on a seasonal basis for the months of June, July, and August, there are only three days with temperatures below freezing. In other words, from September to and including May, at least 241 days of freezing weather can be expected. Included in this number are 132 days at Ft. Yukon with temperatures below zero.

From the standpoint of precipitation the interior is fairly dry. Ft. Yukon reports slightly over six inches annual precipitation. Other stations report as follows *(80, p. 103-105)*: Fairbanks, 11 inches; Eagle, 10 inches; Ruby, 16 inches; and Bethel, 17 inches. In the interior the heaviest rains occur during August at nearly all stations. Even though the annual precipitation is relatively low, the August rains over most of the interior are approximately two inches.

The snowfall of the interior is considerably less than that of the coastal regions. For example the snowfall at Fairbanks for the year is 66 inches. Other stations report annual snowfall as follows: Nome, 59 inches; Ft. Yukon, 42 inches; Circle, 55 inches; and Ruby, 75 inches.

The Arctic Region

The Arctic, or Polar Region, corresponds physiographically to the Arctic Slope, lying principally on the north of the Brooks Range. The Arctic region can be defined on a climatic basis as follows *(116, p. 4):* "The Arctic region is defined on a temperature basis. It is the region in which the mean temperature for the warmest summer month is less than 50°F. . . . The Subarctic region is a belt of variable width south of the Arctic region. Within it the mean temperature of the warmest month is higher than 50°F."

The true climate of this region is clearly shown when considering the number of days below freezing and the number of days below zero. For example, at Pt. Barrow there are 321 days with temperatures below freezing and during the year is no one month during which this condition does not occur. Even in July and August there are 13 and 16 days respectively with temperatures less than freezing *(80, p. 84).* As reported in "Climate and Man" *(79, p. 1214)* there are 170 days out of the year with temperatures below 0°F at Pt. Barrow. The mean annual temperature at Barrow is 10°F. For the warmest months, which are June, July, and August, the monthly means are 34°, 40,° and 38°F respectively. The month of September has a monthly mean of 31 degrees F. During the remainder of the year the monthly means are considerably lower than freezing being somewhere in the neighborhood of 14 to 19 degrees F. The temperature extremes in the Arctic are 78°F at Barrow and 82°F at Kotzebue for maximums, and —56°F at Barrow and —58°F at Kotzebue for minimums.

Precipitation in the Arctic is low resulting in almost desert conditions. Pt. Barrow reports slightly over four inches and Kotzebue slightly over six inches of precipitation. The mean annual snowfall at Barrow is 33 inches and at Kotzebue, 46 inches. At Pt. Barrow, snow can be expected during any month of the year.

The above descriptions of the three climatic regions suggest arid and semi-arid conditions in the Arctic Slope, sub-humid conditions in the Central Plateau and humid conditions along the coast. Areas having low precipitation are usually thought of as being devoid of water. However, in northern Alaska where the precipitation is lowest the ground surfaces even in the upland areas are wet and soggy in the summer. This is a distinct contrast to the arid climate of some of the western states. Smith *(87)* has pointed out that this climatic paradox is due to in part to permafrost near the surface, slow evaporation in the summer, and the thick mantle of moss and marsh vegetation. Taber *(117)* has also called attention to the fact that an increase in mean annual temperature in Alaska would result in the thawing of permafrost and better subsurface drainage. Under these conditions the areas of low rainfall would convert to semi-desert areas unless precipitation were also increased. Taber further comments that an increase in precipitation in conjunction with present prevailing temperatures would bury much of the Territory under ice and snow.

VEGETATION

The geographic position of Alaska with respect to the polar region together with the diversity of physiography and climate, give rise to major contrasts in vegetative cover. Generally speaking the vegetative cover can be divided into three groups which are *(118, p. 5):* the Coastal Forests; the Interior Forests; and the Treeless, or Tundra Area. Two national forests are included in the coastal forest belt of Alaska. These are the Tongass National Forest with 16,074,000 acres and the Chugach National Forest with an area of 4,810,000 acres *(119, p. 2).* The general distribution of vegetative cover in Alaska is shown on a map included in the pocket of the report.

Coastal Forests

The Coastal Forests are a northward extension of the coniferous forests of Washington, Oregon, and the coastal region of western Canada. The Coastal Forests are confined to the "Panhandle", or southeastern part, and to the coast regions as far west as Kodiak Island. This includes the west and southern slopes of the Pacific Mountain System, the Kenai Peninsula, and the Cook Inlet-Susitna Basin. The dense forests include chiefly western hemlock and Sitka spruce *(118, p. 5).* According to a pamphlet published by the Forest Service, the tree species of the southeastern part, with their relative importance in the total stand, are as follows *(119, p. 2, 3):* western hemlock, 73 per cent; Sitka spruce, 21 per cent; western red cedar, 3 per cent; and Alaska cedar, 3 per cent. The Sitka spruce trees are large and vary in height from 160 to 200 feet. They have diameters ranging up to six feet. Spruce grows in combination with hemlock, but pure stands of spruce are common. The western hemlock trees of the region often attain heights of from 100 to 140 feet and diameters of three to four feet *(119, p. 2-4).*

The Coastal Forests in the southeastern part receive heavy precipitation and have a long growing season. Hence, the hill sides, from sea level to about 2,000 to 3,000 feet, are covered with vegetation. In this region the permanent snow line is at approximately 2,000 to 3,000 feet in elevation *(120, p. 12).* From sea level to about 1,500 feet the forests contain a dense growth of berry bushes and other shrubs.

The Coastal Forests are more extensive in the southeastern island group than in the areas to the north and west. The topography in this region is quite rugged; lowland flat areas are lacking. The western arm of the Coastal Forests, which includes the foot hills of the Chugach Mountains, the Kenai Mountains, and the Chigmit Mountains, is less extensive than in the previously mentioned area. The western extension includes two broad lowlands or basins, the Cook Inlet Littoral and the Susitna Basin, which are timbered with Coastal Forest types. In general, the timber in these areas is less dense, contains mixed stands, and is more influenced by climate, topography, and soils than the timber in the island groups to the southeast.

In the Kenai area there are two principal types of vegetation—timber and muskeg. They are associated largely with topographic position, moisture, and soil type. Bennett *(110, p. 36-43)* states that the timber includes white spruce, black spruce, birch, cottonwood, aspen, and hemlock and that the muskeg areas include mosses, berries, Hudson Bay tea, dwarf birch, stunted black spruce, some willow and some alder. He states that the chief difference between the timber of the Cook Inlet-Susitna Basin area and the timber of the southeastern area is the presence of a greater number of deciduous trees in the former region and that the Cook Inlet-Susitna Basin is a transition zone between the dense forested area of the southeast and the treeless zones to the north.

In describing the timber types of the Kenai Region and their sites Bennett *(110, p. 36-43)* says that white spruce and black spruce occur in the forests of the peninsula and that of the two, white spruce is the most abundant and occurs generally on well-drained soils. It does not grow where soils are frozen at shallow depths during the summer, nor does it grow on deep, peaty soils. Black spruce occurs in the more poorly drained areas, particularly in muskegs and where soils are thin. Birch grows from sea level to the timber line and occurs in mixed stands with white spruce. The largest birch occur on deep soil; some are found in the moist stream bottoms. Aspen occurs in burned over areas and on dry soils, frequently occurring on sands. The larger aspen occur on the well-drained soils of the bench lands. Cottonwood are the largest trees in this area and are found in stream bottoms where the soils are gravelly, sandy and silty. Bennett says that hemlock are the largest trees on the Kenai Peninsula; some are four feet or more across at the stumps.

The vegetation in the Susitna Lowland is similar to that of the Kenai Peninsula except for the absence of hemlock. Dense stands of cottonwood, with individual trees often up to four feet in diameter, occur in the flood plains of the rivers. The lowland areas as described by Capps *(108, p. 33-35)* are dotted with scattered marshes and patches of timber. The more poorly drained areas support stunted spruce, while the better drained areas support large spruce. The mountain slopes, up to 2,000 to 2,500 feet, support spruce and birch in scattered groves; dense alder thickets occur above the timber line. Above 3,000 feet the alder give way to mosses, berries and grasses *(109, p. 99)*. Above 5,000 feet the slopes are barren. Farther inland, in the Susitna Basin, the lowland areas are mantled with dense stands of red top grass, which often grows from five to six feet high. This grass occurs on the mountain slopes up to about 2,500 feet *(121, p. 18-20) (122, 109-112)*. In the valleys and the foot hills of the Chugach and Talkeetna Mountains, spruce and birch are the major timber types. The timber line is roughly 1,800 feet in elevation. Cottonwood stands occur along the water courses. Alder and willows occur in thickets between 2,000 and 3,000 feet in elevation. Above 3,000 feet the hills are mantled with mosses, berries and grasses. Stunted black spruce occur in the swampy areas below the timber line *(109, p. 99)*.

Of considerable importance in the Coastal Forest region are the vast muskeg deposits. Dachnowski-Stokes has made a considerable study of the peat resources of Alaska *(123)*, which has necessarily included a study of muskegs. He states that the term muskeg denotes *(123, p. 7)* ". . . an area covered with sphagnum mosses and tussocks of sedges." In discussing the technical differences between muck and peat he says: "The term *muck* is properly used when it refers to any peat material that has been altered by drainage and aeration, the action of micro-organisms, or cultivation and consequently has advanced in stage of decomposition so far that its botanical character is no longer evident. According to its origin muck may be designated as reed muck, sedge muck, etc., the name referring to the type of peat which has undergone decomposition. Muck is residual peat material; it is usually granular in structure and the components are relatively loose and more or less rounded in shape. . . . Muck is generally dark brown to black in color; it differs in the quality of its residues, is relatively low in absorbing capacity for water and soluble salts, and the mineral content may range between 5 and 35 per cent."

Dachnowski-Stokes *(123, p. 3)* classifies muskegs into three types which are Slope Muskegs, Raised Muskegs, and Flat or Valley Muskegs. These classes are contingent on differences in topographic, structural, and developmental conditions of the muskegs. His discussion of these various types is summarized by the following. The slope muskegs develop in coastal regions where peat-forming vegetation is dependent upon cool summers, high precipitation, and high humidity. The peat material accumulates on sloping land and, in places, hummocks of sphagnum moss occur locally. The raised muskegs are characterized by a marked convexity of the surface and by the hummocks of sphagnum moss. Raised muskegs develop under drier climatic conditions than slope muskegs. The flat or valley muskegs are closely related to the slope muskeg. The surface of the valley muskegs is flat to concave. They are confined locally inasmuch as they cannot develop beyond a certain height and cannot extend laterally. These muskegs depend on local ground water and cannot grow above the ground water table.

Interior Forests

The Interior forested region roughly includes all but the western and southwestern parts of the Central Plateaus. The Interior Forests occur in an area where the precipitation is generally low and where the winters are severe *(118, p. 6)*. In addition to occurring where climatic conditions are adverse for timber growth, the Interior Forests are nearly everywhere underlain by permanently frozen subsoils. These factors result in relatively sparse stands of stunted trees. In general, the following major types are included in the Interior Forested region: white spruce, black spruce, aspen, poplar, birch, tamarack, willow, cottonwood, and alder. According to Stoeckeler the vegetation-permafrost relationships are as follows *(78, p. 6)*: ". . . white spruce-paper birch forests occur on both frozen and unfrozen soils; black spruce-tamarack stands grow on frozen muskegs; aspen occurs on dry, unfrozen, south-facing slopes; balsam poplar stands are confined to sites adjacent to active streams having moist, sandy soils unfrozen to a depth of at least 10 feet, pure dense willow stands grow on bare river bars which are unfrozen to 10 feet or more; and pure alder brush occurs on wet peaty soils frozen at a depth of 30 inches."

A diversity of vegetation types and conditions exists in the far western and in the far northern parts of the interior forested region. As the border between the timber and tundra zones is approached the effective timber line becomes progressively lower in elevation. In addition, exposure to light and heat becomes increasingly important. This is perhaps more noticeable in the western parts than in the northern parts, because of the high Brooks Range which forms a natural and somewhat abrupt border on the north.

In the Yukon-Tanana Plateau timber grows up to an average elevation of 2,500 feet depending of course on local conditions of soil and exposure *(90, p. 42)*. Near the timber line the trees become smaller, and above the timber line the trees give way to dwarf varieties, birch and alder predominating. Above this are found grasses, moss and lichens. On south-facing slopes, the timber may extend an additional 1,000 feet more in elevation.

In the far western part the timber line is quite low and in some places can almost be considered as the flood plains. For example, in the lower Yukon in the vicinity of Anvik, the timber line is 600 to 800 feet above the river *(124, p. 14)*. In this area the lowlands are well timbered. Spruce and birch occur in well-developed stands in gullies, near the banks of streams, or on slight rises in the flood plains. In lower portions, according to Harrington *(124)*, cottonwood and willow are the dominating types. Tamarack occurs in swamp location.

In the Seward Peninsula spruce does not extend west of the Niukluk River *(125, p. 72)*. Willow penetrate the tundra and extend farther west. However, they are small and require "the most favorable conditions for growth." Likewise, timber in the form of scattered spruce is found in the lower (eastern part) of the Koyuk River Valley and in the headwaters and mid-parts (southern and eastern parts) of the Buckland River Valley. Progressing westward from the mainland into Seward Peninsula, the area becomes more barren.

Along the northwestern border between the timber and tundra zones, the contrasts are equally as striking as those along the western and southwestern border. In describing the vegetation borders of the Noatak region Smith and Mertie say that latitude is not the controlling factor *(87, p. 74)*. They describe striking contrasts in timber sizes at the actual border and at the effective timber line. For instance, in discussing the Noatak region they say *(87, p. 72)*: ". . . a few hundred yards south of the actual limit the trees are of about the same size as they are for scores of miles to the south, but in that short distance they disappear entirely. On the Unakserak spruce trees 8 to 10 inches in diameter, 30 feet tall, and nearly straight, which apparently have suffered little from strong winds or cold climate, were found at Camp March 17, but 100 yards beyond there were not even dwarf trees or any signs that there had been trees within many miles."

In the Noatak area proper spruce does not occur east of longitude 61°30′. At the eastern limit of the spruce, the trees are 8 to 12 inches in diameter and grow as a narrow fringe along the well-drained river banks, as described by Smith and Mertie. Spruce occurs everywhere in the lowland near the river to a point near the mouth where the ground becomes wet and spruce is absent *(87, p. 72-82)*. Tree sizes and density decrease on nearing the northern limits of tree growth *(126)*.

Treeless, or Tundra Areas

The transition of vegetation from the forest to the tundra is not a continuous or definite line in most cases. The transition zone consists of an intermixed zone of forest and tundra. As described in the Arctic Manual *(116, p. 37)* tundra patches appear first in small openings in the forests and northward the patches of tundra increase in size and in abundance until they equal the forest in extent. Continuing north the forests exist as narrow strips of trees extending along the river valleys where soil and moisture conditions are favorable.

According to the "Pocket Guide to Alaska Trees" *(118, p. 6)* the nonforested parts of Alaska are made up of treeless tundra and grass land. The two areas are situated as follows: "The grassland areas occur over the Alaska Peninsula, the Aleutian Islands, and the south slopes of the Alaska Range, the tundra, over the vast treeless section bordering the Bering Sea and Arctic Ocean and lying south of the Brooks Range." The pocket guide lists three main types as including wet tundra, dry tundra, and rocky or ridge areas. The wet and dry tundra areas contain more plant cover than the ridge areas, while the rocky or ridge type of tundra contains mostly lichens, grasses, and weeds. The wet-tundra type includes chiefly cotton sedges, low or bog shrubs and lichens, but the dry tundra type runs more to the larger shrubs, grasses, weeds and black sedges.

One of the most common plants making up a great part of the tundra area occurs both in the true tundra region and in tundra-like patches in the interior timber zone. It is a plant commonly called "niggerhead". An excellent description of this plant and its site conditions is given by Palmer and Rouse *(127, p. 2, 3)* in a report on a study of Alaskan tundra: "A characteristic of the major part of the tundra is its hummocky surface, not unlike that of a wet meadow much trampled by livestock. Locally the hummocks are called "niggerheads". They vary in size and shape, but are often so uniform in a locality that when viewed from a distance the ground has a level appearance. . . . Hummocks may be from a few inches to knee high, often so closely spaced as to make walking difficult. Circular in form, the hummocks vary in diameter from eight inches or less to a foot or more."

The typical tundra vegetation consists, for the most part, of a dense mat of mosses, sedges, grasses, lichens, berries, Hudson Bay Tea, dwarf birch, dwarf willow, and low brush. Trees and large bushes are not found *(117), (128, p. 62)*. Stunted willows occur in the upland regions of the plateau but are confined chiefly to the valleys. Alders grow on the slopes of hills and in major gullies, chiefly where protection from the severe winds is afforded. Leffingwell mentions finding some cottonwoods 25 feet in height along the upper part of the Canning River. The outer coastal regions, chiefly the Coastal Plain, are mantled with grass, lichens, and mosses. The uplands of the plateaus are mantled with well-developed niggerheads.

In the Arctic Plateau the tundra vegetation includes alder, willow, and dwarf birch. Willows occur along the water courses and often attain a height of 12 to 14 feet in this region. Willows are the largest plants encountered in the tundra region, particularly in the Arctic Plateau and the Seward Peninsula *(78, p. 78)*. On the upland tundra areas, a dwarf variety of willow, only a few inches high, occurs. In the Arctic regions, according to Stoeckeler, snow cover and protection from the wind are considered main factors for controlling the presence of alder. Dense stands of alder occur in the major gullies and on slopes protected from the wind, particularly in locations where deep snow drifts do not last throughout the summer. In the Bethel area, alder occurs on both frozen and unfrozen soil. Dwarf birch also forms another of the tundra types.

Along the Arctic Coast and for some distance inland from the coast, the niggerhead-dwarf birch tundra gives way to other types which, in general, consist of grasses and lichens. Such vegetation as willows, alder, and dwarf birch are almost entirely absent. Willow, however, can be found in some of the major stream valleys to within a few miles of the Arctic Coast.

CHAPTER II

PERMAFROST—ITS OCCURRENCE AND PROBLEMS

Before the advent of extensive military construction programs in the Arctic and Subarctic regions of North America the study of permanently frozen soil was limited to the activities of a very few persons including miners, explorers, some natural scientists, and a limited number of engineers.

During World War II new problems were brought to light in the Arctic and Subarctic lands as a result of the application of construction procedures normally followed in the temperate climates. Time did not permit conducting academic and applied research to establish procedures for combating such a natural phenomenon prior to construction of needed installations. Roads were built and many failed; buildings and other structures were built and some settled severely. Airstrips were constructed on frozen soils only to develop severe settlement because of serious thawing beneath the pavement—thus, creating cracks and rough surfaces.

The strategic situation of Alaska with respect to future routes of air travel, potential statehood, and the added anticipated urban and rural expansion has given added impetus to the quest for knowledge about the permanently frozen soils both from the standpoint of pure and applied science. The installations which were constructed during and following the war have served as a vast proving ground where important observations have been made and where invaluable data have been collected and made available for analysis.

DEFINITIONS

Permafrost may be defined as permanently frozen earth materials which includes bedrocks having a temperature below freezing and other materials which have become solid-like by low temperatures and have remained in such a state continuously for a long period of time. This is essentially what Muller and Taber *(129, p. 3), (117, p. 1436)* say in definitions they have formed for permafrost or permanently frozen soils. Muller *(129, p. 3)* adds that permanently frozen ground is defined exclusively on the basis of temperature, irrespective of texture, degree of induration, water content, or lithologic character. Taber also says *(117, p. 1505)*: "Perennially frozen ground forms where winter freezing exceeds summer thawing." With the exception of a thin surface layer which thaws seasonally, the ground in permafrost regions is perennially frozen to depths ranging up to several hundred feet.

For some time there has been considerable discussion among students of "Permafrost" concerning the development of scientific terminology for the new "sub-science" dealing with the natural phenomenon of frozen soils in arctic and subarctic regions. The reader is referred to the writings of Dr. Kirk Bryan for information pertaining to the creation of a scientific terminology dealing with the natural conditions in arctic and subarctic regions *(130, p. 68), (131), (132, p. 622-642), (133, p. 101).*

DISTRIBUTION

According to a generally accepted definition permafrost occurs in regions where the mean annual temperature is below freezing. This condition affects nearly all of the Arctic and a great portion of the Subarctic. Muller (129, p. 1) discusses the areal extent of permafrost and says that it is a widespread phenomenon in northern Asia and in northern North America and is found in almost one-half of the territory of the U.S.S.R., from the Arctic to northern Mongolia and Manchuria. Permafrost also occurs in most of Alaska and northern Canada. He states that about one-fifth of all the land area of the world is underlain by permanently frozen ground.

Muller and others believe that the areas of permafrost, in general, correspond with the unglaciated areas in the Arctic and Subarctic regions. According to Taber *(117, p. 1437)* the areas in Alaska and western Yukon which were not glaciated include some 370,000 square miles and practically all of this area contains frozen ground. Taber says that in North America some 2,000,000 square miles lie within the permanently frozen region.

In Alaska permafrost is widespread generally in the area north of the Alaska Range extending westward to the Bering Sea; however, in this broad area, particularly in the southwestern part in the Kuskokwim portion of the delta flats, permafrost occurs in scattered locations. South of the Alaska Range scattered permafrost deposits occur in the Copper Basin. With reference to the southern limit of frozen soils, Smith says that the limit of permafrost in Alaska corresponds roughly with the 30° isotherm *(114, p. 71)*.

MODE OF OCCURRENCE

As far as this report is concerned permafrost, or permanently frozen ground, exists in the following forms:

(a) *"An active zone"* representing the layer of ground above the upper surface of the permafrost layer.

(b) The *"frost zone"* which is that portion of the active zone subject to seasonal freezing and thawing. (Where seasonal freezing penetrates permafrost, the frost zone and the active zone are identical. This is common in the more northern latitudes where the climate is severe.)

(c) *Dry frozen* in which the soil mass contains no ice but is rendered solid merely because the temperature is below freezing.

(d) *Detrimentally frozen* in which a large percentage of the soil mass is ice in the form of lenses, wedges, veins, or large masses of ground ice.

The Active Zone

One of the most important features, from an engineering standpoint, of permafrost regions is the fact that the upper, or surface soils, freeze and thaw alternately each year. The portion of the soil mass which thaws each summer is known as the "active layer" *(129, p. 6)*. The active layer is of varying thickness; in arctic regions it is relatively thin and is a matter of 12 to 20 inches in thickness while in the southern parts the active layer is thicker and is often on the order of 36 to 40 or more inches. In any region, either in the Arctic or in the Subarctic, the active layer, or the depth of seasonal thaw, depends on such factors as soil texture, topographic position, vegetative cover (insulation), and exposure to heat. Leffingwell *(128, p. 181)* says that the thickness of this layer, though primarily dependent upon the warmth of the summer is greatly influenced by the nature of the soil and by the nature of the cover on the soil. He says that porous gravels and sand will thaw many times as deep as muck or clay and that moss-carpeted forest-covered areas may thaw only a few inches while neighboring bare gravel bars are thawing many feet.

Dry Frozen Materials

Dry frozen refers to a condition occurring in clastic materials in which the mass is rendered solid by freezing of interstitial water. In their normal, or unfrozen, state such materials would be well-drained internally. Ice lenses, ice wedges, or ground ice in any form are usually lacking and such soils can experience thaw without severe settlement. Both Muller *(129, p. 3)* and Wallace *(134, p. 1)* state that dry frozen soils contain no ice as the cementing substance. As far as Alaska is concerned, dry frozen soils occur for the most part in the broad sand terraces associated with the major streams which are situated high above the flood plain. Some of the more important sand terraces which contain dry frozen soils are at Bethel, Northway, Bettles, and isolated spots along the Alaska Highway. Some sand dunes contain dry permafrost in their lower portions.

Detrimentally Frozen Materials

Detrimentally frozen materials exist in a variety of forms which include: (a) fine-textured soils which contain a large percentage of ice in their mass in the form of crystals, small lenses, or small wedges; (b) soil masses which have been so arranged by segregation of ice and soil particles that they form polygonal blocks of varying sizes and types; (c) materials situated in low topographic position in which large masses of ground ice form an integral part of the mass; and (d) large masses of buried ground ice. Figure 2-1 illustrates some of the more common forms of ice masses in soil.

In summarizing his work on ground ice and polygons Leffingwell says that the following represents the different types of ground ice *(128, p. 241)*; "(1) Grains of clear ice, the largest an inch in diameter, mixed with earth; (2) thin undulating sheets or ribbons of ice alternating with thin beds of earth; (3) heavy horizontal beds of clear ice; (4) heavy beds of ice alternating with beds of earth; (5) heavy deposits of ice with isolated earth inclusions; (6) a network of vertical wedges of ice surrounding polygonal bodies of earth."

Some fine-textured soils contain thin layers of ice and, as Taber says, resemble a banded gneiss *(117, p. 1512)*. Fine-textured soils (silts) have a greater abundance of interstitial ice because of the greater uniformity of particle size *(117, p. 1518)*.

Exposures in placer mines or in cold storage cellars afford an excellent opportunity to view and study various types of ground ice. Excellent ice and ice-soil exposures are to be found in placer mines in the Fairbanks area, the McGrath area, and on the Seward Peninsula. See Figure 2-3. The cold storage cellars at Kotzebue, and Pt. Barrow provided a means of studying ice wedges and ice lenses without the effects of the summer thaw. See Figure 2-4. Taber *(117, p. 1512)* reports finding ice veins nearly a hundred feet below the surface in some mining operations.

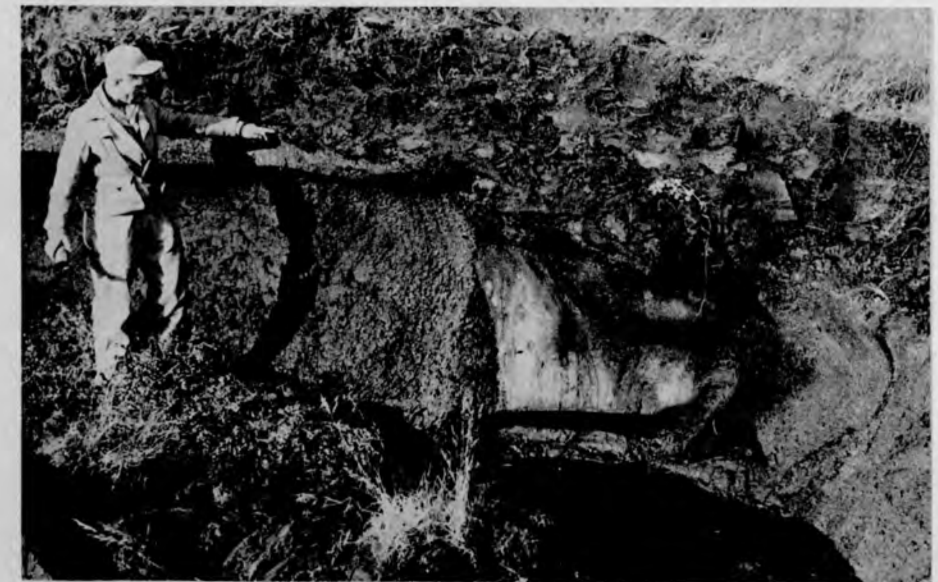
Exposures along the wave-cut banks of streams or the ocean also afford good opportunity for studying ice-soil features (Figure 2-5); however, as Leffingwell points out, one is apt to make erroneous conclusions because of the peculiarities of the combination of overhanging vegetation, ice wedges, wave-cutting activity, and ice caves. Figure 2-6 illustrated slumping and the overhang of vegetation mats. Many writers describe ice exposures as seen along the banks of streams or along the wave cut cliffs of the coast line. Among the more important observations are those of Moffit *(125, p. 53)*, Smith and Mertie *(87,*

13605
10480

10685
15659

(a) Massive ground ice, Sagavanirktok River

(b) Ledge of ground ice, Seward Peninsula



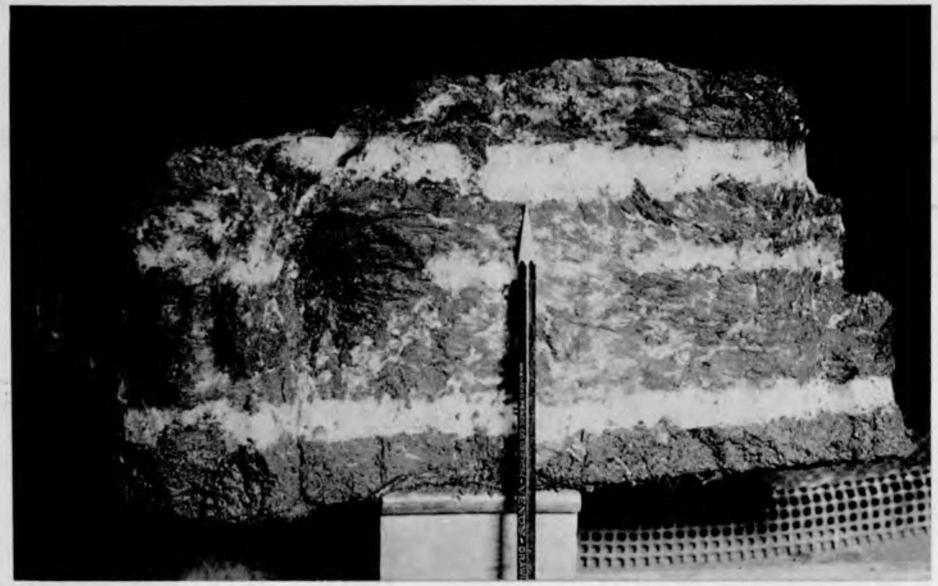
(c) Ice wedge, Nome

(d) Massive ground ice, Kobuk River

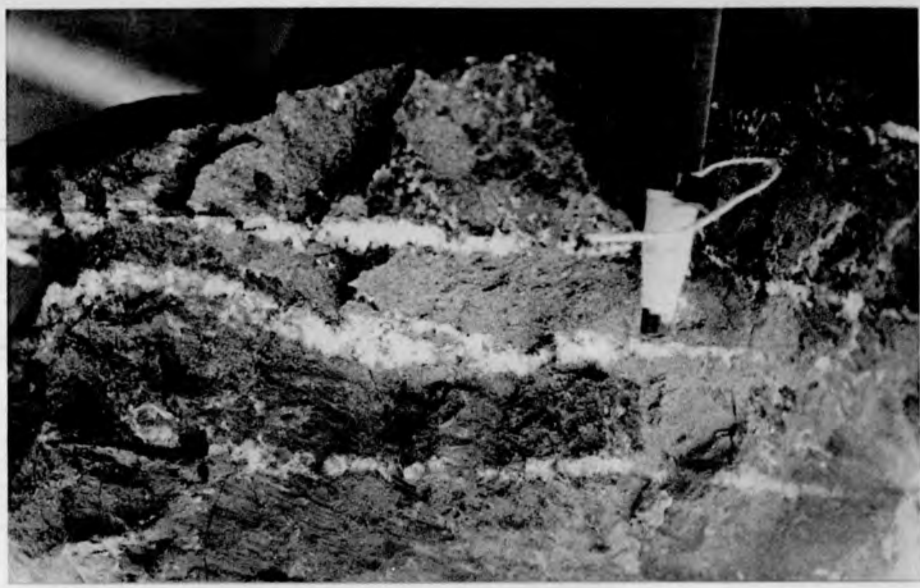
Fig. 2-1 TYPES OF ICE AND ICE-SOIL FORMS

16263
15572

12581
13801

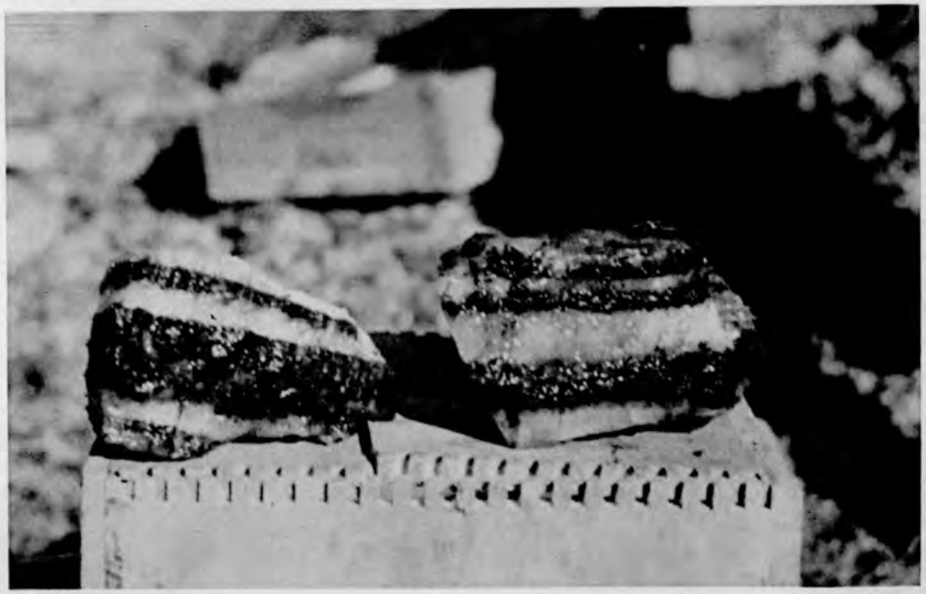


(a) Lacustrine silts



(b) Sands

(c) Sandy Silt



(d) Silts

Fig. 2-2 ICE CRYSTALS AND THIN LAYERS OF ICE IN FINE-TEXTURED SOILS OF THE COASTAL PLAIN

10617
10687

13093
10034


(a) Rainbow Mine, Seward Peninsula


(b) Wolf Creek Mine, Fairbanks


(c) Rainbow Mine, Seward Peninsula


(d) Ester Creek Mine, Fairbanks

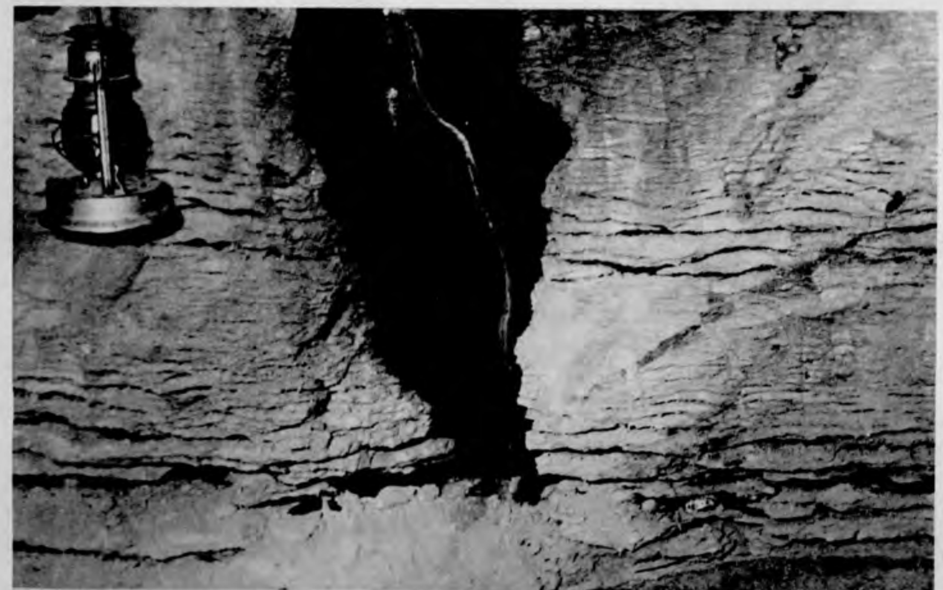
Fig. 2-3 ICE WEDGES AS EXPOSED IN PLACER GOLD MINES

15578
15575

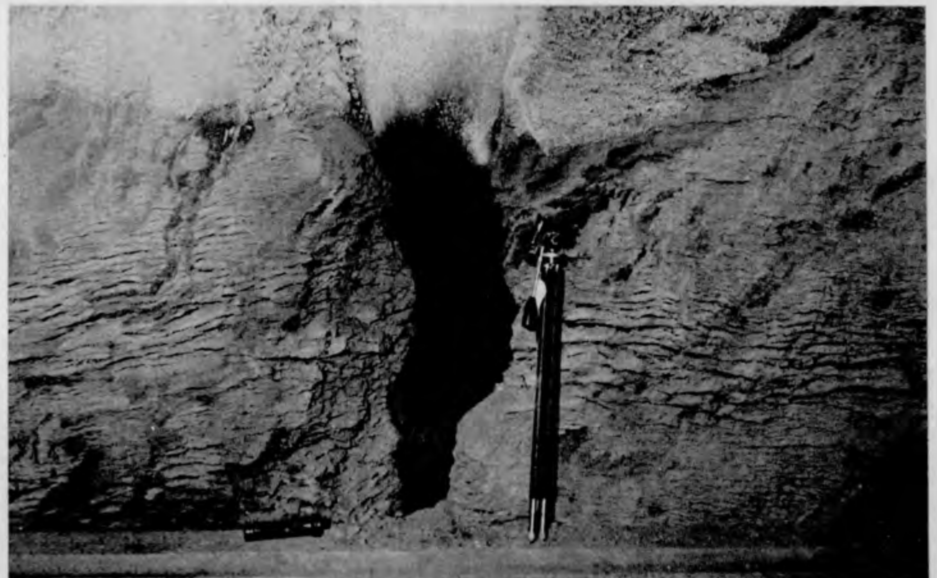
15845
15576

(a) Kotzebue

(b) Kotzebue



(c) Elephant Point



(d) Elephant Point

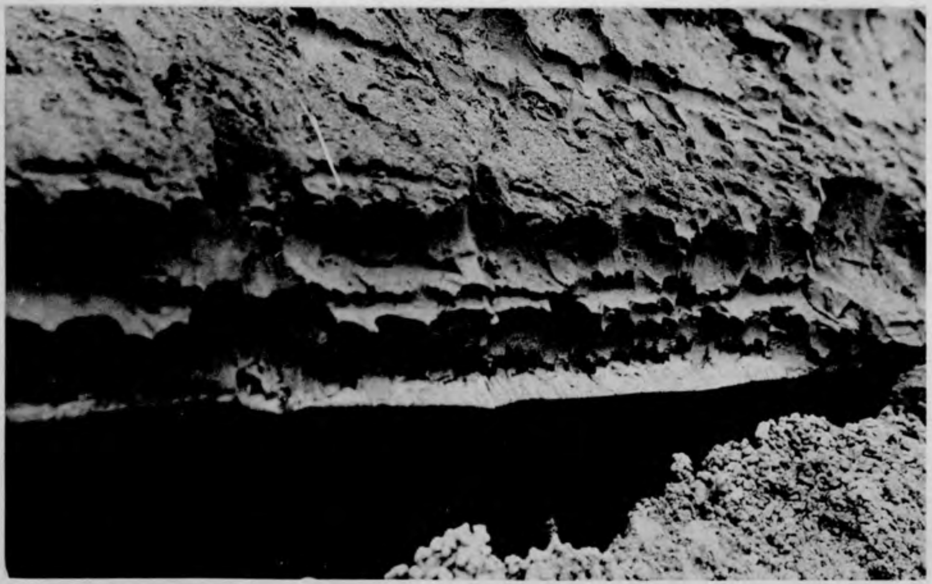
Fig. 2-4 ICE WEDGES AS EXPOSED IN COLD STORAGE CAVES

15698
12160

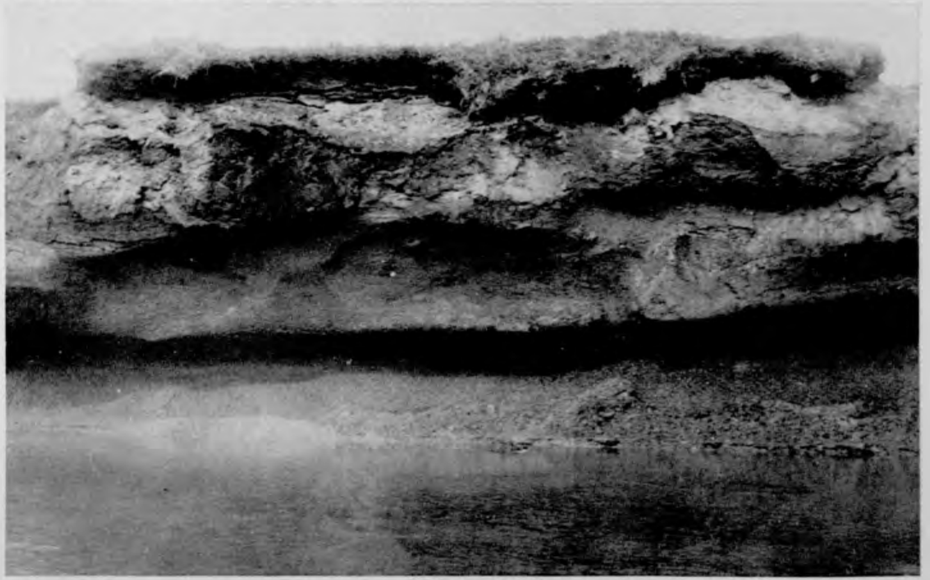
15704
15862

(a) Noatak River near Noatak

(b) Upper Noatak River



(c) Kuskokwim River near Bethel

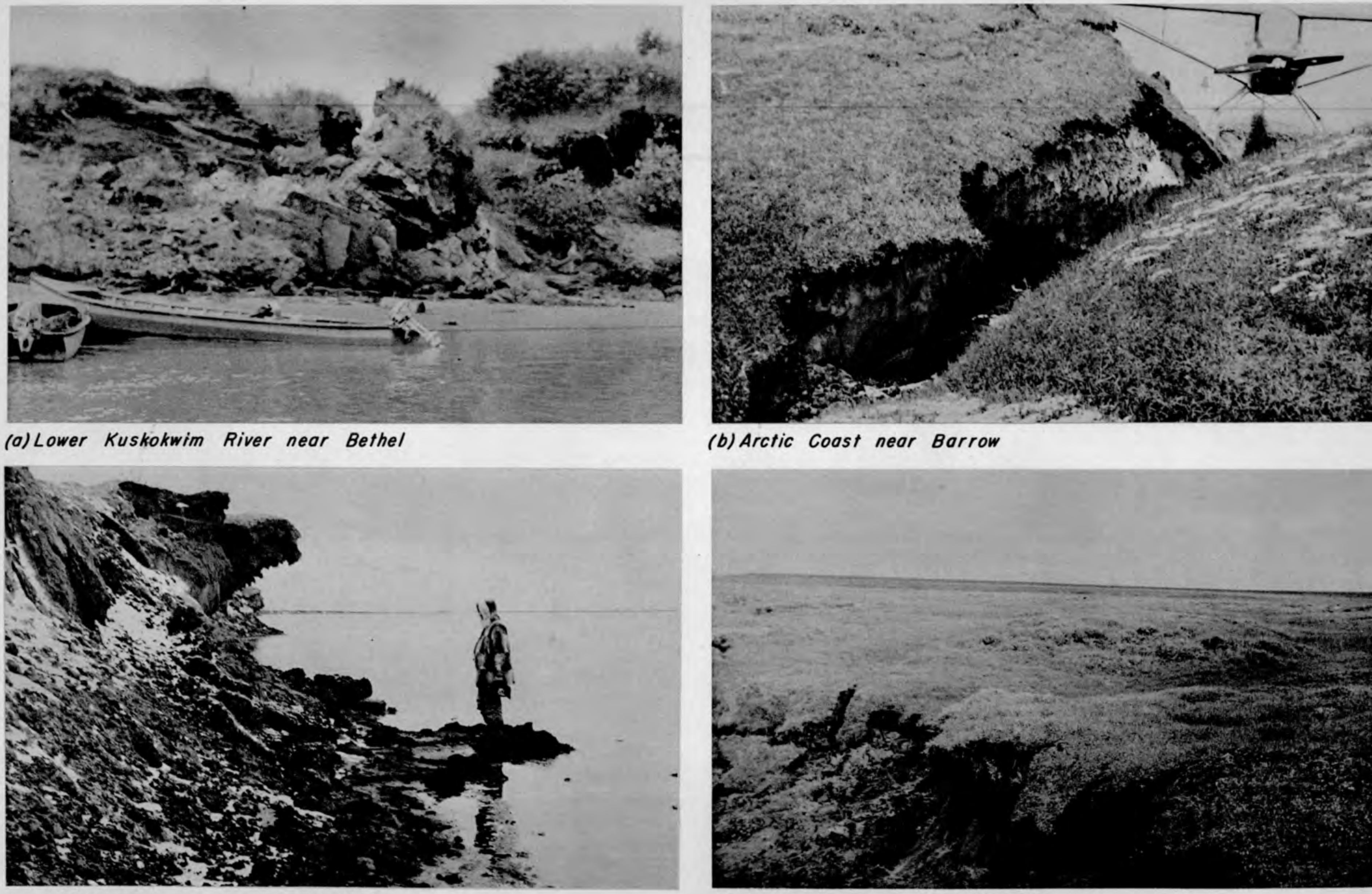


(d) Arctic Ocean near Ceiling Point

Fig. 2-5 FROZEN BANKS CUT BY WAVE AND STREAM ACTION

12168
12617

12608
12532



(a) Lower Kuskokwim River near Bethel

(b) Arctic Coast near Barrow

(c) Arctic Coast near Barter Island

(d) Arctic Coast near Skull Cliff

Fig. 2-6 OVERHANGING MATS OF VEGETATION ALONG WAVE-CUT FACES OF FROZEN BANKS *p. 251)*, Smith *(135, p. 91)*, and Schrader *(136, p. 96)*.

For additional information of ice and ice soil forms the reader is referred to the writings of Nikiforoff *(137)* and Cressey *(138)* who discuss limits of permafrost and formation theories in connection with permafrost in the U.S.S.R.; while Taber *(139)* and Beskow *(140)* discuss the frost action processes. Additional data and theories on permafrost are presented by Tyrrell *(141)* and Wernecke *(142)*.

POLYGONS

One of the most significant features of permafrost regions in which detrimentally frozen soils abound is the presence of soil polygons. The term "soil polygon", as generally accepted, refers to the geometric configuration of surface markings in regions of permanently frozen soils.

Many types of polygons exist and are recognized in the literature including stone-centered ones *(143)* and polygon nets *(144)*. There are a variety of types, sizes, shapes, and situations but the most important two types are as follows: (a) those with depressed centers or pans which are enclosed by raised dykes or perimeters; and (b) those with raised centers and depressed perimeters or outlining channels. Figures 2-7 to 2-11 are views of some of the various types of polygons.

Leffingwell *(128)* observed the two general polygon types and he describes them as "elevated blocks" and "depressed blocks", in his Canning River Report. He describes the action of the surface soils tilting upward adjacent to an ice wedge or in the ridges that occur along the side of a polygon crack. He believes that the depressed blocks are associated with generally depressed and poorly drained areas and that the elevated blocks are associated with better drained topographic situations.

Soil polygons are confined to unconsolidated materials which have been rendered solid by freezing. They do not occur as an integral part of bedrock areas. The only place polygons occur in bedrock areas is in the colluvial materials on the side slopes of hills or in places where the bedrock is overlain by a relatively deep unrelated soil mantle. Polygons commonly occur throughout most of the permafrost regions. In the Arctic Regions polygons abound, being particularly abundant in the Arctic Coastal Plain where they are easily seen because of the absence of timber cover. To the south, and in the timbered regions polygons are less abundant and are more closely associated with topography, soil type and available moisture than are those above the Arctic Circle. In the Arctic Regions polygons are found on silt, sand, and one variation is found on gravel soils. To the south, polygons are more closely associated with silt soils, a low topographic position and a source of water. This limits their occurrence to those alluvial and colluvial silts which satisfy the requirements of topography and moisture. Taber verifies these observations in part in his description of polygons in the Fairbanks area *(117, p. 1513)* by saying that the ice veins which develop in thick deposits of flat-lying silts inclose polygon blocks.

Leffingwell developed a theory on the formation of ice wedges in 1914 as a result of his having spent nine summers in the northern part of Alaska. The following summarizes his observations and theories as presented in his paper on the Canning River Region *(128, p. 205-212)*. He believes that the pattern is an adjustment to the tensile strains set up which result from raising and lowering of the temperature and the associated expansion and contraction. In the summer the cracks are filled with melt-water from the snow. The water freezes which causes a vertical wedge of ice. He is of the opinion that the action is a continuing one and that wedge ice grows from year to year. It is possible for one-fifth of a polygon area to be underlain by ice as a result of the growing processes *(128, p. 206)*.

Raised-Center Type Polygons

Polygons of the raised type consist, for the most part, of a soil mass in block form which is outlined or surrounded by a perimeter consisting of a series of channels. They occur widespread in the tundra areas and to a lesser extent in the timbered areas.

ARCTIC AND SUBARCTIC TUNDRA. The largest and best-developed raised-center type polygons are situated in the Arctic Coastal Plain and on the silt-covered alluvial terraces of the Seward Peninsula. The largest are often over 200 feet across with the surrounding channels often 10 to 15 feet in width and 4 to 6 feet in depth. Quite frequently a secondary system of smaller polygons will have formed within the larger outlines. In the interior of the Seward Peninsula, well-developed polygons of this type are associated with frozen-silt soils. Frequently, well-formed polygons occur in bedrock areas but they are confined to broad valley-fill situations and to lower and mid-colluvial slopes of hills. Elsewhere on the Seward Peninsula they are confined to the coastal plain soils.

In the Arctic portions of the tundra region (north of the Brooks Range) raised-center polygons occur in silt, sand, and gravel areas; however, certain distinct features were noted about polygons in each soil type, thus making identification and evaluation possible. In Alaska the largest and most perfectly formed polygons of the raised-center type are situated on higher parts of silt covered terraces in the plateau region; on a silty mantle which overlies the shales of the Arctic Plateau; on the broad valley-fills of the plateau where soils are chiefly silty, and on lower colluvial slopes of certain shale hills of the plateau region.

TIMBERED REGIONS. Polygons undoubtedly occur widespread throughout the timbered areas but they are difficult to find because of the dense vegetative cover. It is believed that those occurring in the timbered areas (south of the Brooks Range) are more closely related to topography, slope, soils, moisture, and vegetative cover than those occurring in the tundra regions. The polygons are somewhat smaller than those which occur north of the Brooks Range; they are also smaller than those occurring to the west in the Seward Peninsula. Shapes and designs vary considerably but five- and six-sided figures seem to predominate. In water-deposited materials, particularly stream valleys, polygons are confined to low intermediate situations in which the major soil type is silt. Within the timbered regions they occur both in areas covered with timber and in areas covered with tundra-type vegetation. Polygons also occur in the broad, valley-fill situations in bedrock areas where the major soil is colluvial silt and peat. In areas of gold-bearing rock, where placer mining is active, it is possible to study ice wedges and other forms of ground ice in the placer exposures. In the local valley-fill situations the soils are often stratified with layers of peat, silt, ice, and occasionally fractured rock.

Of all polygons and polygon areas studied south of the Brooks Range none was found on soils other than silt and silt-peat mixtures. One exception, however, was noted in the Big Delta Area where polygons were found on gravel outwash.

Depressed Center Polygons

The depressed-center type polygons are most commonly associated with a depressed topographic position and occur in such situations as a depression in an old flood plain, a depression of a stream terrace, the bed of an old lake, or in broad and generally depressed areas of coastal plains. Depressed-center type polygons are almost entirely confined to the area north of the Brooks Range and to a limited extent occur on parts of the Seward Peninsula.

This type polygon consists of a "pan" or "paddie" surrounded by a raised rim or dykes. The centers usually consist of a thick mat of floating grass and roots; often the water is as much as two feet in depth. The dykes, which completely inclose the polygon, are often two feet above the water level (or the level of the inclosed pan surface) and they are covered with grass, moss, lichens and occasionally niggerheads. The dykes, or mounds, have longitudinal cracks or depressions in their centers. The dykes often attain a width at the base of 8 to 10 feet and at the top four to five feet. The small channels in the center of the dykes are often as much as a foot below the top surface of the dykes. These channels frequently are partly filled with water and a thick mat of moss.

In general the depressed-center type polygons are not as large as the raised-center type. When the two types are found in close association the depressed-center type occupies the lowest topographic position. In transition zones, such as the change between the beach of a lakebed and the adjacent upland, the two types of polygons often merge into one another with geometric regularity. Figure 2-12 contains ground views of depressed-center polygons typical of arctic regions.

Many polygons of this type were sampled in the Arctic Slope Region particularly at Barter Island (coastal plain), Umiat (a terrace of the Colville River), Point Barrow (lower coastal plain), and at a few scattered areas along the Meade River (upper coastal plain). Sampling is extremely difficult because of general swampy conditions in polygon areas and because of the rapid thaw which occurs when an area is disturbed. Sampling and general study is best accomplished using dynamite and a light "cat" equipped with a dozer blade. It was found that a D-8 is nearly helpless because of the heavy weight together with the tremendous drag on the under carriage which is caused by the accumulation of peat and vegetation. The unevenness of the frozen surface makes traction and blading extremely difficult with heavy equipment.

Description of Some Polygons Sampled

During the summer of 1946 a large raised-center type polygon was studied in detail near the Kougarok Airstrip on the Seward Peninsula. This was done in September during a time when the summer thaw was believed to be near its maximum depth. By using a D-8 tractor to blade off the vegetative cover it was possible to view and photograph the surface soils and ice. None of the frozen peat, frozen silt, or ice could be removed with the tractor blade. Blading was done on a rather warm day during a light rain the combination of which aided in increasing the thaw in the polygon area. Once the vegetation was removed, thaw of the underlying frozen peat and silt progressed at a rapid rate. Surface water and silty soils made working in this area extremely difficult. In this polygon area the mat of vegetation on the center part consisted of well-developed niggerheads, moss, Laborador Tea and grasses. The upper limit of permafrost was 18 inches below the surface. Surface soils in the center were frozen silt. In the polygon channel, surface water was about six inches deep and vegetation consisted of moss and grass. Ice, which was found in wedge form, was confined to the channel area and was covered by a thin layer of frozen peat. Ice was not found near the surface of the area inclosed by polygon channels.

Extensive study and sampling was conducted near Umiat in an area containing depressed-center poly-

13270
16172

13281
16109

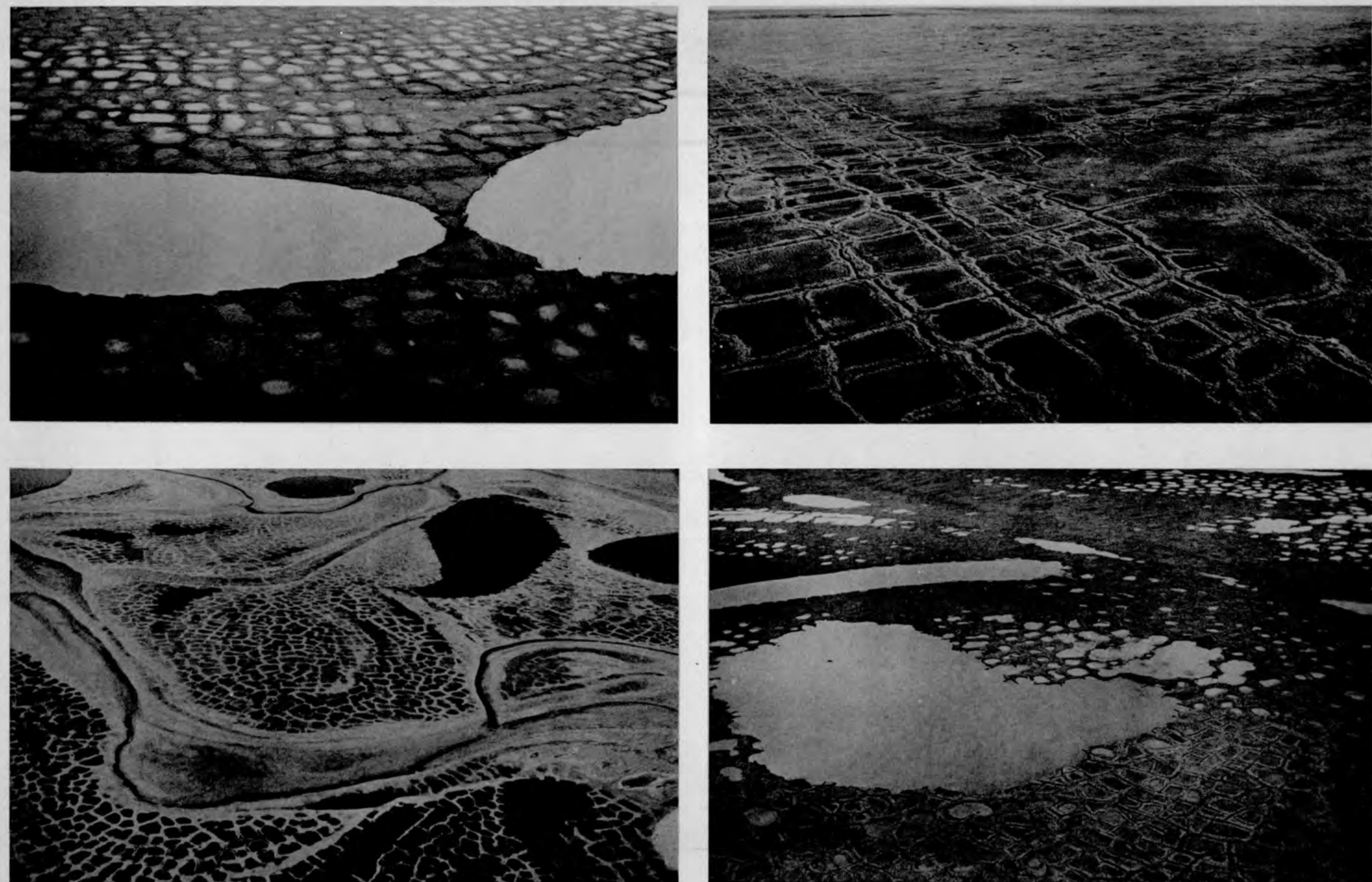
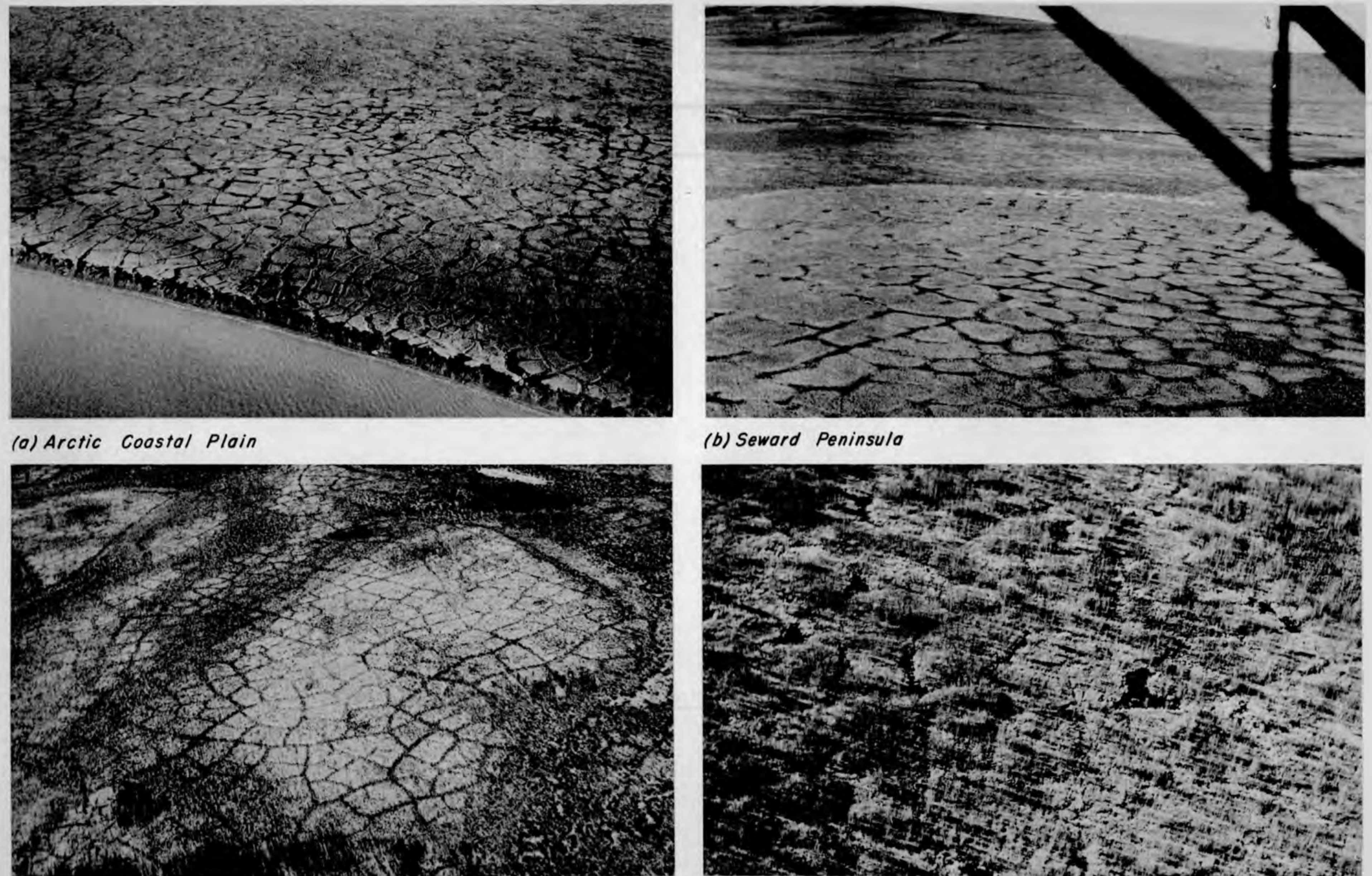


Fig. 2-7 LOW ALTITUDE OBLIQUE PHOTOS OF DEPRESSED-CENTER TYPE POLYGONS IN THE ALASKAN COASTAL PLAIN

13679
12781

10557
10948



(a) Arctic Coastal Plain

(b) Seward Peninsula

(c) Yukon Flats

(d) Tanana Valley

Fig. 2-8 LOW ALTITUDE OBLIQUE PHOTOS OF RAISED-CENTER TYPE POLYGONS IN ALASKA

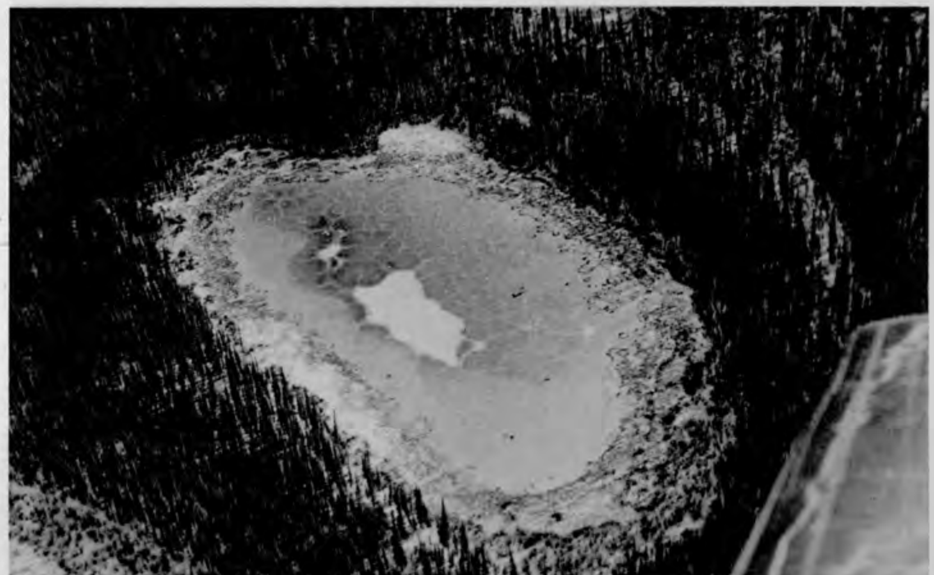
13273
16015

17050
12785

(a) Arctic Coastal Plain

(b) Rectangular polygons, Buckland Delta

(c) Rectangular polygons, Meade Delta



(d) Polygons forming on ice, Yukon Flats

Fig. 2-9 POLYGON TYPES IN ALASKA

16008
13672

16012
16281

(a) Admiralty Bay, Arctic Coast

(b) Admiralty Bay, Arctic Coast

(c) Barter Island, Arctic Coast

(d) Barter Island, Arctic Coast

Fig. 2-10 POLYGONS OCCURRING ON SAND AND GRAVEL SPITS

10532
13379

15689
15796

(a) Valley fill, Seward Peninsula

(b) Colluvial slopes, Noatak Valley near Kiana

(c) Valley fill, Arctic Plateau

(d) Colluvial slopes, near Kivalina

Fig. 2-11 POLYGONS OCCURRING IN VALLEY FILL AND COLLUVIAL SITUATIONS

13761
16260

15970
13748

(a) Depression on a terrace, Umiat

(b) Lakebed Area, Barrow

(c) Coastal Plain depression, Barter Island

(d) Coastal Plain, Meade River

Fig. 2-12 GROUND VIEWS OF DEPRESSED-CENTER TYPE POLYGONS IN THE ARCTIC SLOPE gons. One of the areas for study included the intersection of three dykes and a part of a pan of one polygon adjacent to the intersection.

On the particular day that the blading was done the weather was warm and the rate of thaw was rapid. After the moss and unfrozen material had been removed from part of the intersection of the dykes and a small part of the pan (by use of the "cat" and the hand shovels) five holes were drilled into the cleared area. These were placed in such a manner as to provide a trench which would cross the dyke. Dynamite was used to blast this trench in the permafrost. It was found that the pan contained a surface layer of clear ice and that the mounds or dykes consisted largely of frozen silt with an ice wedge occurring beneath the longitudinal crack in the dyke. The frozen peat and silt in the dyke contained small lenses of ice. No sand or gravel occurred in any part of the area exposed by the blast. Ice in the channel, which represented the wedge in the center of the dyke, extended downward at least six feet below the top of the dyke. Ice in the pan was at least two feet thick and it was not possible to determine its lower limit because of the large volume of water in the pan above the ice. Within a few hours after blading had been started and the original insulation had been disturbed the test pit had filled with water to a depth of about four inches. By the next day it was impossible to walk in the area because of the great thaw penetration. Figures 2-13 and 2-14 illustrate this operation at Umiat.

Polygons of both types were also studied at Barter Island, Pt. Barrow, Kotzebue, Pt. Hope, and many locations along the Colville River and along the Arctic Coast.

Polygons of a different type—nearly rectangular in shape—were found on some of the gravel bars and gravel spits or other low depressed areas adjacent to the coast. Polygon markings of this type were seen on gravel spits at the following locations: Pt. Barrow, Barter Island, Kotzebue, Pt. Hope, and at a few other miscellaneous locations along the Arctic Coast. In most of these situations the surface of the beach deposit was a matter of a few feet above the water level and soils were gravel or sand. Whether or not ice existed at any depth beneath the polygon markings could not be determined since sampling was done with a shovel and with a soil auger (dangers encountered with using dynamite in loose gravel precluded its use); however, the patterns, their shapes and arrangements, are believed to be significant even though the full significance is not clearly understood. For the most part the polygons were rectangular in shape; channels did not always intersect at common corners. Sizes were found to vary considerably as did the depths of the channels. For example, on Barter Island some channels were as much as five feet in depth and about eight feet across; surface water was present in the channels. The only vegetation consisted of lichens and grass—grass occurred in the channels.

In one instance, a low spit on Admiralty Bay, in which the soils were entirely sand, was studied. This particular area was divided into rectangular polygons which were approximately 50 feet across; channels were roughly rectangular in cross-section. The entire area was grass-covered and very wet. Permafrost was found in the center of the polygon area approximately 24 inches below the surface and about 30 inches below the water surface in the polygon channels. In this one instance recent beach deposits, formed by wave action and perhaps ice shoving, were encroaching on the polygon area.

Polygon Erosion and Destruction

Polygons erode chiefly by thawing which action is influenced by ground slope, exposure, vegetative cover, soil texture, and surface water. Figures 2-15 and 2-16 show various types of polygon destruction. Of all of the above factors running water exerts the most influence on the destruction of polygons. Along the stream banks or along the ocean where the wave action produces under-cutting, the action of running water and exposure to high summer temperatures causes the removal of large quantities of silt and ice. This causes caves to develop which extend inward a considerable distance. Excessive under-cutting and the weight of the overhanging material are sufficient to cause large frozen soil masses to collapse. Where polygons intersect a water line or shore line the ice in the channels usually thaws first causing a general subsidence in and adjacent to the polygon channel. This results in a series of overhanging "vegetation mats" along water courses which extend inland—often a full polygon width. If thawing is particularly active due to the addition of excess surface water, or a particularly warm summer, the effect will extend back for a considerable distance inland and will influence several rows in a polygon net. Complete thaw leaves isolated mounds of soil and peat which formerly had been inclosed by ice wedges. If erosion by running water commences in a polygon area the polygon channels serve as gullies and the action of running water results in an increased rate of thaw. Inland, and some distance away from the immediate effects of a coast line, or erosional base level, thaw in polygon areas starts at the intersections of the polygon channels by forming small circular pools of water. If any surface flow is established the course of flow follows one of the polygon channels thus resulting in an irregular or an angular arrangement to the gully plan. This type of drainage is commonly called "button drainage" and occurs widespread in the Arctic Slope particularly in some of the broad upland valley-fill situations.

When polygonal ground is cleared for thaw prior to cultivation the thermal balance is upset resulting in melting of ice in the soil. If surface gullying does not start or is not allowed to progress the subsoils will thaw slowly and the water will flow away as ground water. If subsurface thaw is rapid the results will include considerable settlement in areas underlain by ice wedges or other ice masses and will result in a topography consisting of a series of domes or mounds. Excellent examples of this can be found near Fairbanks in some of the recently cleared farm lands—particularly on sloping grounds. Taber *(117, p. 1514)* describes some of these in the Fairbanks area as creating a polygonal pattern of closely spaced, rounded hummocks, with relief sufficient to interfere with cultivation. He believes that the surface pattern developed as it did because the field was cleared; it is probably due to the deep thawing of ice veins as a result of the removal of the original vegetal cover.

Soil Flows, Solifluction, and other forms of Lateral Earth Movement

Some of the forms of soil movement associated in part with frost activity create rather unique surface markings or patterns. These are easily seen and can be identified both from airphoto study and from ground study. Perhaps the greatest percentage of such soil movement can be attributed to a combination of slope, gravity, freezing and thawing action, type of plant cover, and water. They occupy shapes ranging from curved lobate markings, which appear to scallop hillsides, to nearly dome-like small mounds. Figures 2-17 and 2-18 illustrate some of the soil flow phenomenon.

In the Arctic and the Subarctic regions the processes of solifluction, or soil creep, are active agents of erosion or land destruction. Lobeck defines solifluction as *(145, p. 83):* ". . . a term applied to the slow imperceptible flowing from higher to lower ground of masses of rock and soil saturated with water." Solifluction creates the impression as though the entire hillsides are sliding down the slopes by the presence of long ridges or streamers of vegetation and materials which have a directional trend down the hillside.

In describing a series of earth runs on the Seward Peninsula, Smith *(105, p. 97)* says: "It seems probable, however, that there is a slipping of the overlying burden of waste through the thawing of the ground ice in the summer time, and a consequent production of unstable equilibrium which finally causes movement. As the material flows down hill the tendency is constantly to decrease the angle of slope so that the lower angle arrests further movement. This movement of the material in some cases must be rather slow, for in some of the smaller examples the turf was not even broken . . . . At the extreme front the slope was very steep and the turf had not been ruptured, but the inclination of the vegetation standing nearly normal to the slope of the front showed that the carpet of turf had been wrinkled by the movement of the mass beneath."

Capps, in discussing soil flows in the Kantishna region *(96, p. 66-68)* says that the products of disintegration and weathering are removed by soil creep or soil flow and that both the sudden soil flows and the slow flowage types are found. He says that vegetation forms a tenacious fibrous mat which resists the removal of loose material by surface waters. The vegetation is also an insulator which keeps the permanently frozen soil level close to the surface. In the summer the combination of melting, excess surface water, mechanical breakdown of soils and rocks, and the weight of the vegetation results in a tendancy to move down the slope.

A good description of solifluction and other mass soil movement phenomenon, including, in particular, altiplanation terraces in Alaska, is presented by Eakin in his report on the Yukon-Koyukuk Region *(146, p. 76-82)*. In discussing solifluction Eakin believes that solifluction is limited to areas having a thin surface mantle and that depth of thaw, texture, porosity and vegetative cover are influencing factors for the soil mantle in motion. In describing altiplanation terraces Eakin says that they represent a particular type of solifluction and that *(146, p. 78):* ". . . under certain conditions, expresses itself in terrace-like forms and flattened summits and passes that are essentially accumulations of loose rock materials." He says that even though the terraces vary in certain physical features they are bounded by scarps that drop off to lower levels. These terraces are marked with a scarp face which is barren and composed of angular talus blocks. He states that surface water or a growth of moisture-loving plants occurs generally at the base of each scarp. Solifluction and tilted terraces resulting from solifluction causes in the Anvik-Andreafski region are discussed by Harrington *(124, p. 55)* who confines them to areas of igneous rocks and areas of sedimentary rocks. He believes that their formation appears to be favored by certain conditions of vegetal growth, for so far as known they do not appear below timber line. Altiplanation terraces are often marked with minute frost-heaved mounds in areas where fine materials prevail.

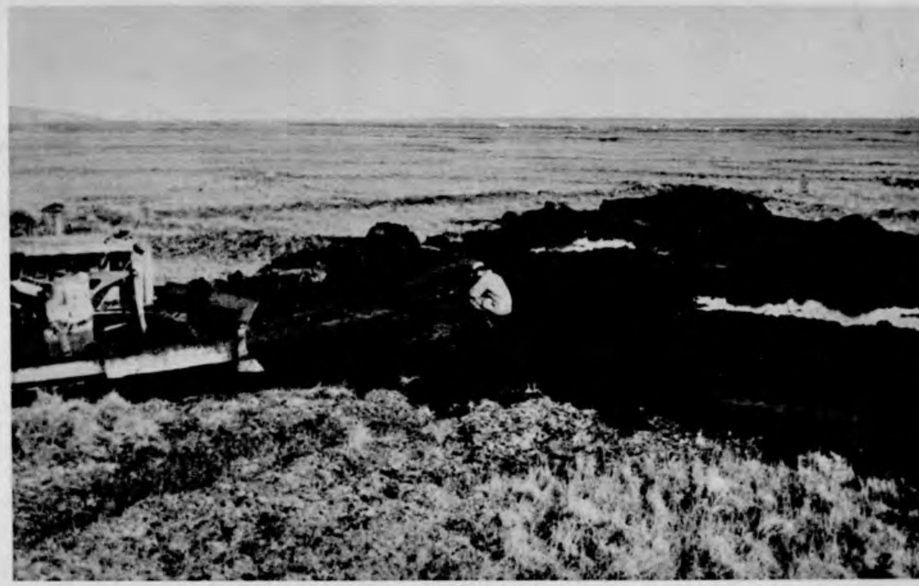
Eakin *(146, p. 80)* says that the mounds are composed of rock fragments and clays. From study of the mounds he believes that there are indications of strong upward currents through the center of the mounds and indications of downward currents around the periphery. The currents cause the segregation of the materials.

Others have written descriptions about soil flows of various types and it appears that they occur widespread throughout the Territory. For example,

13764
13767

13762
13791

(a) Polygon before blading



(b) Blading operations

(c) Drilling a hole for a dynamite charge

(d) Dynamite blast

Fig. 2-13 BLADING AND SAMPLING OPERATIONS IN A DEPRESSED-CENTER POLYGON AREA NEAR UMIAT

13769
13770

13776
13789

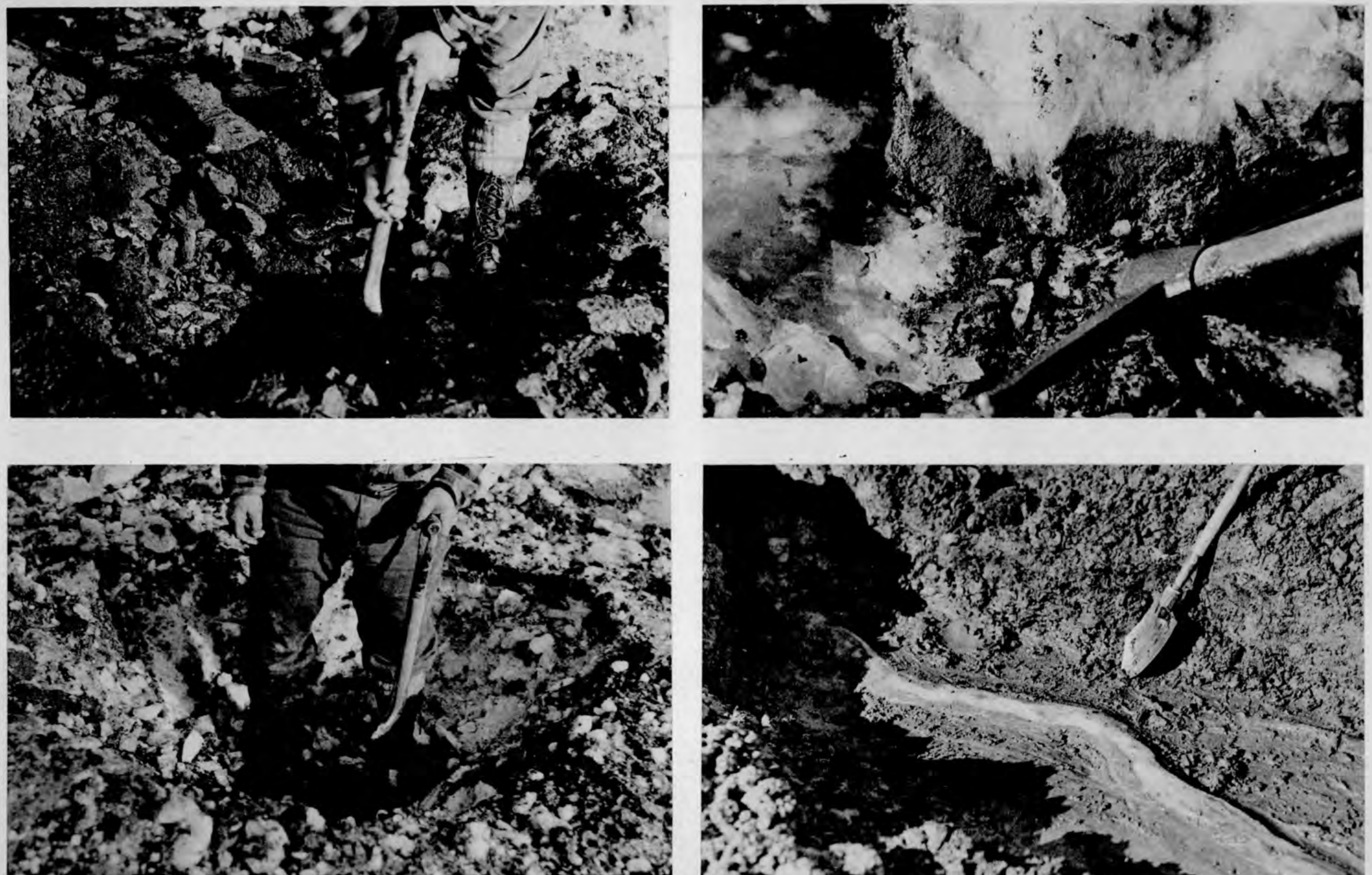


Fig. 2-14 ICE-FROZEN SOIL RELATIONSHIPS AS FOUND IN THE UMIAT POLYGON TEST SITE

16071
12534

16061
13678

(a) Polygon under cutting along the Arctic Coast

(b) Polygon channel erosion, Skull Cliff

(c) Polygon channel thaw, Arctic Coast

(d) Polygon channel thaw, Arctic Plateau

Fig. 2-15 POLYGON EROSION AND DESTRUCTION

16577
13511

13819
16102

(a) Destruction by internal thaw, Fairbanks

(b) Silt center of a destroyed polygon, Arctic Plateau

(c) Thaw by running water, Arctic Slope

(d) Polygon remnant, Arctic Coastal Plain

Fig. 2-16 POLYGON EROSION AND DESTRUCTION

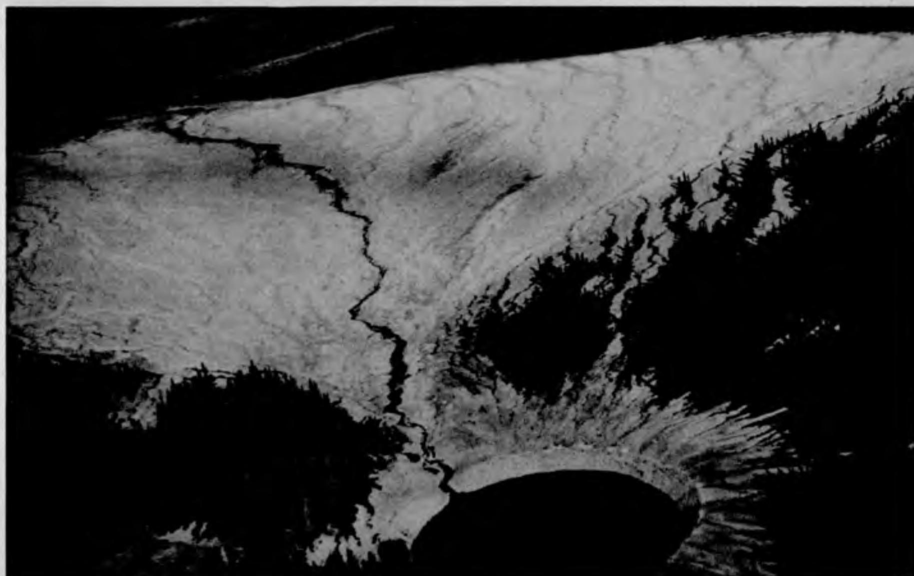
10712
17769

10774
17773

(a) Soil flow markings, Seward Peninsula

(b) Soil flow markings, Seward Peninsula

(c) Mud volcano, Gulkana

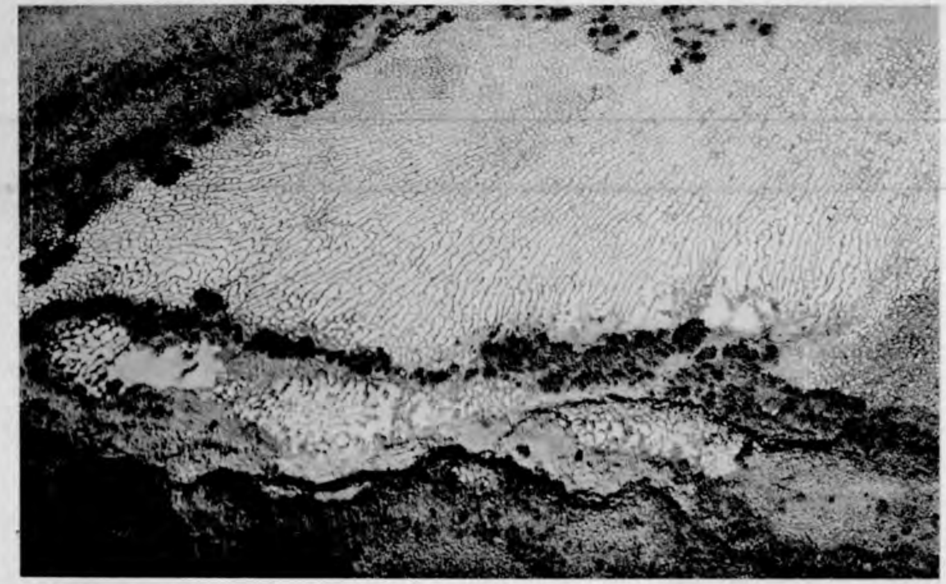


(d) Mud volcano, Gulkana

Fig. 2-17 SOIL FLOW PHENOMENA

13568
16946

13234
16997



(a) "Mud boils" and soil flow, Umiat

(b) Ground view of the area in (a)

(c) Soil flows, west of Kaltag

(d) Altiplanation terraces near Shaktolik

Fig. 2-18 SOIL FLOW PHENOMENA

Moffitt describes the soil flows of the Gulkana region, particularly at the head of Valdez Creek. Moffit says *(147, p. 45)* that the flows are the result of gradual downward movement of the soil on the hill slopes and can be compared to the flow of a viscuous substance, such as thick tar, on an inclined plane. Capps *(108, p. 167-170)* describes soil flows in the Alaska Railroad Region. He says that north of the Alaska Range in permafrost areas soil flowage is very active while on the south side, where there is little permafrost soil flow is not common except above altitudes of 3000 feet. He describes the minute dome-like hummocks which occur near the upper limit of vegetation. About them he says *(108 p. 169):* "Some such areas look as if they had been furrowed with a plow; others as if the soil had been hilled up in low mounds in cultivation of some crop. In these areas the appearance of soil movement is not conspicuous, but the surface forms are doubtless due to the interrelation of vegetation, soil, frozen ground, water content, and frost action, and all these phases are part of the general phenomenon of soil movement under subarctic conditions, a type of erosion that deserves much more intensive study than has so far been given to it." Capps *(121, p. 20)* describes minute mounds as occurring above the altitude to which ferns and grasses grow and as consisting of various hummocks or ridges; they are believed to be caused by the action of freezing and thawing.

Pingos and Other Frost Mounds

Frost mounds of many types occur at scattered locations throughout the northern and far western coastal regions of the Territory. The most outstanding mounds are those in the Arctic Coastal Plain which are called "Pingos". Physiographically speaking mounds occur in the Arctic Coastal Plain Province extending from the Canadian border generally westward to Wainwright; in the narrow coastal plain region between Pt. Hope and the Seward Peninsula; the coastal plain which forms a fringe around the major part of the Seward Peninsula; to a limited extent in the delta region of the lower Kuskokwim-Yukon Valleys; and in the interior of the Seward Peninsula which is in the Kuzitrin-Noxapaga Basin. A few scattered mounds believed to be associated with other frost phenomenon occur in isolated areas in the interior principally in some of the major stream valleys. Figures 2-19 and 2-20 illustrate pingos which are believed to be associated with frost heave processes.

The pingos seem to be of three general types as far as the writer is able to determine both from observation and from literature survey. These are: (a) the true pingos or frost mounds which are believed to be the result of upheaval of the earth's crust from pressure of ice from beneath the surface and (b) the isolated dome-shaped terrace remnant, which are the result of peculiarities of arctic erosion and dissection which rendered the mounds conical in shape, and (c) those mounds formed by upward flow of water and/or soils to the surface through an orifice of some type.

The mounds in the Arctic Coastal Plain are distinctively different from those which occur in other parts of the Territory. Many writers mention seeing them and have given short descriptions. Porsild, *(148, p. 46-58)* in his article on earth mounds suggest a theory concerning their formation. He describes mounds on the Seward Peninsula, mounds in the Mackenzie District and mounds in the Kotzebue District. The most outstanding type he describes are those which show signs of having been forced upward by pressure from below as suggested by the great cracks or fissures which occur in the crest of these mounds and radiate downward. He mentions some having hollow craters nestled in the cavity in the top. Some of the largest ones he describes as being 160 feet high and in one instance he tells of one having a circumference of 2700 feet. Of particular interest are his remarks about finding stratified soils in the inside of a particular pingo which consisted of interstratified lacustrine soils—clay and peat.

Smith *(135, p. 28)* in his report of the Noatak-Kobuk Region mentions seeing mounds in the Mission Lowland of the Noatak Basin and he says: "Here and there rounded hills one-half mile in diameter at the base rise 100 to 300 feet above the general surface of this plain. They are symmetrical in shape and, although irregularly distributed over the plain, suggest, when viewed from a distance, giant haystacks."

One of the best descriptions of the arctic mounds is that given by Leffingwell in his report on the Canning River *(128, p. 150 to 155)*. In describing those of northern Alaska he mentions that east of the Shaviovik River that the mounds are scarce and that west of the river they are abundant. In one instance he cites having seen about 30 mounds from a single point *(128, p. 150)*. He has measured mounds which were 230 feet above the plain. Most of the mounds have rounded tops and side slopes of less than 15 degrees; however, he has found some which were steep sided and having an angular break at the level top. Some of those he studied contained coarse gravel. Leffingwell, too, ventures a theory as to the origin of these mounds. In general his remarks can be summarized as follows. The large mounds have coarser material than the small ones and his theory of their formation is based on the following working hypotheses *(128, p. 153):* "(1) destructional—that they are erosion remnants left as manadnocks upon a peneplain; (2) constructional—(a) that they are a glacial deposit; (b) that they were formed by hydraulic pressure." In discussing these hypotheses he believes that the result of hydraulic pressure offers the best explanation. Briefly he believes that the freezing of the slightly tilted coastal plain soils from the surface downward formed an impervious barrier over tilted water-bearing stratum. The blocking of subsurface flow and an increase in hydraulic pressure resulted in fracture of the frozen layer and the formation of artesian springs. These springs caused the accumulation of soils into the form of mounds on the surface of the plain.

As a matter of interest, and by way of general observation, some of the pingos or frost mounds appear to be associated with the elongated lakes of the Coastal Plain since many of the mounds occur in the geometric center of elongated lakes and almost invariably in those lakes which are either in the process of drying up or which recently have been dried up. Several of these were visited by the Purdue party; one in particular was studied in detail and is worthy of detailed description. The mound in question was situated in the center of an elliptical lake the longest dimenson of which was approximately three-fourths of a mile. The surrounding rim was situated about 30 feet above bottom of the lakebed and was somewhat serrated. The mound was oblong and was estimated to be 85 or 90 feet in height. Situated in the mound was a great V-shaped cleft which extended more than half way down the mound. See Figure 2-19. The side slopes of the mound were quite steep and were covered with a dense mat of willow. The trees on the mound were much larger than the miniature willow in the surrounding area. Those on the outside of the mound were about four or five feet in height and were densely tangled. In the cleft of the mound the willows were six to eight feet in height. The bottom of the cleft contained about three feet of water; ice occurred beneath the water. The soils, as exposed on the sides of the cleft, were horizontally stratified and were tilted parallel to the outside slope of the mound. In this one instance the surface material consisted of brown peat underlain with three or four inches of what appear to be volcanic ash. Beneath the volcanic ash were stratified sands of various colors. The remainder of the material as exposed in the cleft was sand.

At this particular location there appeared to be a series of low benches or shelves between the mound and the highest rim which formed concentric patterns about the mound. There were various types of polygons and various stages of polygon development in this particular basin. The mound, together with the surrounding lake basin, had the appearance of having been formed recently since the normal processes of erosion had not begun to destroy or alter the surface features of the mound or the cleft in the mound.

Other mounds were studied and photographed on the ground and from the air in the northern coastal plain region. One of the largest mounds seen occurs as a prominent landmark near the Arctic Coast east of the Sagavanirktok River in the vicinity of the Kadleroshilik River. This mound is estimated to be over three hundred feet high and at least 1500 feet long. It was not possible to make a landing near this site but the mound appeared to be covered with gravel. It was irregular in shape and in surface outline.

From studies made on the ground, studies of air-photos, and studies of a reconnaissance nature from the air of many of these arctic mounds the following general statements can be made: (a) the mounds are situated in depressions which resemble old lakebeds; (b) the lakebeds are either dried up or contain very little water; (c) the lakebed soils generally contain a peat surface cover on top of stratified lacustrine sands and silts; (d) the mounds are surrounded by a polygon pattern within the confines of the lakebed which is arranged such that concentric groupings of polygons occur; (e) mounds do not occur in the high coastal plain areas where surface drainage is particularly well developed; (f) some mounds, which appeared to be young in their stage of development, were merely "bulged-up" areas and the polygon net appeared to cross the "bulge portion" without any apparent relationship to the axis of the bulge; (g) mounds vary in shape from nearly conical and somewhat symmetrical domes to irregularly shaped dome-like expressions; (h) for the most part the mounds in the areas east of the Colville appear to be older, larger, and more irregularly shaped than the mounds west of the Colville which appear to be young, newly formed, regular in shape, associated with recently drained lakes, and are little altered by erosion.

There are other areas of Alaska in which mounds occur which are believed to be formed by the upward flowing of water. One in particular, near Ruby, is described by Mertie and Harrington *(149, p. 8)*. This mound is about 75 to 100 yards long, is composed of fine sand and silt, and has a small water-filled crater in the crest.

Many have been interested in the mounds which occur in the interior of the Seward Peninsula which are of another type—those formed by erosion and are dissected terrace remnants. Collier *(107, p. 27)* compares them to "haystacks". Brooks *(103, p. 310)* calls them "hillocks or stratified gravels which stand here and there above the floor of the Kuzitrin lowland". Figure 2-21 shows some of the gravel mounds occurring in the Seward Peninsula.

13347
13648

13813
13338

(a) Arctic Coastal Plain, southeast of Barrow

(b) Arctic Coastal Plain, southeast of Barrow

(c) Arctic Coastal Plain, east of Colville River

(d) Arctic Coastal Plain, southeast of Barrow

Fig. 2-19 PINGOS IN NORTHERN ALASKA

13683
13414

15789
15670

(a) Arctic Coastal Plain near the Kadleroshilik River

(b) Coastal Plain near Kivilina

(c) Arctic Coastal Plain east of the Colville River

(d) Coastal Plain near Kotzebue

Fig. 2-20 **PINGOS IN NORTHERN AND WESTERN ALASKA**

10559
10741

15526
15527

(a) Kuzitrin River Basin

(b) Noxapaga River Basin

(c) Kuzitrin River Basin

(d) Noxapaga River Basin

Fig. 2-21 GRAVEL MOUNDS BELIEVED TO BE DISSECTED TERRACE REMNANTS, SEWARD PENINSULA

Elongated Sand Dunes

In discussing the many natural oddities of the Arctic one cannot help mentioning the numerous long sand ridges which, in general, occur at right angles to the major axis of the elongated lakes. (See Figure 2-22.) These sand ridges are long and narrow; they often attain a length of over a mile and a width of possibly a hundred yards. In height the dunes range from a few feet to perhaps 30 or 40 feet. They are oriented so that the long axis of the ridges have a bearing of a few degrees north of east, (True). In general the ridges which are believed to be wind-blown deposits, are regular in shape and seldom deviate from this bearing. These dunes are composed of fine sand and are generally confined to the sandy portion of the coastal plain; however, they do occur as a surface deposit on coastal plain material of a general silt texture. A few of the ridges or dunes end in crescents which give that portion of the dune a "barchane" shape. One large group of dunes extends from Atigru Point generally westward to the vicinity of Meade River. The general area affected by these dunes is a narrow band possibly 15 to 20 miles wide in the inner part of the lower coastal plain. It is interesting to note that many of the polygons in these areas do not cross the sand ridges; the ends of the polygon channels stop on the outer and lower slopes of the dunes.

Elongated Lakes

One of the outstanding features in the almost featureless Arctic Coastal Plain is the presence of a myriad of elongated lakes *(150), (151)*. Each of these elliptical lakes has its major axis generally along a bearing of a few degrees west of true north. (See Figure 2-23.) As a matter of interest bush pilots often use these lakes as navigational aids in determining approximate true north-south bearing. On the ground it is difficult to visualize or to appreciate the uniformity and regularity of such features as size and directional trend of these lakes. In general, the lakes are confined to the outer or lowest portion of the Coastal Plain Province. The greatest concentration of these lakes occurs between Wainwright and the mouth of the Colville River. East of the Colville River the lakes are smaller in size and occur less frequently. Along the northern coast, particularly between Barrow and the Colville River, the lakes, or lakebeds, abruptly end at the coast line without passing through a transition zone; this indicates that wave cutting and other types of beach erosion are removing the coastal plain materials faster than normal processes of erosion of the land surface. Scattered elongated lakes of a similiar nature occur in the narrow coastal shelf generally between Kotzebue and Pt. Hope. However, some of these are being destroyed by beach erosion; some are being covered by beach deposits. These lakes are not as outstanding or as significant as those in the northern coastal plain; however, some clue as to the mode of origin of the elongated lakes in any geographic location may be obtained by a detailed study of some of those occurring in the Kotzebue-Pt. Hope region. Texturally, the lakes occur in areas of fine sand and silt of the Arctic Coastal Plain.

There is considerable discussion as to the origin of elongated lakes of this type *(150) (151)*. Scattered throughout other parts of the world, particularly in coastal plain soils, are similar features which may or may not be related in method of origin. For example the Carolina Bays *(152)* which occur in the coastal plain soils occur in clusters, are elliptical in shape, and are directional in trend. Similarly, there are bays in part of the Texas Coastal Plain. Several theories have been advanced on the formation of these elliptical bays among which include meteor showers and related craters, certain erosional processes, solution sinks developing in the coastal plain, and depositional activity related to the ocean currents *(152)*.

From airphoto study and observation in the field these elongated lakes occur in a variety of situations. They are often rather large (two or three miles in length) and some appear to be rather deeply incised in the coastal plain; these usually contain deep water. Frequently they are low topographically and do not have an abrupt or steep shore line; some of this type contain shallow and rather brackish water. One interesting observation about the lakes which are incised below the plain is that the surrounding rim is not everywhere at the same elevation. In some instances the rim, or shore, at the ends of the major axis are 75 to 100 feet high while the rims on the sides are approximately 10 to 30 feet high. In general, the lakes which are situated low topographically and whose water surface is not much lower than the surrounding rim, have an outlining rim which is serrated.

Many of the lakes are being invaded slowly by vegetation consisting of a tangled mass of reeds and other swamp-type vegetation which often extends far out into the lake proper; this makes float-plane landings difficult. Quite often it is possible to trace polygon cracks or great earth cracks of some type on the floor or bottom of the lakes in the shallower portions, particularly when the wind does not break up the water surface thereby permitting visibility.

Some of the elongated lakes no longer contain water and they exist as grass-covered oval depressions—often marked with polygons. The basins are quite regular, inasmuch as the basin topography slopes in all directions toward the center or major axis. In many of the lakebeds an outstanding feature is the regularity of the arrangement of polygons into a series of concentric groups of polygon rings.

These may or may not be associated with certain stages of lakebed development or degradation. Some lakebeds are almost perfectly flat and contain no visible polygon markings.

Thermokarst

Thermokarst generally refers to lakes or basins in permafrost areas which are believed to have been formed largely by thawing and settlement of large masses of ground ice. The resulting depressions, in contrast to the oval lakes of the coastal plain, are irregular in shape. Figure 2-24 illustrates thermokarst markings.

Wallace *(134, p. 2)*, who has made a considerable study of permafrost and thermokarst near Northway defines thermokarst as follows: ". . . lakes whose basins result from ground caving after thawing of materials which occupies less volume when thawed than when frozen. The term 'thermokarst' alludes to the similarity of origin and appearance of these lakes to the better-known karst lakes in areas underlain by limestone. Both are formed by subsidence of the ground surface, which in the one case is caused by shrinkage of subsurface material as a result of thawing and in the other by the removal of underlying bedrock by solution."

Thermokarst lakes are characterized by a scalloped shore line *(153)* and by leaning or "S" shaped trees. Moffit *(154, p. 121)* describes thaw sinks as being characterized by vertical banks with overhanging fringes of moss and vegetation. The slumping of the banks in many cases causes the trees to fall inward creating a "radial" arrangement. Thaw lakes or thaw sinks occurring in the Seward Peninsula are described by Hopkins *(155)*.

ENGINEERING SIGNIFICANCE

With regard to the effect of permafrost on engineering construction, it has been found that both good and bad soil areas occur in the permafrost region. For the most part the good construction areas contain well-drained granular materials which occur in elevated positions in comparison to the surrounding terrain. The poor areas generally consist of fine-grained soils with subsurface ice layers and ice wedges extending both laterally and vertically. The latter areas frequently contain, although not always poorly-drained soils located in depressed situations.

The successful performance of engineering structures in permafrost regions is contingent on the proper identification and areal extent of permafrost and the location, design and construction of the structure in relationship to the permafrost. Engineering construction on frozen soil is difficult and costly—the degree of permafrost, topographic position, surface drainage, soil texture, and depth of overburden are all important features. The destruction of the surface-insulating blanket of peat and moss either by heavy equipment or by complete removal creates perhaps one of the most serious problems—that of thawing. The difficulties involved in such a situation depend on natural surface drainage, soil textures, depth of overburden, and presence or absence of ground ice. Frozen soil and ice-soil mixtures are stable until disturbed *(156)*. In general, granular soils can be permitted to thaw without severe subsidence or loss of supporting power. In contrast, fine-textured soils become unstable and will carry little or no load when thawing occurs. This is extremely important in the location and design of large structures such as airfield hangers, heated buildings, or runways *(157), (158), (159), (160)*. Figures 2-25 and 2-26 illustrate the severity of thaw in permafrost regions. Considerable engineering experience has been gained by construction in permafrost regions as indicated by Levin *(161)* in his report on foundation design, by the Engineering News-Record reports *(162)* covering construction of an earth-fill dam, and by the many references covering construction of highways, airfields and flight strips, pipe lines, and other types of engineering structures *(75), (163 to 174, inclusive)*. The problems associated with the construction and site selection of roads, airfields, buildings, and other engineering works as they apply to military installations are discussed in War Department TB 5-255-3 *(170)* and by S. W. Muller *(129)* in his discussion of permafrost and related engineering problems. The proceedings of a school held by the Alaska District, C. E. contain several papers and discussions on permafrost and associated problems *(171)*. A short discussion about permafrost problems is also presented in an issue of the Civil Engineer Corps Bulletin *(175)*. Considerable work has been done by Alter on sewage problems in Alaska for the Alaska Department of Health *(176)*.

Highway Significance

In order to fully appreciate the highway engineering significance of the effects of permafrost it is necessary to observe performance on some of the highways which have been constructed in the Arctic and Subarctic. Figures 2-27 and 2-28 illustrate highway problems in permafrost regions. As far as highway problems are concerned in permafrost areas the most serious problems are those associated with frozen-silt soils which have a large amount of ice in the soil mass. The most detrimentally frozen soils are those which occur in association with either polygons or those colluvial silts which occur on the lower and outward slopes of hills in rolling topography. Needless to say highways constructed on polygon areas suffer from severe settlement and pavement distress resulting from thaw and loss of subgrade support. The difficulty of working in polygon areas

16115
12495

16170
16161

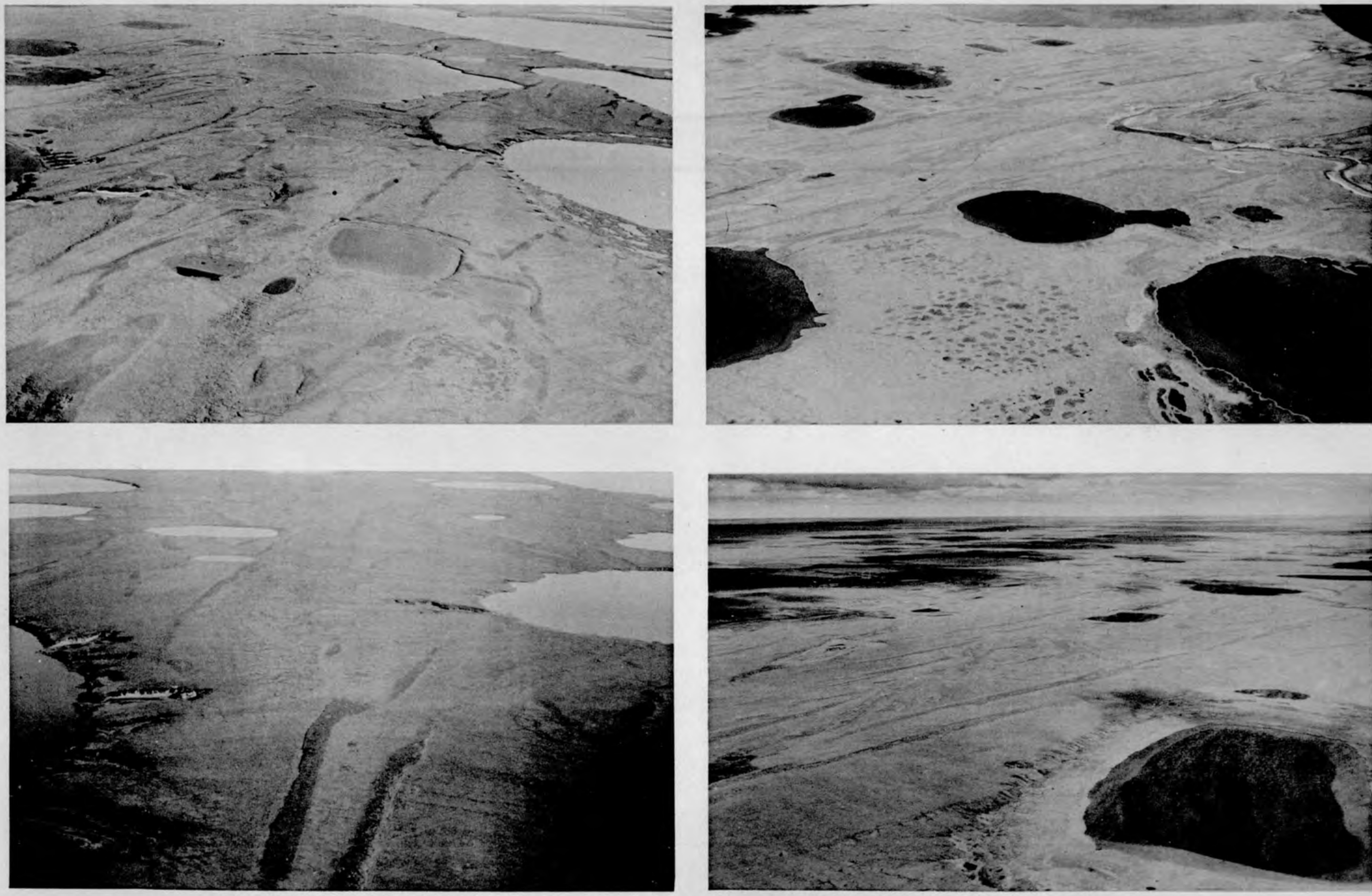


Fig. 2-22 **ELONGATED SAND DUNES IN THE ARCTIC COASTAL PLAIN**

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13430

13426
15915

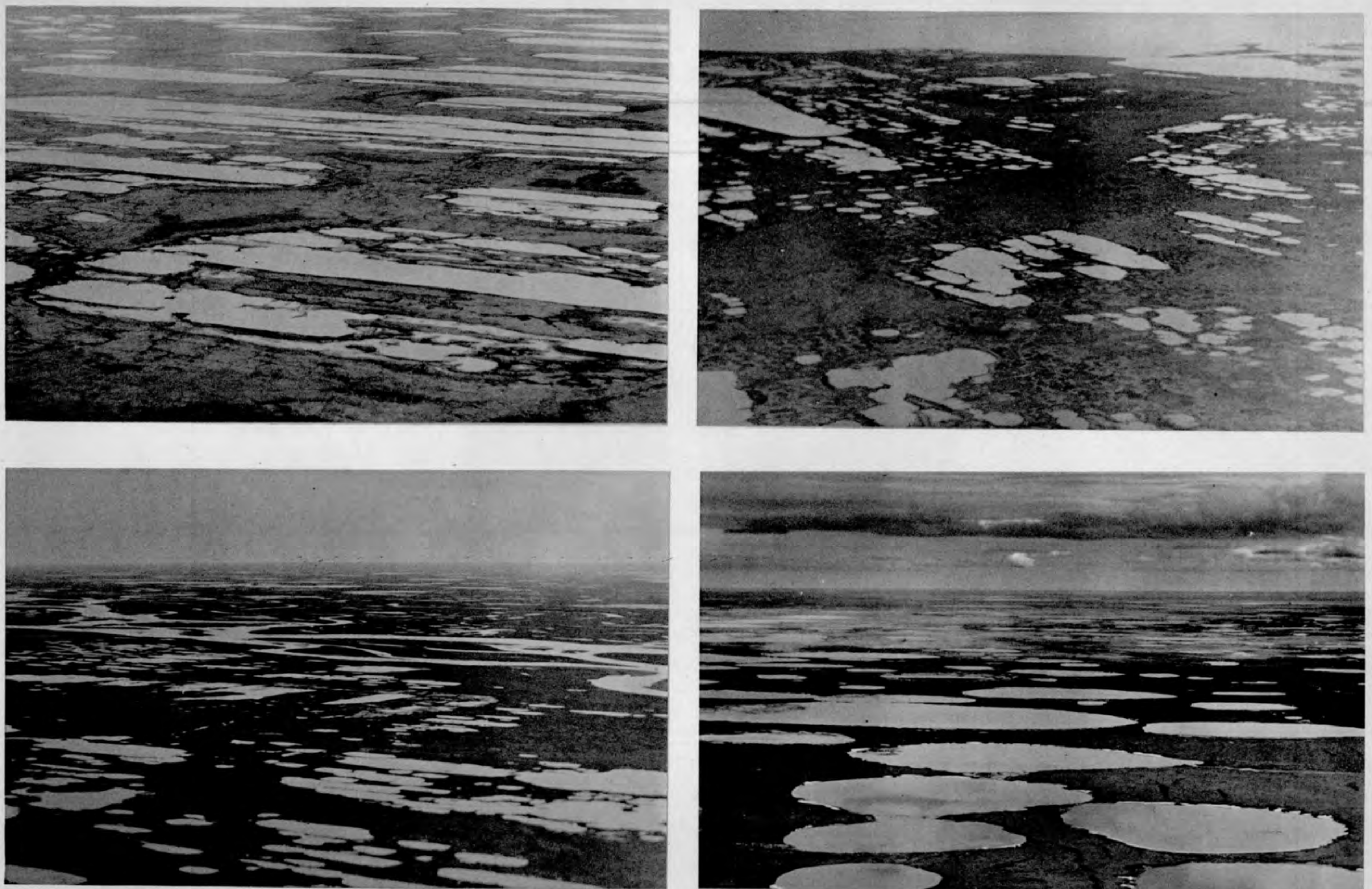


Fig. 2-23 EELIPTICAL LAKES IN THE OUTER COASTAL PLAIN

15675
12271

17548
12764

(a) Kotzebue Sound

(b) Northway

(c) Bethel

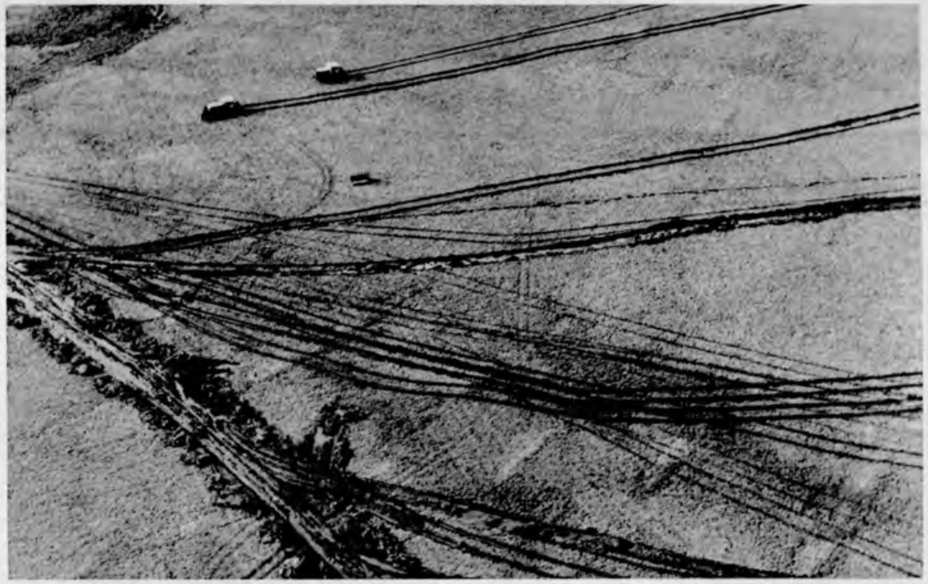
(d) Yukon

Fig. 2-24 LAKES BELIEVED TO HAVE BEEN CAUSED BY THERMOKARST PROCESSES

13386
10409

13326
13211

(a) Stream terrace, Umiat



(b) Coastal Plain, southeast of Barrow

(c) Flood plain, Northway

(d) Stream terrace, Umiat

Fig. 2-25 THAW IN THE "TRACKS" LEFT BY HEAVY EQUIPMENT

10389
13733

16311

(a) Unchecked highway culvert effluent

(b) Seven foot cavity in the "cat tracks" in 24 hours of thaw, Barter Island

(c) Drainage ditch thaw near Umiat

Fig. 2-26 ACCELERATED EROSION RESULTING FROM RUNNING WATER PASSING OVER FROZEN SOILS

10526
16251

13125
13730

(a) Highway crossing polygon channel, Seward Peninsula

(b) Thaw and poor subgrade support, Steese Highway

(c) Highway crossing polygon channels, Barter Island

(d) Gullying along the shoulder, Umiat

Fig. 2-27 VARIOUS TYPES OF HIGHWAY FAILURES IN PERMAFROST AREAS

12811
13127

12809
17652

(a) Settlement of a fill near Goldstream

(b) Fill settlement in frozen silt, near Goldstream

(c) Thaw caused by ditch, Steese Highway

(d) Spring break-up, Alaska Highway

Fig. 2-28 VARIOUS TYPES OF HIGHWAY AND RAILROAD FAILURES IN PERMAFROST AREAS in the summer time is incomprehensible because of the rapidity of thaw progression once the surface insulation of vegetation has been destroyed. A few passes of heavy equipment over such material during the summer renders them impassable. In particularly level areas the accumulation of surface water becomes a severe problem because of the difficulty of providing drainage and the difficulty of draining peat and silt even though the drainage ditches could be constructed and made to function properly. The problem of handling surface water in frozen-silt materials makes ditch construction of some consequence because of the abnormal rate of thaw which will result when running water passes over frozen silts.

In the southern part of permafrost regions the depth of seasonal thaw is much greater than that in the northern part. This fact together with a generally lower soil temperature tends to increase the seriousness of unnatural thaws due to construction. In the northern areas soil temperatures are much colder and the depth of seasonal thaw is less which fact makes the use of some heavy construction equipment somewhat easier during the period of maximum thaw. The drag on the under carriage of heavy equipment caused by accumulations of peat, moss, and unfrozen soils which are pushed ahead will, in short time, render heavy equipment ineffective. Little power is left for grading or removal of moss and other unfrozen materials when this condition occurs. Heavy equipment experiences little difficulty in traction or blading in the far north where the annual thaw is shallow. However, once an area has been disturbed by heavy vehicles or once the vegetation has been removed, the area, if silt, is soon rendered non-trafficable for additional heavy vehicles.

As far as highway construction is concerned polygon areas and frozen silt are to be avoided at all cost particularly if there are other location possibilities within reasonable distances. To illustrate the severity of the permafrost factor in highway construction a description of a short stretch of road on the Seward Peninsula is given. This road crosses polygons with the exception of a short stretch which is part on rock and part on gravel. Part of this road was constructed using willow sticks and other brush as part of a base. Gravel is abundant in the area at scattered locations, particularly where the silt and peat overburden is shallow or absent. The major part of the road consists of a gravel fill on frozen silt and a minor part of a gravel fill on the mat built up of branches and willow sticks.

During the time this area was visited the maintenance crew was actively engaged not only in extending the road but in maintaining the existing road as well. It was noted that at every place where the road crossed a polygon channel a severe settlement had occurred leaving a pond of considerable size in the road. The area in between polygon channels along the road right-of-way was suffering from severe settlement inasmuch as the entire gravel fill (which in reality would have amounted to several feet) had settled until the entire road surface was slightly lower than the surrounding ground surface. The only traffic on the road was maintenance trucks which were hauling gravel for the road extension. The areas between the gravel pit and the portion being extended were suffering the most severely from the effects of traffic and thaw. Hence, it became a matter of continuous maintenance on the road particularly in the polygon channel areas to keep the road in such a condition that additional gravel could be hauled for the extension. The foreman of the maintenance crew stated that many truck loads of gravel had been dumped in some of the polygon channels only "to gradually sink out of sight". The areas of road which were on natural gravel or bedrock were performing satisfactorily. Those areas in which branches had been used in the subgrade were performing more satisfactorily than were those where the branches were not used. Additional traffic on this road would in a short time necessitate abandoning the project.

Highway construction of any type is to be avoided in depressed-center type polygon areas; it is almost out of the question because of the excess surface water and the generally swampy condition together with the possibility of large amounts of ground ice in the centers of the depressed polygons. Such areas are extremely difficult to cross with ordinary construction equipment. Special equipment such as "weasels", "alligators" or "camels" can cross these areas with little difficulty.

Airfield Significance

Because of the topographic requirements for airfields, site selection and the permafrost problem become more acute. Airfields, for the most part must be confined to physiographic features associated with water deposition. This includes coastal plains, broad valleys, and outwash. It is in water deposited soils that the widest variations occur both in soil textures and in permafrost conditions. Texturally, alluvial soils range from gravels to silt (clay sized material is, in general, rather scarce). Permafrost conditions vary from unfrozen in high gravels to detrimentally frozen in depressed silts containing numerous polygons and considerable ground ice. As far as engineering conditions are concerned it goes without saying that the best sites are the unfrozen well-drained gravels. Perhaps next in order of preference are the frozen gravels, frozen sands, and last but reluctantly—the frozen silts. Wherever possible all engineering construction should be confined to the more granular soils which in many instances are unfrozen.

In Alaska it is possible to study the performance of structures as related to soils and permafrost because airstrips and other structures are situated on a variety of conditions of soils and permafrost. Figures 2-29 to 2-32 depict airfield problems in permafrost regions. As an example, the airstrip at Big Delta is situated on a well-drained and unfrozen gravel terrace—an ideal situation as far as engineering soils are concerned. There is little or no difficulty resulting from frozen subsoil as far as engineering performance is concerned. Soil conditions in some of the natural levees are similar to those associated with high gravel terraces with the exception that a proposed runway may be crossed by several silt-filled channels which are potential frost heaving materials. One airstrip in a broad valley is for the most part constructed on frozen silt; however, one end of the strip is on sand which is a terrace remnant. A performance survey of this runway showed that the portion in sand was performing satisfactorily and that the surface was relatively smooth while the part of the runway on silt contained numerous settlement areas and had many cracks in the pavement. The performance was rated poor. This portion of the runway was rather rough at the time of the survey. In addition to the difficulty experience on the silt portion of the runway the buildings were suffering severe distress due to settling associated with thaw. Figure 2-33 shows satisfactory pavement performance in areas of good engineering soils. Reports have been prepared by the U. S. Geological Survey on some of the airfields of Alaska—they are listed in the bibliography *(177), (178), (179), (180).*

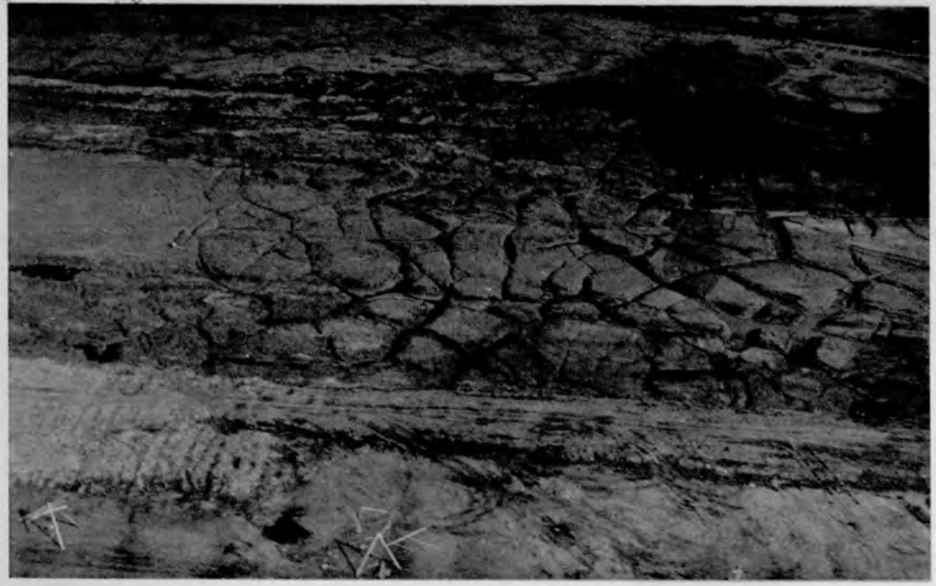
Scattered throughout the permafrost regions are numerous small airstrips which are used largely by miners and bush pilots. These also are constructed on a variety of soil and permafrost types. In many instances these have been constructed in polygon areas and the polygon channels provide rough spots even though considerable fill material has been used in leveling the area following the melting of ice. The airstrip at Circle is crossed by a network of polygon markings. Many areas have been cleared of the moss and vegetation only for the personnel to discover that the severe thaw associated with the polygon channel rendered the strips in-operational. As an example, the airstrip at Atkasuk, the small strip at Lava Lake, and the addition to the winter runway at Barrow are outstanding.

The series of elongated sand dunes which are scattered throughout the Arctic Coastal Plain are, from an engineering soils standpoint, potential airstrip sites. These can be used for emergencies with little or no preparation. In one instance a small airstrip was situated in part on the sand dune and in part on the adjacent silt and as far as engineering performance was concerned the sand soils performed satisfactorily while silt soils did not.

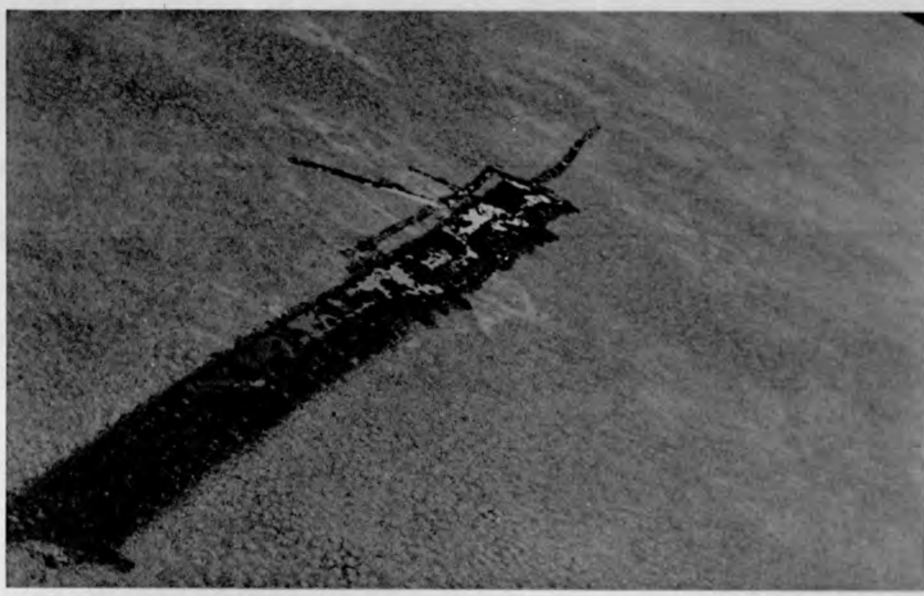
Considerable research is needed in many regions of Alaska in order that the many problems peculiar to construction in permafrost areas can be studied and solved. Figures 2-34 to 2-39 illustrate the effects of permafrost on other structures in Alaska.

16189
16452

10732
16041



(a) Barrow, winter strip



(b) Lava Lake strip

(c) Airstrip at Circle

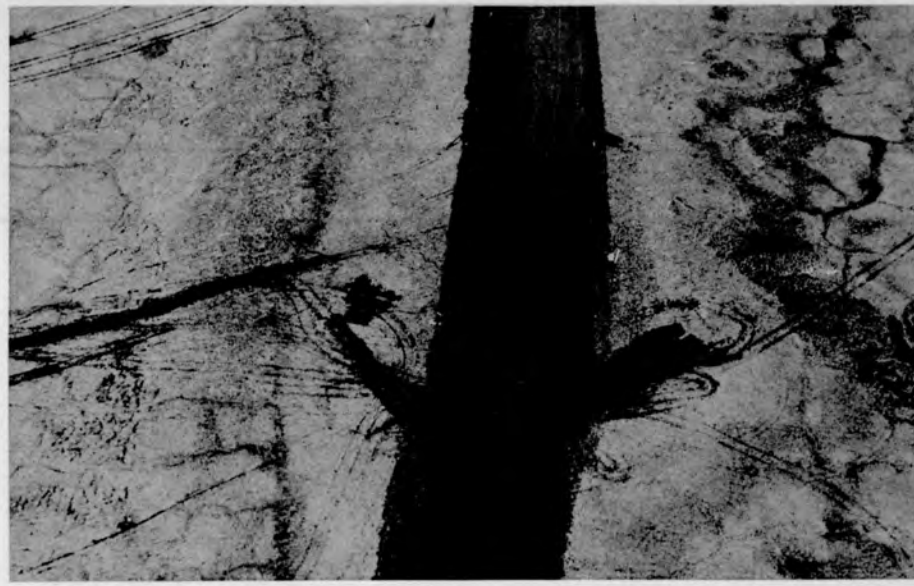
(d) Airstrip at Atkasuk

Fig. 2-29 GRADED AIRSTRIPS IN POLYGON AREAS

16116
16174

13334
16117

(a) Emergency strip on a sand dune



(b) Emergency strip on a sand dune

(c) Airstrip on a beach ridge

(d) Surface of strip on a sand dune

Fig. 2-30 TWO EXAMPLES OF WELL CHOSEN SITES IN PERMAFROST SOIL AREAS

16474
10407

13471

(a) Soft and wet spots in a gravel surface

(b) Crack in a gravel surface

(c) Severe settlement

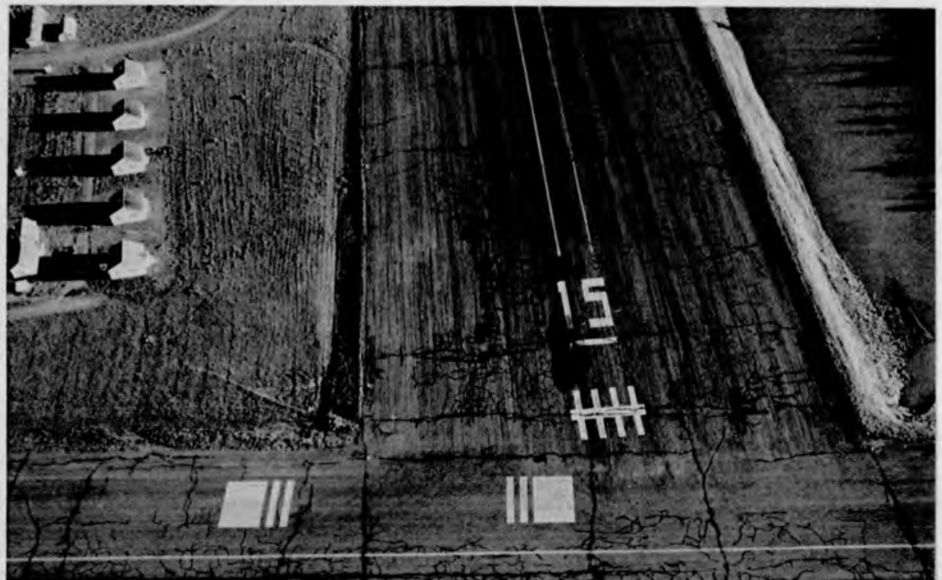
Fig. 2-31 SEVERE PAVEMENT DISTRESS RESULTING FROM PERMAFROST INFLUENCE AT AIRFIELD RUNWAYS

9009
16758

13178
13116

(a) Construction in a silt-filled channel

(b) Subgrade settlements



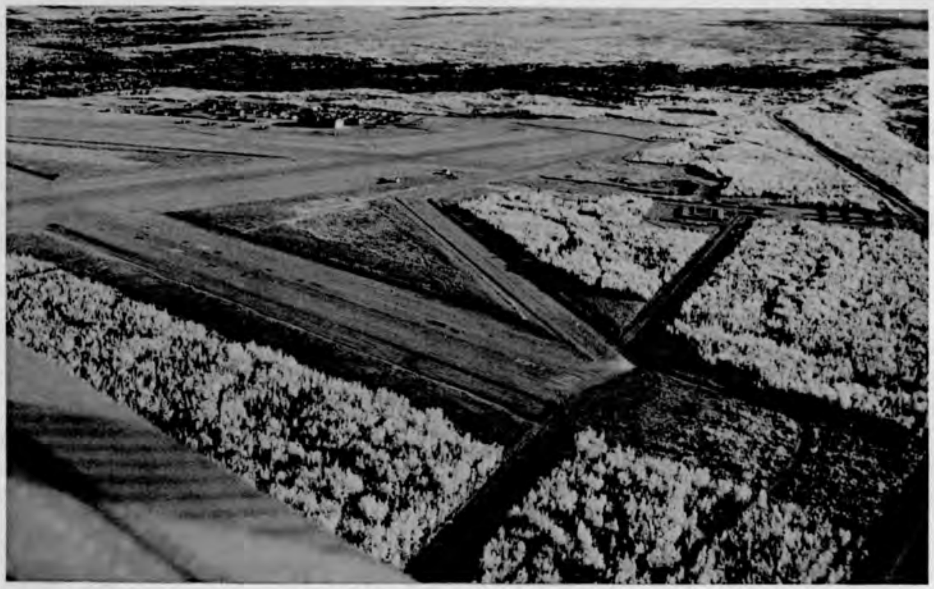
(c) Excessive cracking

(d) Silt-filled channel

Fig. 2-32 PROBLEMS AT MAJOR AIRFIELDS, IN PART DUE TO PERMAFROST

17751
16719

18642
11783



(a) Runways on gravel terrace

(b) Gravel Outwash soils

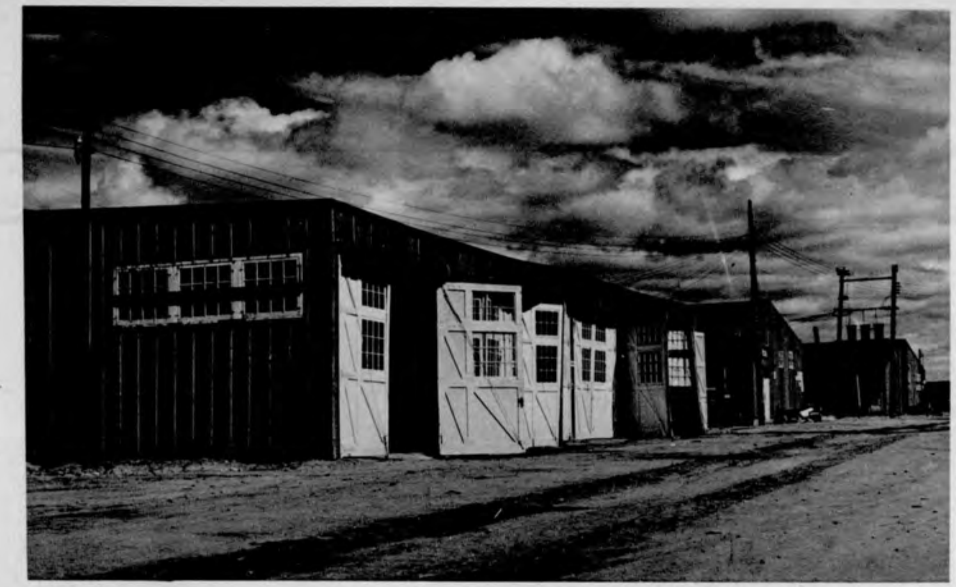
(c) Airstrip on a gravel outwash

(d) Airstrip on a gravel terrace

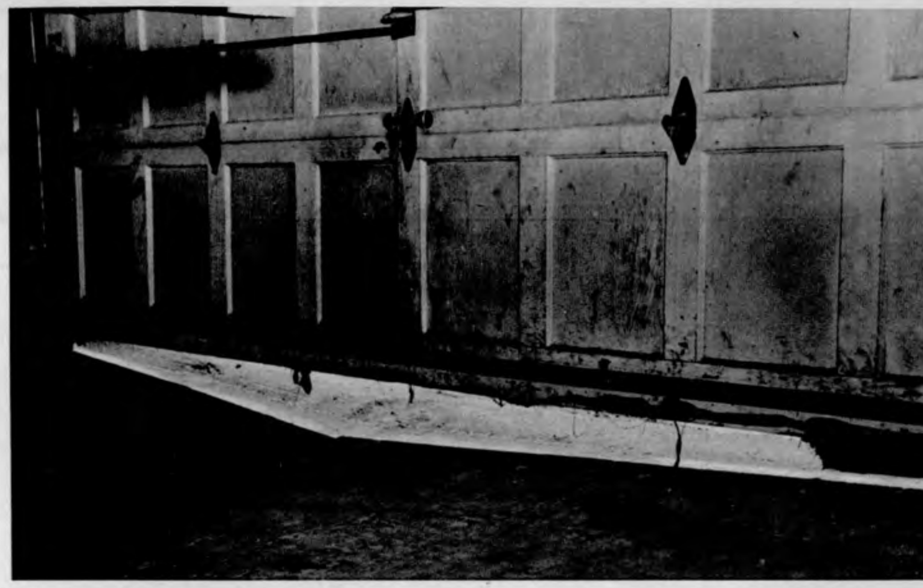
Fig. 2-33 EXAMPLES OF GOOD PERFORMANCE OF RUNWAYS IN GOOD ENGINEERING SOIL AREAS

12100
12655

12652
12651



(a) General view



(b) Floor slab settlement

(c) Severe break in the concrete floor slab

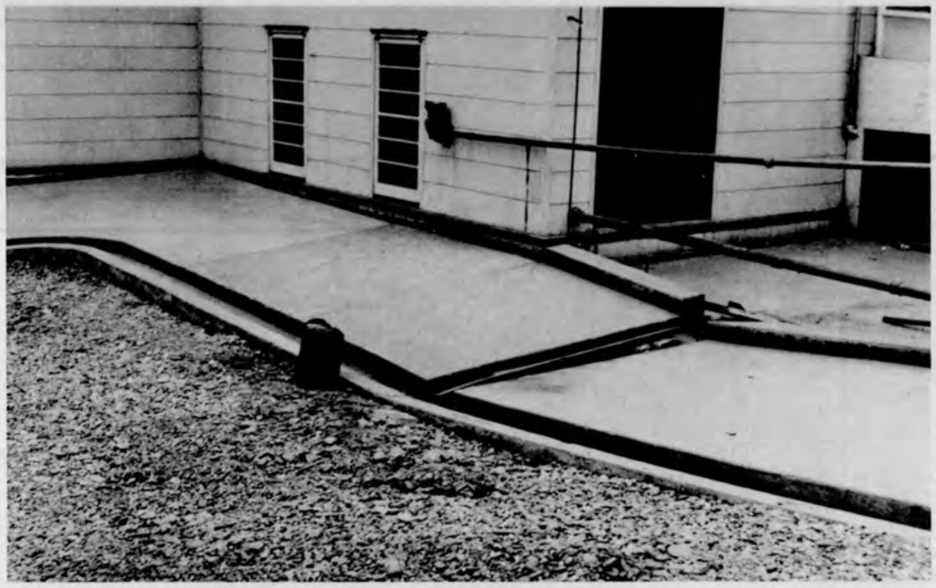
(d) Floor settlement as indicated by the door alignment

Fig. 2-34 SEVERE SETTLEMENT OF A GARAGE AT NORTHWAY

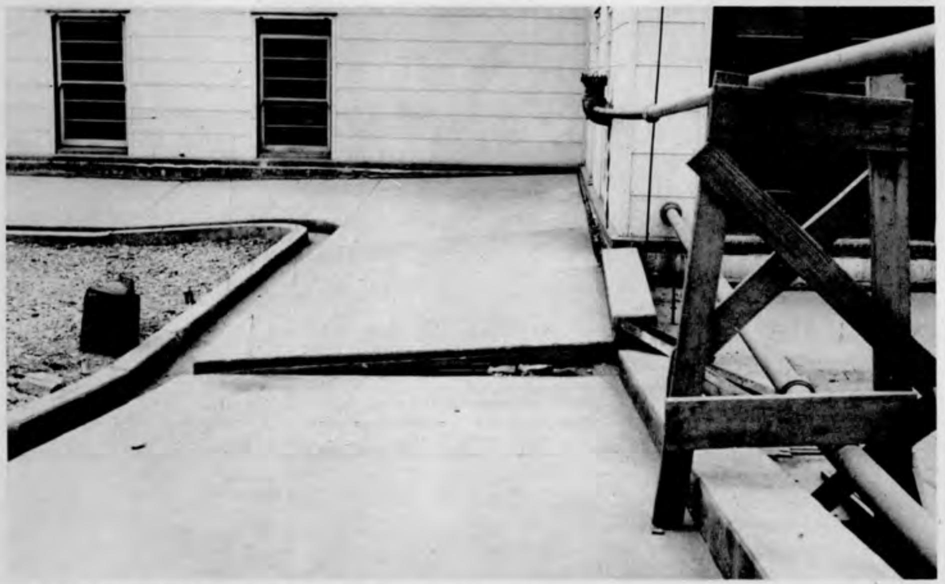
10467
11081

11080
11085

(a) Nome Post Office



(b) Settlement indicated in the sidewalk



(c) Settlements indicated in the sidewalks

(d) The floor has pulled away from the door jam

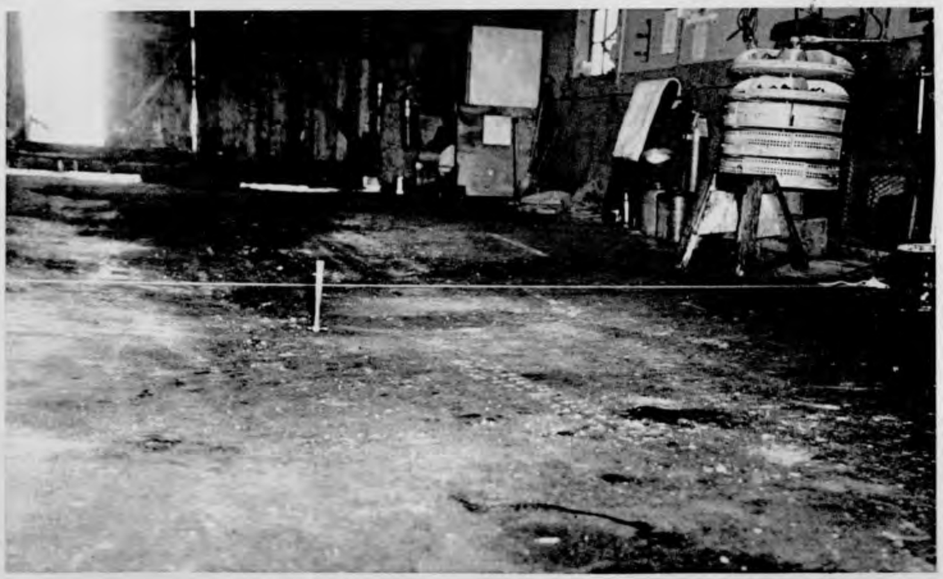
Fig. 2-35 SEVERE DISTRESS IN THE NOME POST OFFICE RESULTING FROM PERMAFROST DIFFICULTIES

16241
16237

16307
16337

(a) Thawing subsoil

(b) Placing a gravel fill on thawing peat and silt



(c) Settlement in a garage

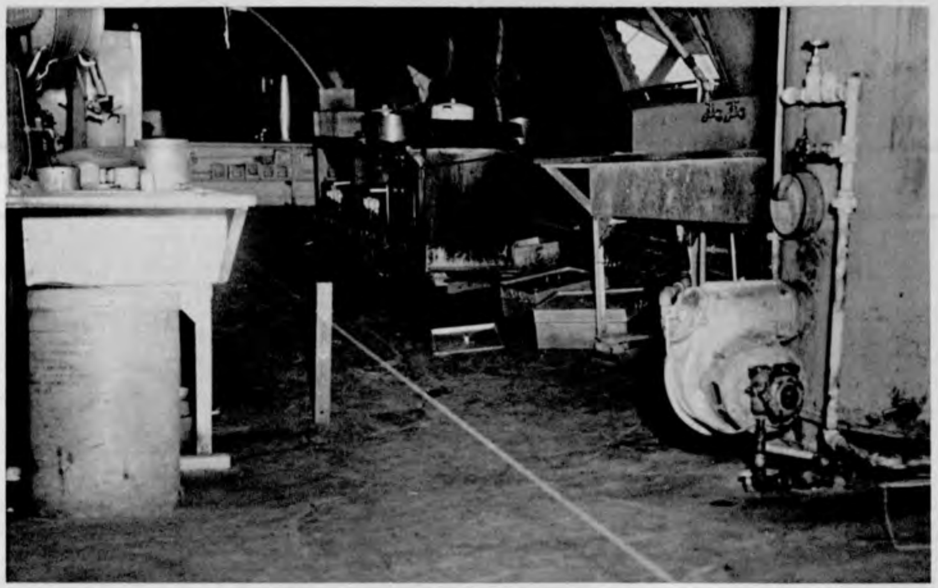
(d) C-47 stuck in soft gravel

Fig. 2-36 PERMAFROST PROBLEMS AT A SMALL AIRFIELD

16236
16227

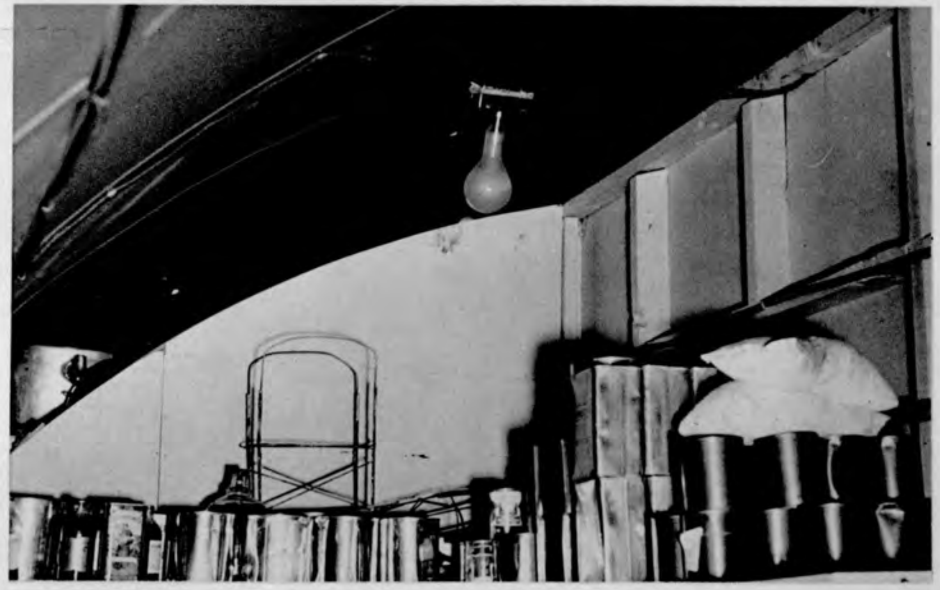
16233
16229

(a) Settlement beneath the stoves



(b) Floor settlement as indicated by the chalk string

(c) Leaning and propped-up utilities



(d) Separation of wall from the roof

Fig. 2-37 PERMAFROST DIFFICULTIES IN A MESS HALL

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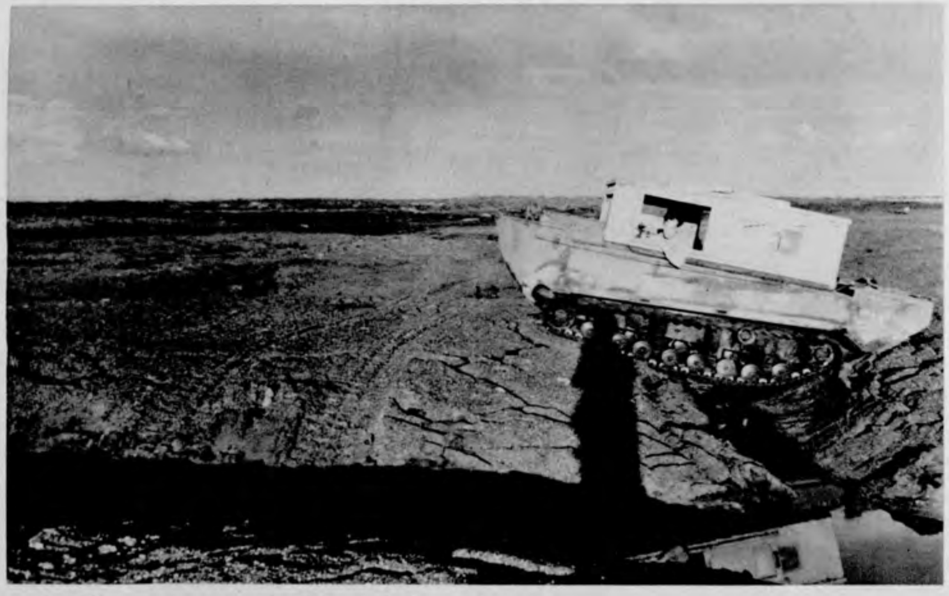
15997

(a) Use of piles for a new building



(c) Thaw cracks in the winter runway

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(b) Floor settlement in a warehouse

Fig. 2-38 PERMAFROST PROBLEMS AT PT. BARROW

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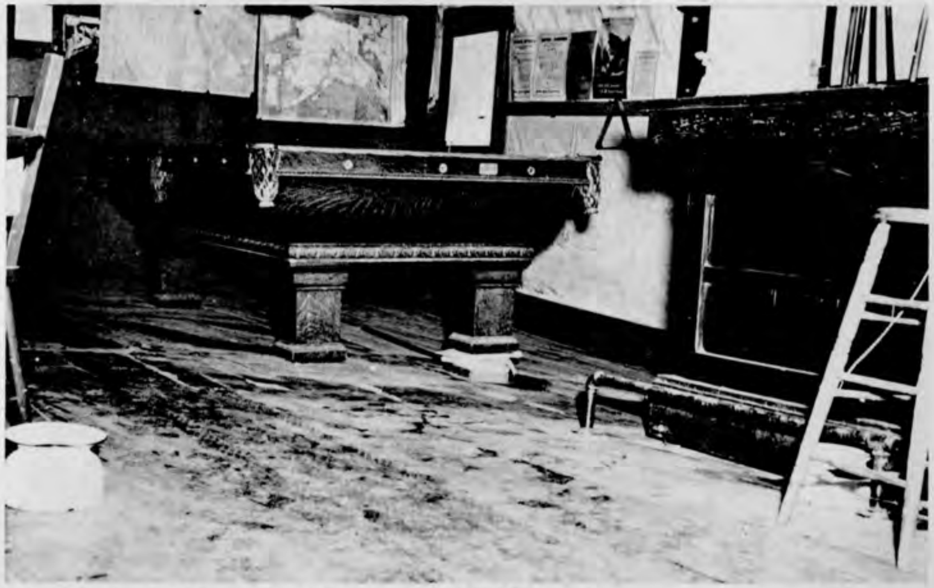
(a) Private dwelling, Nome

(b) Telephone pole construction in permafrost areas

(c) Private dwelling, Fairbanks



(d) Floor settlement, Livengood Pool Hall

Fig. 2-39 OTHER PERMAFROST PROBLEMS

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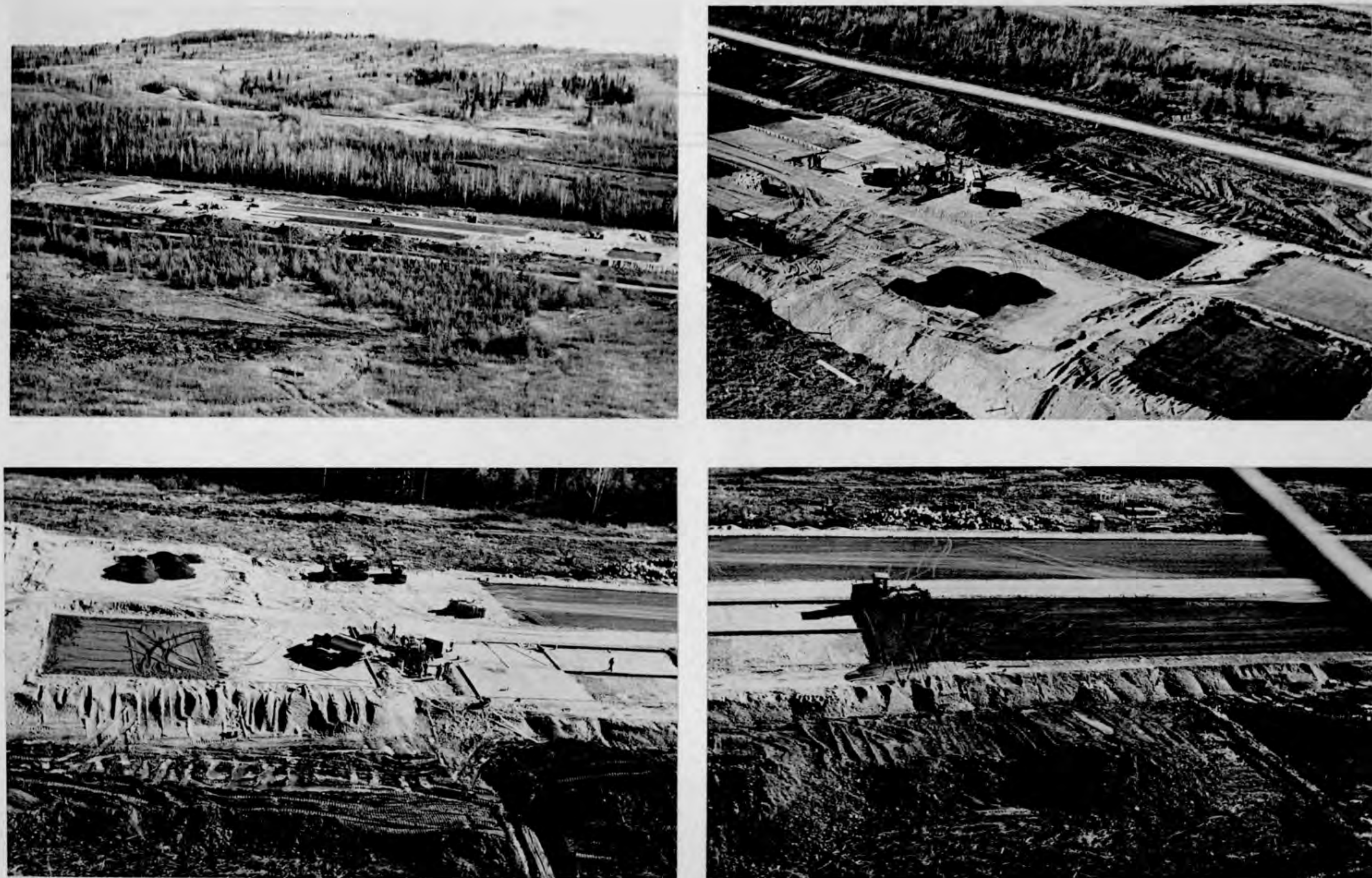

Fig. 2-40 PERMAFROST RESEARCH AREA NEAR FAIRBANKS—TYPICAL RUNWAY SECTIONS

CHAPTER III

THE TECHNIQUE OF AIRPHOTO INTERPRETATION OF ENGINEERING SOILS

An aerial photograph is a picture of the earth's surface which records both the natural and man-made features. An individual studying a photograph will see and recognize certain objects with which he is familiar. He will evaluate these in the light of his background and experience. At first glance an airphoto may show only a dense forest cover or a cultivated region with a patchwork of field shapes. To the geologist, in contrast, the aerial photo reveals the structure of rock formations and the arrangement of physical features as influenced by certain geologic processes, regardless of forest cover or cultivation. To the agronomist, the same airphoto provides a method of evaluating crop cover, agricultural possibilities, or soil erosion. The forester may be interested primarily in the type and amount of timber cover. The photogrammetrist is concerned chiefly with obtaining reliable measurements from photos, correcting various distortions, and aerial photos for mapping. The engineer is concerned with many and varied uses, some of which apply to regional planning, flood control, the location of a certain structure or any of a number of other uses. Thus, it can be seen that each specialist in his own field, whether he is a geologist, agronomist, geographer, conservationist, or one of a number of others, will attempt to evaluate the features indicated in a photo in line with his experience, background, and interest.

This study is devoted to the presentation and discussion of a method of analysis of airphotos largely for the engineer, or for the person who has the task of evaluating natural surface conditions in connection with engineering needs. Primarily, it is aimed at a method of using airphotos for soil evaluation in connection with location, design, construction, and maintenance of bases, airfields, highways, and railroads, particularly in arctic and subarctic regions. This manual and the methods set forth will be of greatest value to the engineer when used for preliminary surveys involving reconnaissance of large areas. It is not intended that the airphoto method replace the ground survey nor is it intended to infer that the airphoto method can produce the ultimate in accuracy. It is to be stressed that the airphoto method is a tool which, when used properly, will greatly assist the engineer in problems influenced by surface materials.

The purpose of this chapter is to review the techniques of airphoto interpretation in order that the reader can best understand the information contained in the remainder of the report. This chapter contains a discussion of the Limitations of the method, Principles involved in the method, and Procedures to follow in identification and evaluation of patterns.

LIMITATIONS

Before considering the procedures used for airphoto interpretation it is important that the limitations imposed on this method of survey be discussed in order that the interpreter may learn to recognize conditions beyond which he cannot successfully evaluate. These limitations may be discussed under three main headings as follows: Natural, Photographic, and Human.

Natural

In order to evaluate soil conditions from airphotos, certain natural conditions existing at the time the photography was obtained must be considered. Usually, these conditions can be interpreted and evaluated by observing deviations from the normal of some of the natural patterns. The limitations imposed by nature include anomalies caused by climate, erosional features, and vegetation.

CLIMATIC. The climatic influence is important in connection with erosional features and soil-color tones and it imposes a serious limitation for soil-texture interpretation. In general, the climatic influence is indicated on the photos by the distribution and type of vegetation, or by the absence of vegetation. Super humid and tropical conditions are usually associated with a dense vegetative cover in which individual trees are large and so closely spaced that details on the ground surface are often completely obliterated while in arid regions an almost complete absence of vegetation is apparent. Figure 3-1 compares average vegetative cover patterns in such general climatic zones as tropic, humid, subhumid, semiarid, arid, and arctic.

Soil color tones are influenced materially by the prevailing climatic conditions. To illustrate the importance of the climatic limitations and its effect on soil color tones, it has often been said that "light-textured and well-drained soils will photograph light in color while poorly drained and fine-textured soils will photograph dark in color". This statement is true when the climatic influences are evaluated properly. For instance, a dry sand dune on a sand plain in a humid region will photograph light in color against a dark background because of the influence of topographic position on the drainage characteristics rather than because of a difference in soil texture. In contrast, a sand dune in an arid region on a sand plain will photograph to a color tone similar to that of the surrounding sand plain because there is usually not sufficient moisture in either situation to cause an appreciable color-tone difference.

Figure 3-2 illustrates patterns of sand dunes under different climatic conditions. In part (a), the sand dunes are situated on a sand plain and exist under arid climatic conditions. Color tones of the dune and of the surroundings are similar shades. Note that sunlight and shadow provide a color tone differential between opposite faces of each dune. Part (b), of Figure 3-2 exhibits high contrast, in print tones because the dunes are constantly shifting because of wind action which together with a clean, non grass-covered, sand creates the extreme white pattern. The high reflection of sand grains also adds to the general brilliance.

In part (c) the dunes have the same general color tone as the adjacent sand plain even though the general climatic conditions are rated as humid. This is because of a generally dry season preceeding and during the time of photography. Part (d) is similar to part (a) except that part (d) represents a sand dune condition in Alaska under low rainfall. Part (e) shows a sand dune pattern in a cultivated region (humid) during a rather wet season.

In contrast to the above conditions clay soils can photograph either light or dark depending on the moisture content and the general climate. Hence, the same tone relationships may hold true for clays which exist for sands. With this in mind, the element of soil-color tone may be unreliable, if the climatic factor is not evaluated properly.

SEASON. Of major importance in the evaluation of soil conditions is the season of the year during which the photography was taken. The date of the photography is usually indicated in one of the margins of the photos; however, it is possible from a study of the photos to determine by inference the season and general conditions under which photos were made (See Figures 3-3 and 3-4). In cultivated regions, this may be in the form of certain stages of crop development as indicated in the fields. Exceedingly contrasting soil-color tones with excessive surface water may indicate photography taken shortly after heavy rains. The general season of the year in timbered areas may be indicated further by the coloration of the foliage of deciduous trees or by the absence of foliage in the case of winter photography. Winter photography is also indicated by the presence of ice in lakes and small streams and by snow sweeps in prairies and by snow-filled gullies in dissected topography. The interpreter, therefore, must be able to recognize the climatic influence before he can place much reliability in color tones, vegetation, and erosional features.

VEGETATION. With respect to vegetation, two additional natural conditions are important in certain climatic zones namely direction of sunlight as indicated by shadows, and the location of the timber line with respect to latitude, elevation, and exposure to sunlight. The latter factor is important, particularly in subarctic regions where the timberline is relatively low topographically and varies considerably in location depending upon the exposure conditions (Figure 3-5). For instance, in some situations the north-facing slopes will be mantled with spruce whereas south-facing slopes will be mantled with aspen. Near the northern limits of timber cover, the east- and south-facing slopes may be timbered while the north-facing slopes are barren.

Mr. E. G. Stoeckeler (78, *p.* 27) in his report on arctic and subarctic vegetation says that the interpreter should realize that the vegetation cover is constantly changing and that the factors governing changes are local in effect. The interpreter should have cognizance of complex factors of plant succession. This is particularly important in evaluating burned over areas.

Spurr *(21, p. 194)* in his book on airphoto interpretation of trees says that species identification is an ecological problem and that the interpreter must have an understanding of the distribution of species as correlated with topography and site. Without this understanding he can make only limited identifications. A discussion of photo classification of forest sites is presented in two publications by Moessner *(181, 182)*.

EROSION. One of the most reliable among the elements of the soil pattern is that of *erosional features,* provided the rainfall-runoff-erosion characteristics are evaluated correctly. In general, it can be said that gully cross-section and gradient are indicators of soil textures; however, the climatic conditions under which the gullies were formed must be considered. It must be decided whether or not erosion has taken a long or a relatively short period of time to form. This important limitation is illustrated in comparing erosional features in clay-shale areas in arid-badland regions with those in clay-shale areas in humid regions. In arid regions, intense rainfall in the form of flash floods usually carves soft clay shales into fantastic shapes with unnatural vertical slopes. In areas of uniform rainfall, in contrast, gullies in the clay-shales erode into softly rounded slopes (Figures 3-6.)

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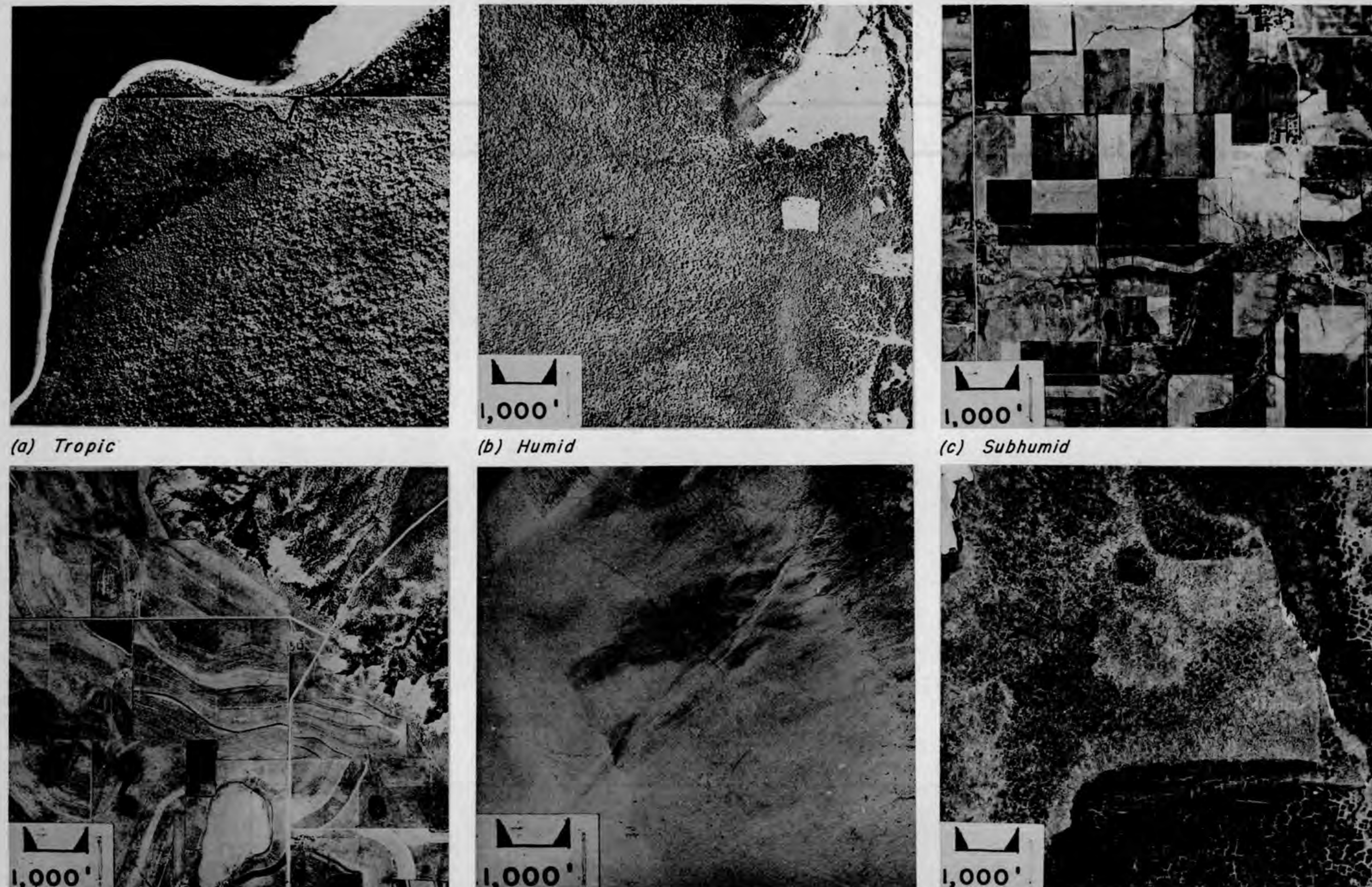

(a) Tropic
(b) Humid
(c) Subhumid
(d) Semiarid
(e) Arid
(f) Arctic

Fig. 3-1 GENERAL CLIMATE AS INDICATED BY VEGETATION

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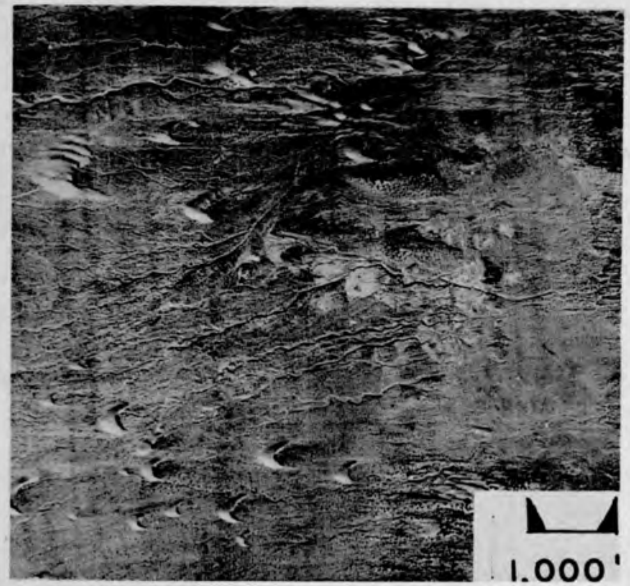
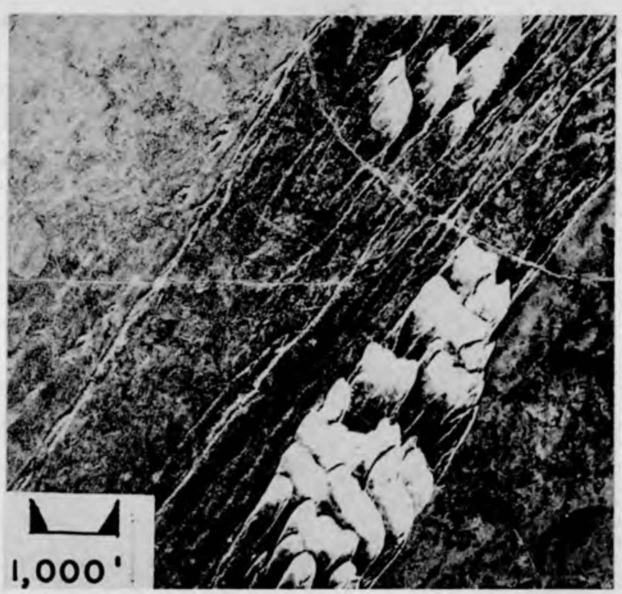


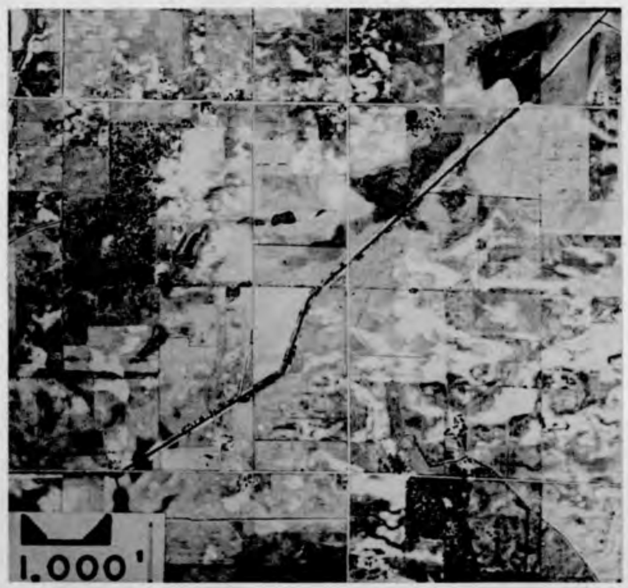
(a) Arid



(b) Semiarid

(c) Humid, dry season

(d) Arctic, frozen plain



(e) Humid, wet season

Fig. 3-2 COLOR TONES OF SAND DUNES ON SAND PLAINS AS INFLUENCED BY CLIMATE AND MOISTURE

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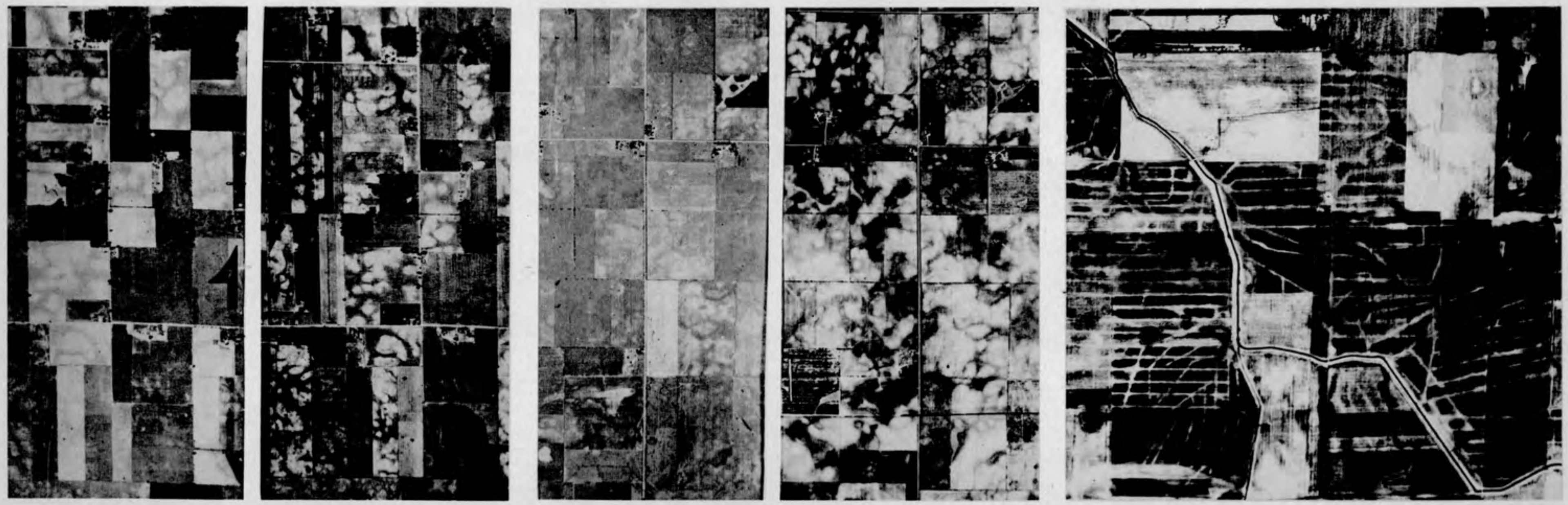

Dry Wet June July

(a) The same area— different moisture conditions

(b) The same area— different field patterns

(c) Influence of buried farm tiles

Fig. 3-3 SOIL COLOR TONES OF SILTY CLAYS AND CLAYS AS INFLUENCED BY MOISTURE

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(a) Winter (b) Summer (c) Fall

Fig. 3-4 PHOTOGRAPHY OF THE SAME AREA OBTAINED DURING VARIOUS SEASONS

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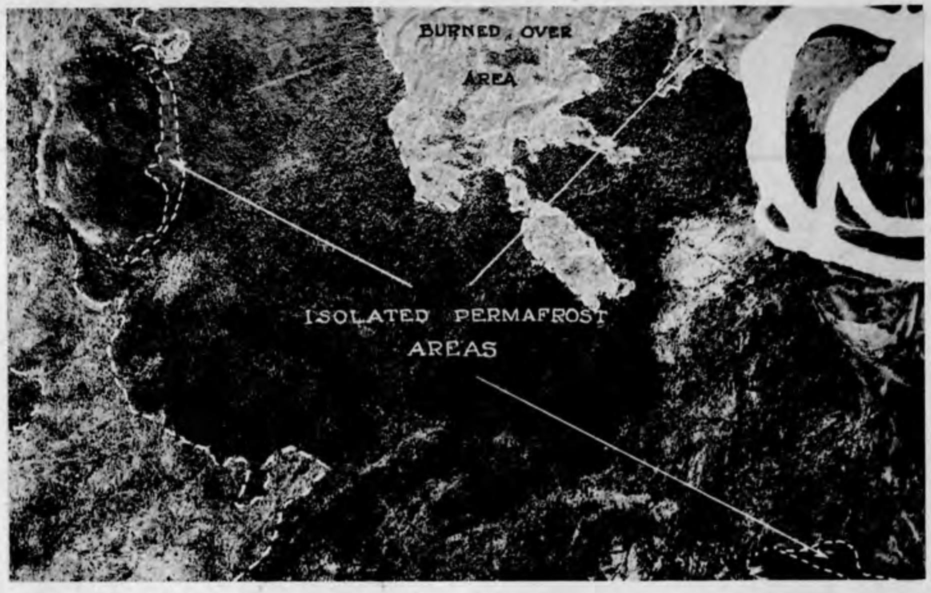
(a) Exposure to sunlight, Beaver



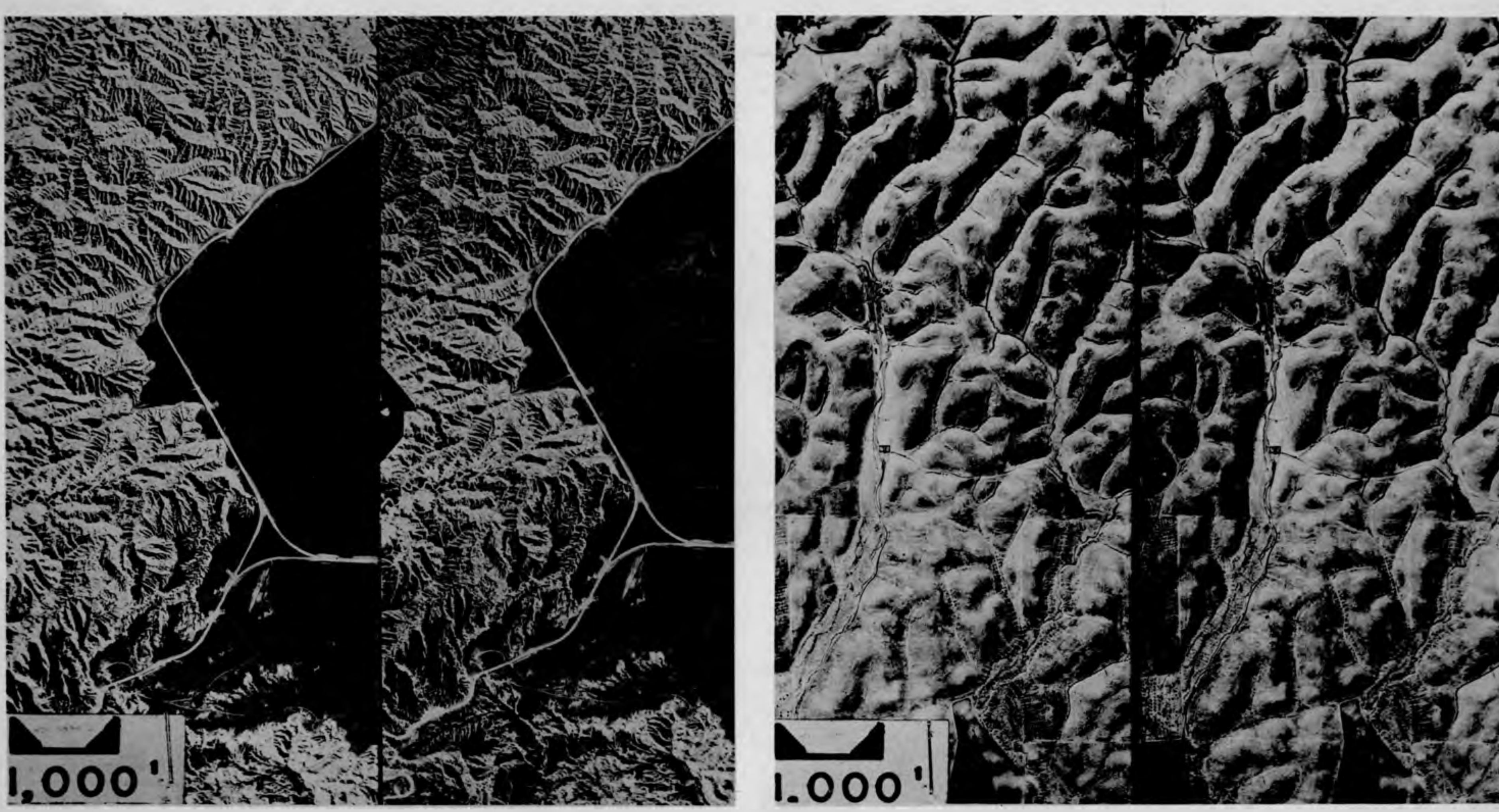
(b) Destruction by fire, Tanana Valley

(c) Valley floor-timber line, Norton Sound

(d) Timber line in gullies, Norton Sound

Fig. 3-5 VEGETATION LIMITATIONS IN ALASKA

18428 18429



(a) Flash flood conditions (b) Uniform rainfall conditions

Fig. 3-6 EROSION OF CLAY SHALES AS INFLUENCED BY RAINFALL IN WESTERN UNITED STATES

Photographic

There are three main types of photography used in aerial-survey work in connection with soils engineering surveys, and it is important that the limitations of each particular type be understood.

Type. The three major types consist of trimetrogon, vertical-stereo coverage, and continuous strip. Trimetrogon photography consists of three photos covering horizon to horizon in the form of a left oblique photo, a vertical photo, and a right oblique photo. Trimetrogon photography is used chiefly in reconnaissance mapping of large areas and for this purpose it is usually obtained from high altitudes with a resulting small scale. See Figure 3-7. A large area is usually covered in a series of parallel flight strips flown several miles apart. For engineering soils survey purposes, trimetrogon photography should be limited to reconnaissance use for the establishment of major physiographic boundaries of an area. The most reliable information concerning engineering soils or geology can be obtained from the photos of the center strip of the trimetrogon series since they contain less distortions and can be used stereoscopically. Furthermore, trimetrogon photos can be used to distinguish whether or not a pattern is widespread or local and whether the pattern is simple or complex. When taken from high altitudes with normal focal length lenses, the scale is so small that the fine detail is lost. The oblique photos, at best, give mainly a picture of the extent of the physiographic features. It is difficult to determine soil characteristics from a study of obliques, particularly from high-altitude obliques.

Vertical airphoto coverage is the most common and most practical of all types of photography used for engineering surveys dealing with mapping of surface materials. See Figure 3-8. When photography is unavailable for an area and time does not permit obtaining complete vertical photo coverage, a practical substitution consists of obtaining a series of widely spaced trimetrogon strips which may be later supplemented by vertical coverage of local areas where more detail is desired. Detailed study of the trimetrogon photos will indicate those areas for which vertical coverage would be most desirable. Detailed but preliminary soil maps are then made from the vertical photos.

Continuous strip photography is best suited for making performance surveys of such engineering projects as runways, railroads, highways, or airstrips (Figure 3-9). It is possible to correlate pavement performance with soil textures and when photos are obtained at periodic intervals, they provide a permanent record of progressive changes in performance. Another important use of continuous strip photography is that of tree identification and in sampling forest areas photographically *(21, p. 15)*. Other possible uses of continuous strip photography are in connection with pipelines, road and railroad location, soil surveys, and other engineering surveys.

SCALE. There is no standard scale which will satisfy the many uses of airphotos. If photos were taken to specifications furnished by several agencies, each having a different objective, there would be a number of scale requirements. A scale varying between 1:15,000 to 1:22,000 is satisfactory for most soil mapping used for engineering purposes. Larger scales such as from 1:5,000 provides a good workable scale for vegetation identification and classification *(21, p. 194)*. For use in soil mapping, such scales are too large and the photos cover insufficient area per print. Furthermore, when such photos are obtained for stereoscopic use, the relief is difficult to study with commonly used instruments. Scales from 1:30,000 or 1:40,000 result in images much too small for use in engineering soil work. At such scales, the areal coverage is good, but the fine detail often is lost. Figure 3-10 compares scales of photos of the same area.

PRESENTATION. The methods of presenting aerial photos for use in map work or other interpretative studies are important. The photos may be provided in either contact or enlarged size; they may be assembled into an uncontrolled mosiac; they may be provided in stereo-pairs on a variety of paper surfaces and weights; index sheets may be furnished; or controlled mosaics can be made. Each method of presentation has its advantages for certain uses, and each has certain limitations for other uses. Prints made at contact size are either 9 x 18, 7 x 9, or 9 x 9; and, when they are made in stereo-pairs, they are of practical scale and size for use for detailed analysis. Simple stereoscopes can be used which will permit a considerable amount of magnification of the physical features. Enlarged prints give added visual detail only by providing a picture at much larger scale; the mere fact that photos are enlarged does not enhance the survey or create finer detail. Furthermore, it must be remembered that all blemishes, errors, and distortions are magnified in enlargements.

It is important in ordering photographic prints to obtain stereo-pairs, in other words, photographs taken with sufficient overlap to produce an image which can be viewed in stereo relief. In vertical mapping photography, the photographs are taken in such a manner that the overlap along the line of flight is about 66 percent. This means that each point on the ground is contained in three vertical photos and that the adjacent prints (those numbered consecutively) can be viewed stereoscopically. By obtaining consecutively numbered photos of an area, full stereo-coverage is obtained. By obtaining alternate prints of an area physical coverage is obtained. It is not possible to study the area stereoscopically using alternate prints since stereo-vision is not possible in the portion in which there is no photo overlap.

It is common practice to assemble vertical photographs into an uncontrolled mosaic of an area and to designate each print by an appropriate serial number. Photography obtained for the Department of Agriculture is on a county basis and each county has an individual serial number. In this system, the individual rolls are numbered and prints are numbered consecutively in each roll. As an example, a certain print in Tippecanoe County, Indiana, has the following serial number: BFV-7-1. The first *(BFV)* is the county symbol; the second figure *(7)* is the roll number; and the third *(1)* is the individual print number. For convenience of locating aerial photographs in some politcal unit such as a county, these numbers are placed on the proper photos in the uncontrolled mosaic and the entire group is photographed. The resulting photograph is known as the county index sheet. These are usually reproduced to the scale of one or two inches to the mile and are for sale by the Department of Agriculture (Production and Marketing Administration).

The chief use of an index sheet is in showing the location of existing photography in any given region. Figure 3-11 is an airphoto index sheet. Airphoto index sheets often can be used to a limited extent in soil mapping, particularly in areas where major physiographic units are not complex and where soil patterns do not vary greatly. Major boundaries between different soil areas can often be drawn; however, the final boundary should be located from detailed stereoscopic study of contact photos.

Controlled mosaics of an area provide an accurate map from which measurements of distance can be obtained. Their use in soil survey work should be confined to study of the major physiographic units, contrasting soil patterns, or differences in vegetation. The amount of detail necessary for complete soil evaluation cannot be obtained from study of a mosaic of any type. Accurate soil determinations are obtained from stereoscopic study of individual photographs.

FILM. Of lesser importance in soil interpretation from airphotos is the type of film used. The use of varying filter and film combinations will, of course, influence the overall reproduction of the airphoto pattern in varying degrees. Most of the mapping is done by using some type of moderately fast panchromatic film exposed usually with some type of yellow filter for blue-haze penetration. A considerable discussion on the use of film and filters with respect to vegetation is presented in Chapter III of "Aerial Photographs in Forestry", by Stephen H. Spurr *(21)*.

PAPER. Occasionally, print quality and contrast can impose serious limitations in soil work, particularly in evaluating soil color tones which normally are reflected as a series of gray scale values. Prints of negatives of average contrast which are made on contrast photo papers often lack detail in the bright, or highlight areas, while prints made on extremely soft papers often appear flat with little variation in tonal values. Color tones resulting from photography manipulation in processing can be determined by comparing prints in adjacent flight lines.

Human

The third major limitation lies within the province of the interpreter. Such items as background, vision (eyesight in both eyes), imagination, and interest are of great importance in evaluating airphotos.

BACKGROUND. It is not necessary that the interpreter be especially trained to the extent that he is a specialist in geology, pedology, physiography, ecology, agronomy, climatology, geomorphology, or in any other of the natural sciences dealing with the surface features of the earth. The interpreter should be aware of the chief sources of literature in any of the related fields. This is of paramount importance in obtaining background material about any particular area. It is beyond the engineer's training or major interest to understand the biotic factors of plant succession, and, similarly it is beyond his training or major interest to learn the names of the geologic column. It is more important that the interpreter, or observer, be able to recognize changes in vegetation or changes in bedrock types and to be able to realize that such changes often may mean changes in the natural soil conditions. Herein lies the importance of interest, background, or training. The interpreter must develop a keen appreciation of the relationship between natural conditions and engineering problems. Many engineering problems are more closely related to the materials on which a structure lies than to the theoretical aspects of certain design formula. All natural situations should be evaluated in the light of potential engineering problems. Perhaps the most important basic concept is that soils and engineering problems are areal in nature and extent. A change in soil parent material is accompanied by a change in engineering problems which in turn should be accompanied by a corresponding change in some design feature. The realization of this will aid the interpreter in photo determinations.

VISION AND STUDY AREA. For the interpreter to gain the most from airphotos, he must be able to see stereoscopically and must be able to observe and perceive fine detail. The ability to detect minute contrasts is important. Good vision in both eyes is necessary. Good lighting on the prints during study is important in combating eye strain. The working place should be comfortable.

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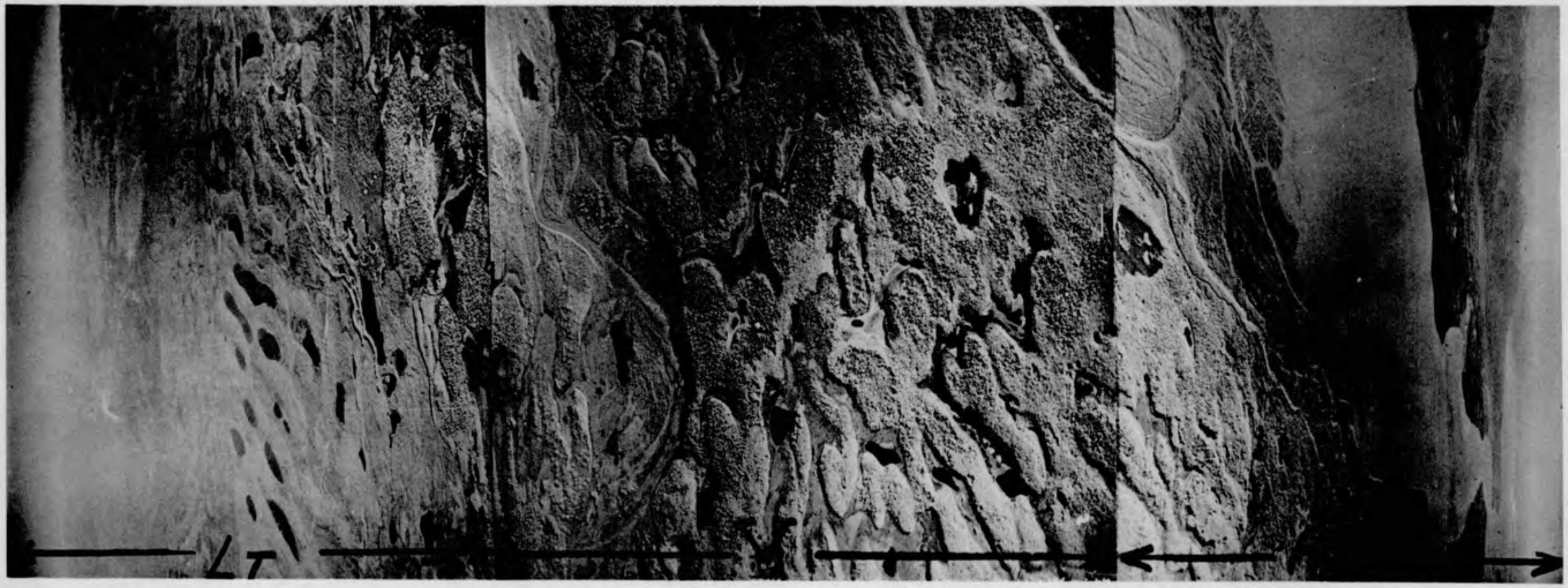

Left Vertical Right

Fig. 3-7 TRIMETROGON PHOTOGRAPHY (NEAR ANCHORAGE, ALASKA)

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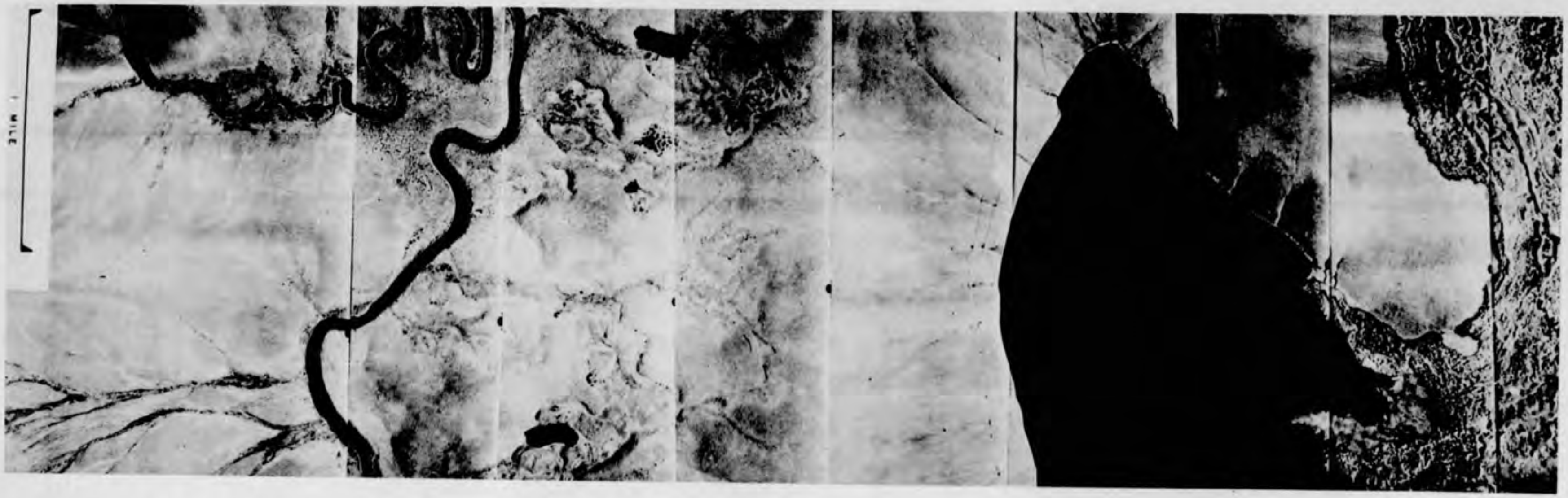
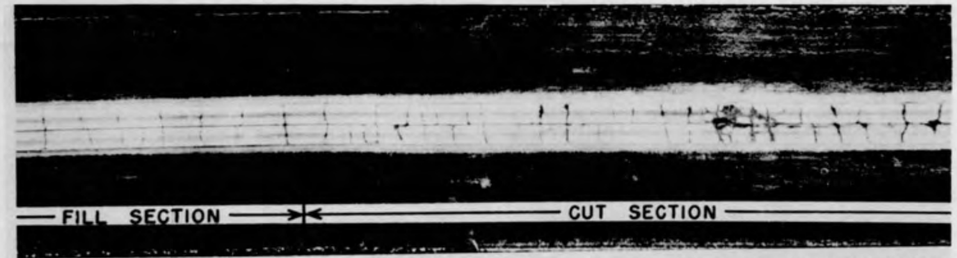


(a) K-18 type (9"x 18") prints

(b) Ordinary 9"x 9" prints

Fig. 3-8 TWO TYPES OF VERTICAL PHOTOGRAPHY (ALASKA PHOTOGRAPHY)

8795 8797 8800



SOIL TEXTURE INFLUENCE ON PERFORMANCE

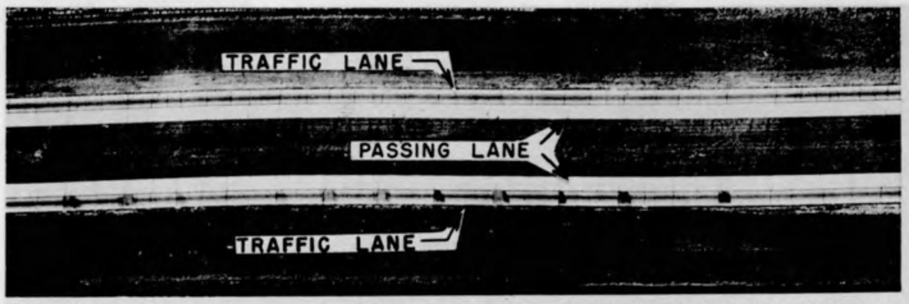
S.R. 25 — (1929)

INDIANA

SOIL TEXTURE INFLUENCE ON PERFORMANCE

U.S. 31 — (1938)

INDIANA



LIGHTER TRAFFIC

HEAVY TRAFFIC

TRAFFIC INFLUENCE ON PERFORMANCE

U.S. 30 — (1938)

INDIANA

Fig. 3-9 CONTINUOUS STRIP PHOTOGRAPHY (NOTHERN INDIANA)

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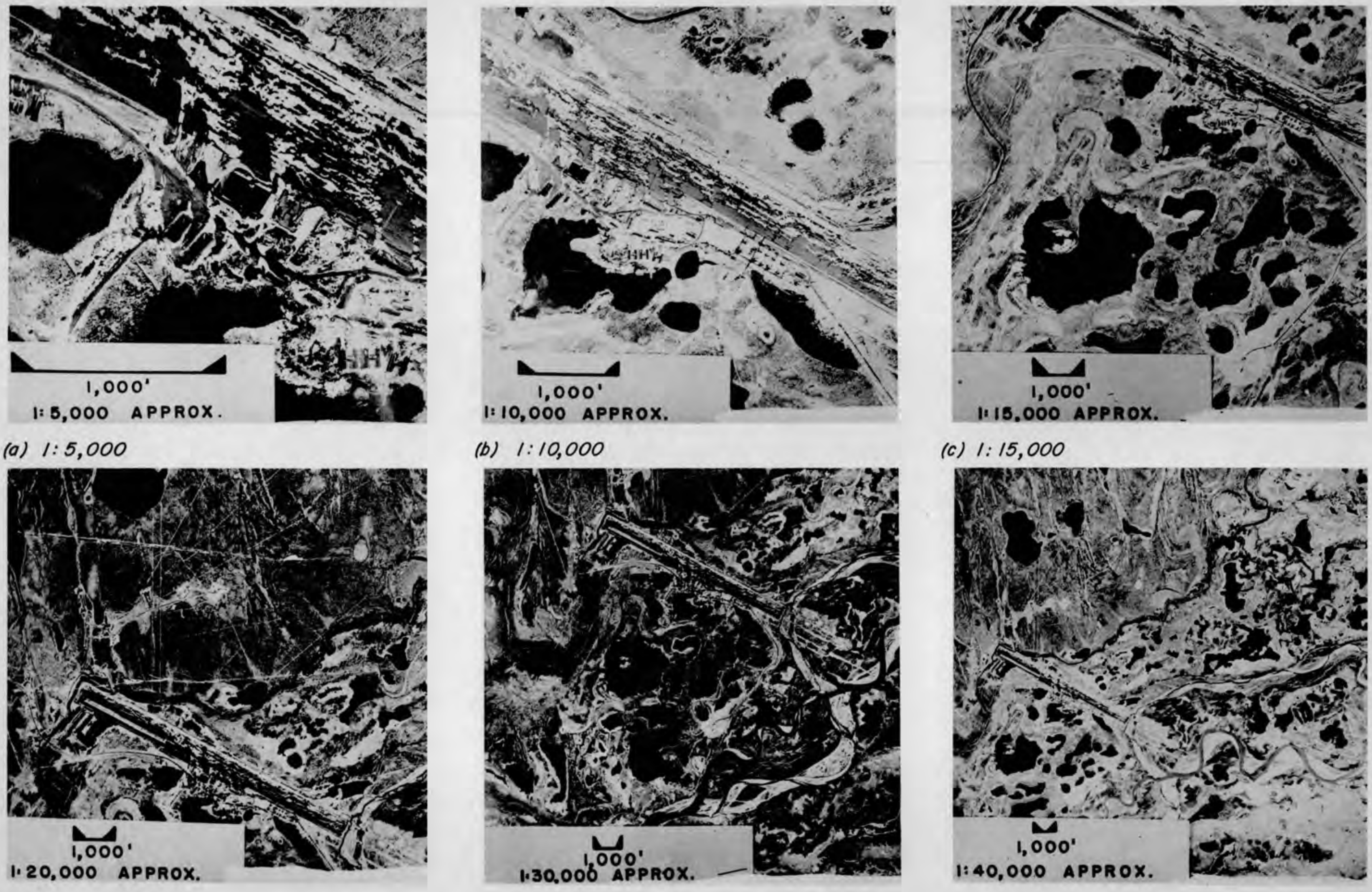
18436 18437 18438



(a) 1:5,000 (b) 1:10,000 (c) 1:15,000

(d) 1:20,000 (e) 1:30,000 (f) 1:40,000

Fig. 3-10 SCALE VARIATIONS OF AERIAL PHOTOGRAPHY, NORTHWAY, ALASKA

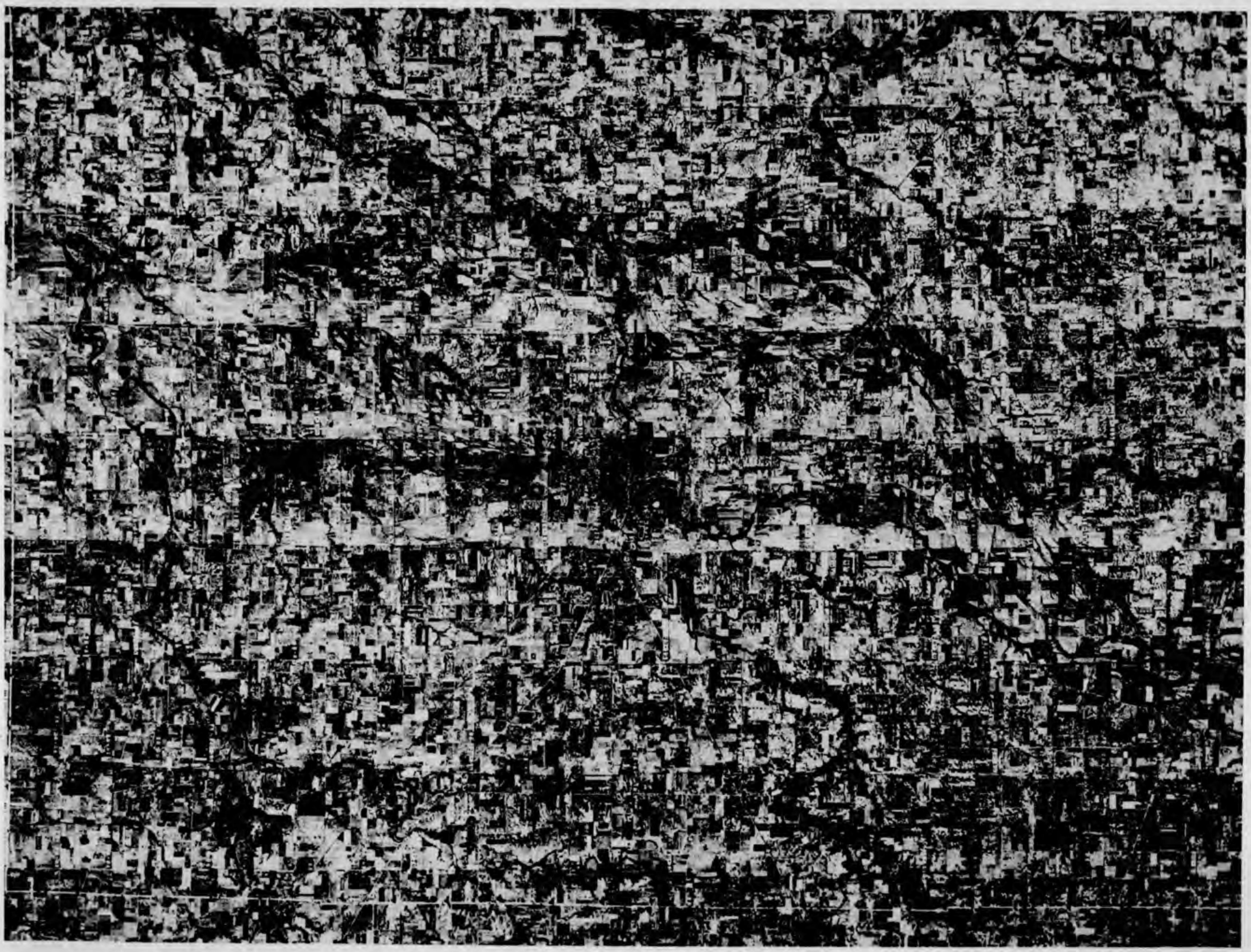


Fig. 3-11 COUNTY INDEX SHEET (SHELBY COUNTY, INDIANA)

IMAGINATION. The interpreter must possess or develop a keen imagination in order that he can visualize natural conditions as they actually exist. The ability to follow deductive reasoning processes based on logic is important. The development of these will result from constant use of airphotos in the office coupled with field checking and literature survey. Detailed study of photos in advance of field operations where predictions are checked, either verified or modified to fit conditions, will develop confidence on the part of the interpreter.

PHOTO COVERAGE. Soils evaluation should never be made from too small a number of prints representing an area. Sufficient photo coverage of an area should be available to enable the observer to determine the extent of local conditions and the expected variations in the soil parent material. This may be complete vertical coverage or trimetrogon coverage supplemented with local vertical coverage of small portions of the area. Certain textural predictions can often be made from one or two photos where the major land forms are outstanding or represent some particular type of material which exists in one of the more simple land forms—such as the identification of barchane sand dunes.

PRINCIPLES OF SOIL EVALUATION

The aerial photograph records the results of natural processes in the development of residual soils and in the occurrence of transported soils. Repeated field checks have shown that similar patterns do indicate similar materials and that airphotos can be used to identify soil and rock textures, to bound areas of similar materials, to select better construction sites, and to locate and identify materials for engineering construction.

Basic Principles

An aerial photopraph is a tool which can be used for classifying soils because soil patterns are repetetive in nature, that is, any two materials derived from the same soil or rock parent material or deposited in a similar manner and both occupy the same relative topographic position and existing under the same climatic conditions will have similar pedological profiles, will support the same native vegetation, will have similar engineering properties, and will exhibit the same airphoto pattern *(33)*.

NATURAL SCIENCES. Successful use of aerial photographs for soil interpretation purposes is contingent on recognizing certain natural processes, particularly those of a geologic and pedologic nature. Of importance is the study of geomorphology or the study of land forms and the related study, physiograhy. For example, in the location of granular materials for engineering use, considerable time and expense can be saved if the engineer is familiar with the various methods of deposition of these materials. Knowledge of the "rhyme and reason" of granular deposition often will be a deciding factor in the amount of time required in an area since granular deposition follows the natural laws or methods of deposition and can be expected to be found existing only under certain conditions. Figure 3-12 illustrates some of the land forms associated with granular materials.

A knowledge of some of the principles of pedology will aid the engineer in evaluating soil weathering and soil profile development. Figure 3-13 contains examples of profile development. Similarly, a knowledge of the influence of certain climatic factors on soil and rock weathering is very important in airphoto interpretation work. In regard to vegetation, it is not necessary that the engineer be a forester, biologist, or ecologist to appreciate the significance of the vegetative portion of the photo pattern. It is important to recognize changes in vegetative cover which may or may not necessarily reflect changes in engineering soil conditions.

SEQUENCE OF EVENTS. The process of mapping and evaluating soils by a study of aerial photographs requires an understanding of the "rhyme and reason" of how a given deposit developed. Being able to trace the original causes and subsequent events responsible for the development of a given soil deposit makes the process of soil evaluation with airphotos not a chance occurrence but an expected reality. For instance, flat-lying sandstone in a humid region weathers to produce a definite land form with a definite drainage pattern; the rocks have weathered to produce a particular type of soil; and they support a particular type of vegetative cover. Likewise, limestone in a humid region will weather to create its own characteristic land form with its own particular drainage pattern; it will have weathered to produce a particular type of soil; and it will support a particular type of cover. When comparing patterns of the two, it will be found that they differ in almost all respects. Often a single airphoto contains sufficient information to determine the sequence of events which contributed to the development of a certain physiographic condition. In Figure 3-14 the pattern in the upper left (A) is that created by limestone while the pattern in (B) is that created by sandstone. When sandstone occurs on top of limestone it often creates a pattern like the one in (C). The map in (D) is of the sandstone on limestone pattern of (C). All photos are from Indiana.

In Figure 3-15 there are three different parent materials and three vastly different airphoto patterns. Area A represents the pattern of a granite intrusion. It is the highest part of the area. The adjacent band of material represented by B consists of upturned sedimentary rocks in which sandstones are adjacent to the granites and shales border area C. Area C represents an outwash area of materials eroded from area B and spread out on area C. The isolated hill at D is too small in areal extent to permit positive identification, however, it can be said that it is a local protuberance which is being buried by material in C.

SOIL PATTERNS. In airphoto interpretation work, it is an important fact that many soil deposits of similar physical characteristics occur over a considerable area and that areas of similar materials may be repeated several times in a general physiographic region. These deposits, or patterns, then can be considered as areal soil patterns. However, within any given physiographic region, a variety of patterns are likely to occur as a result of local variations within the province. For example, in a region of tilted sedimentary rocks containing sandstone, limestone, and shale, the airphoto will show these materials as bands, each band representing the pattern which is typical of the rock included. Figure 3-16 is of an area in Maryland and illustrates such a condition. Note that the patterns of the three are vastly different.

Airphoto patterns can be divided into two major groups: the Standard Pattern and the Complex Pattern. The standard pattern represents a material which is of sufficient depth and areal proportions to blanket an area uniformly, thus showing similar pattern features *(36, p. 563)*. The complex pattern depicts an area where several different soil materials are exposed at the surface. This may be caused by geologic activity such as the earth's crustal disturbances, ice invasions, fluviatile activity, and aeolian action; or by a combination of these factors and others. In areas where contrasting materials occur soils mapping for engineering use is not difficult and is accomplished by merely bounding the parent materials as indicated by the contrasts in patterns. When those patterns are of great extent and are relatively easy to identify they may be thought of as standard patterns and need occasional spot field checks.

An outstanding example of contrasting patterns is that of Illinoian drift and Wisconsin drift as shown in Figure 3-17. The patterns contained in the parts A and B are standard patterns and are relatively easily identified. Part A represents Wisconsin drift and part B represents Illinoian drift. In areas where the Wisconsin drift—Illinoian drift border occurs the patterns can be separated by outlining the major contrasts as in part C. Note the similarity existing between the Wisconsin drift area in C with the pattern in A. Also note the similarity between the Illinoian drift area in C with the pattern in B.

Areas represented by complex airphoto patterns should be sampled frequently, particularly at each indicated change in pattern. Figure 3-18 is of an area having a fairly complex pattern—that of loessial silt on Illinoian drift. Both soils are silt and would have similar physical test characteristics; however, because of structure and topographic position they are vastly different in an undisturbed state. The left half of the area has a typical Illinoian drift pattern while the area in the right half has been modified by a loess cover and creates a complex pattern.

ENGINEERING ASPECT. Among the many advantages of mapping soils with airphotos are low cost and the effective conservation of time. When used in site selection or in location surveys for highways and railroads, it is possible to evaluate sites in a matter of days or even hours. Once a site or a location has been selected, the photos are useful in making field checks and in making a detailed analysis of soil conditions of the particular area. Poor soil areas can be delineated with ease, likewise, areas suitable for borrow material can be located. By conducting performance surveys of existing situations and by correlating these data with engineering soil types and the corresponding patterns, it is possible to use photos for design purposes. Figure 3-19 shows an airphoto pattern of a drift soil situation, an oblique airphoto, a ground photo, and a photo showing the performance typical of pavements in this situation.

A more detailed discussion on the use of technique in airfield site selection occurs in the last chapter.

Elements of the Airphoto Pattern

The tools which the interpreter uses in analyzing soils from airphotos are known as elements of the soil pattern. It is necessary that the interpreter group the physical features into some logical classification and that he establish definite procedures to follow in analyzing any soil area.

The elements of the airphoto pattern are land form, regional drainage, erosional features, soil-color tones, vegetation, and certain special elements. In addition to the elements of the pattern produced by nature, there are man-made features which are often directly related to the natural elements since climate, topography, and soils often govern man's land-use practices. In arctic and subarctic regions another element can be added—permafrost.

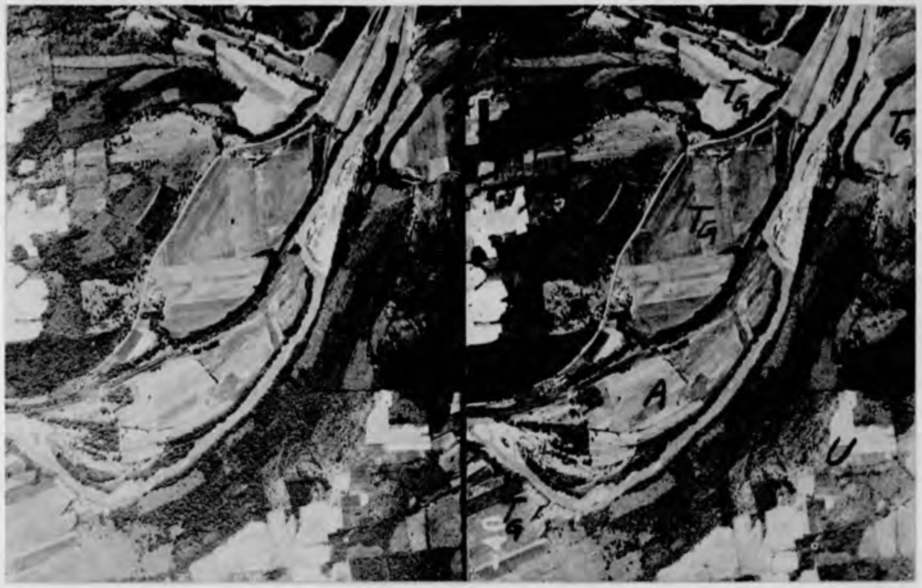
LAND FORM. The land form is the topographic arrangement of a deposit and its location with respect to the surrounding area. It is indicated by general relief, shape, topography, slope, surface features, field patterns, and road pattern. Land form has been define by Brown and Runner as *(183)*: ". . . physical features of the land surface developed by the processes of erosion".

One of the best discussions on land forms is presented in a text, GEOMORPHOLOGY by Lobeck *(145)*. In this text Lobeck presents empirical and explanatory descriptions of land forms. His state-

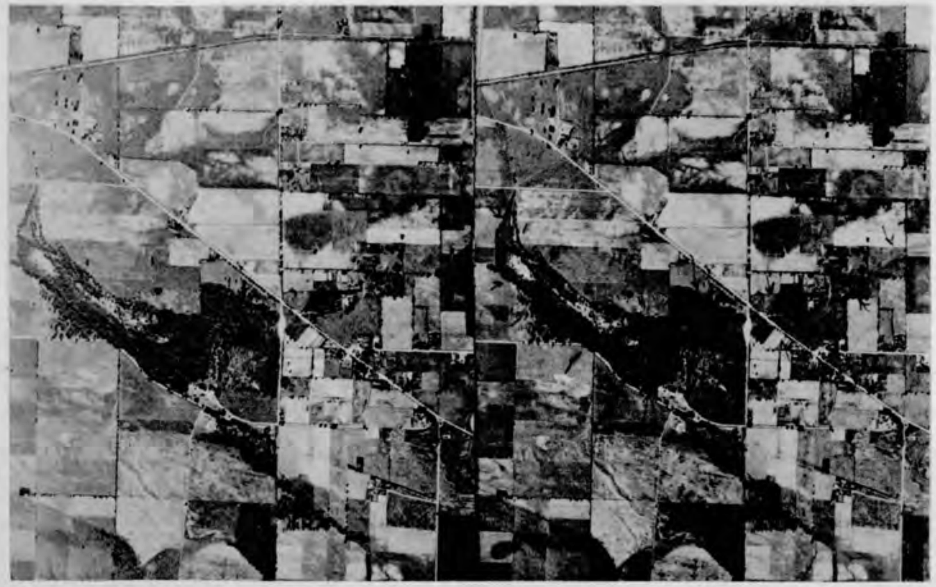
18443
7189

7131
7194

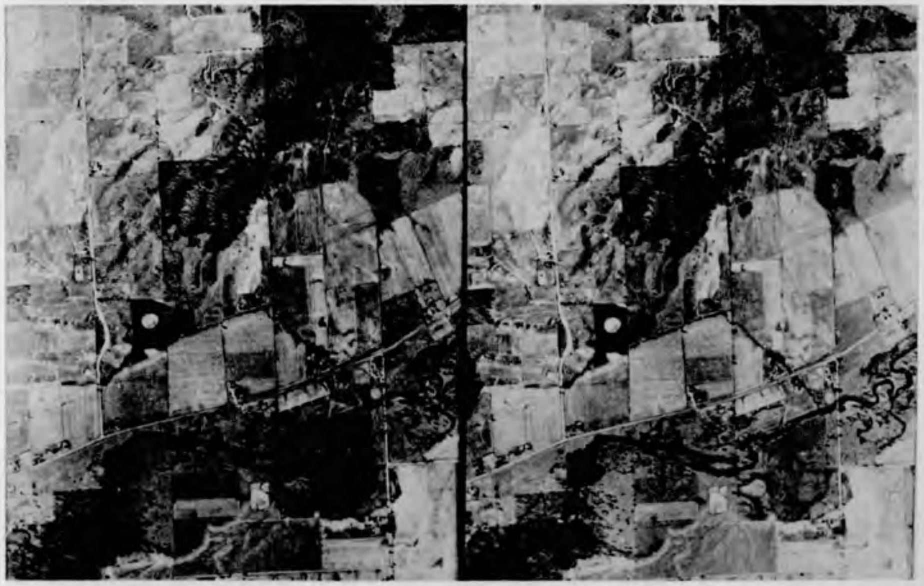
(a) Outwash



(b) Terrace



(c) Esker



(d) Kame

Fig. 3-12 STEREOPHOTOS OF COMMON LAND FORMS ASSOCIATED WITH GRANULAR DEPOSITION (INDIANA)

5081
374-c

9445
1285-c

(a) Illinoian glacial drift

(b) Wisconsin glacial drift

(c) Limestone residual soils

(d) Metamorphic residual soils

Fig. 3-13 EXAMPLES OF SOIL PROFILE DEVELOPMENT

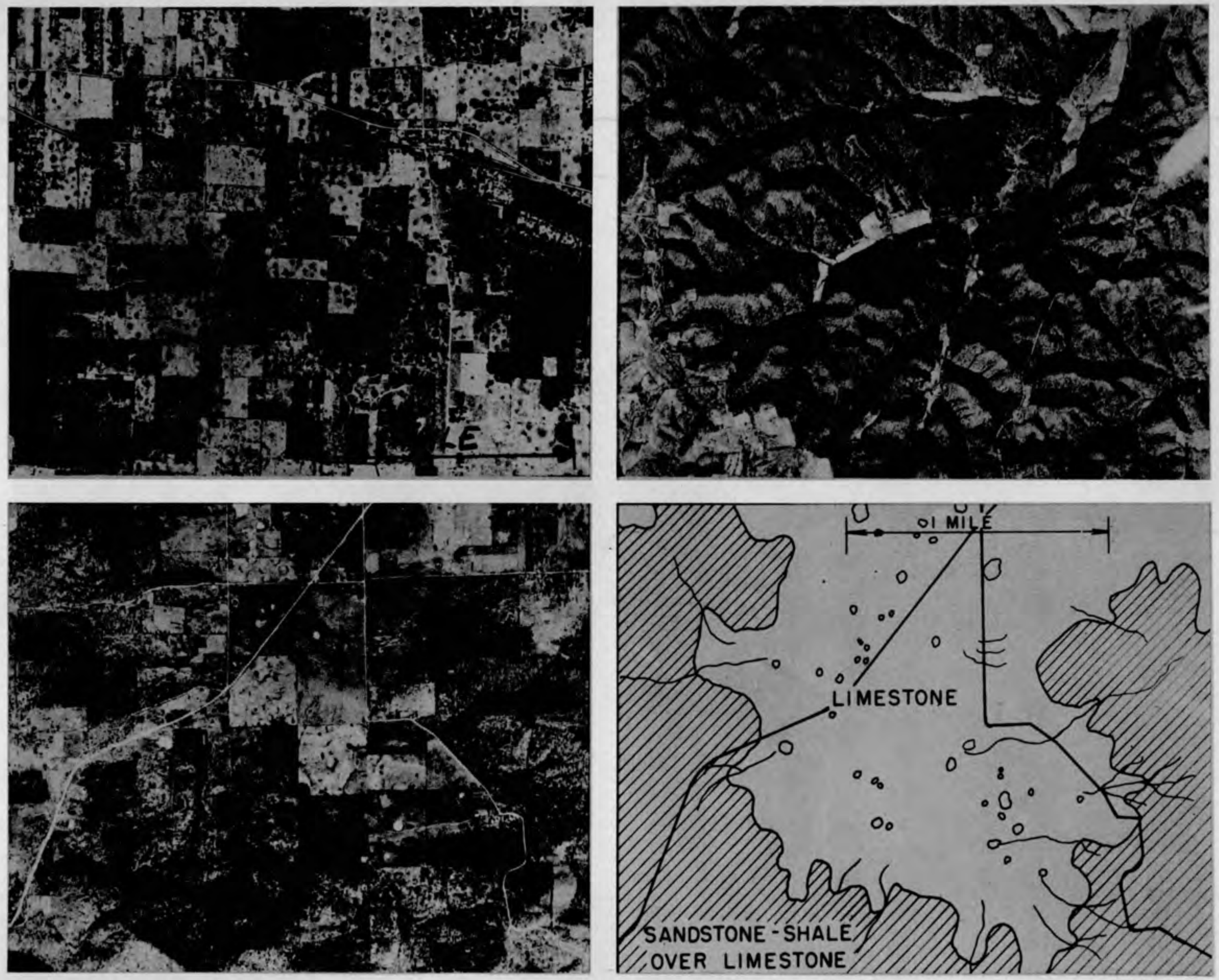


Fig. 3-14 ***UNLIKE MATERIALS CREATE UNLIKE AIRPHOTO PATTERNS (INDIANA)***

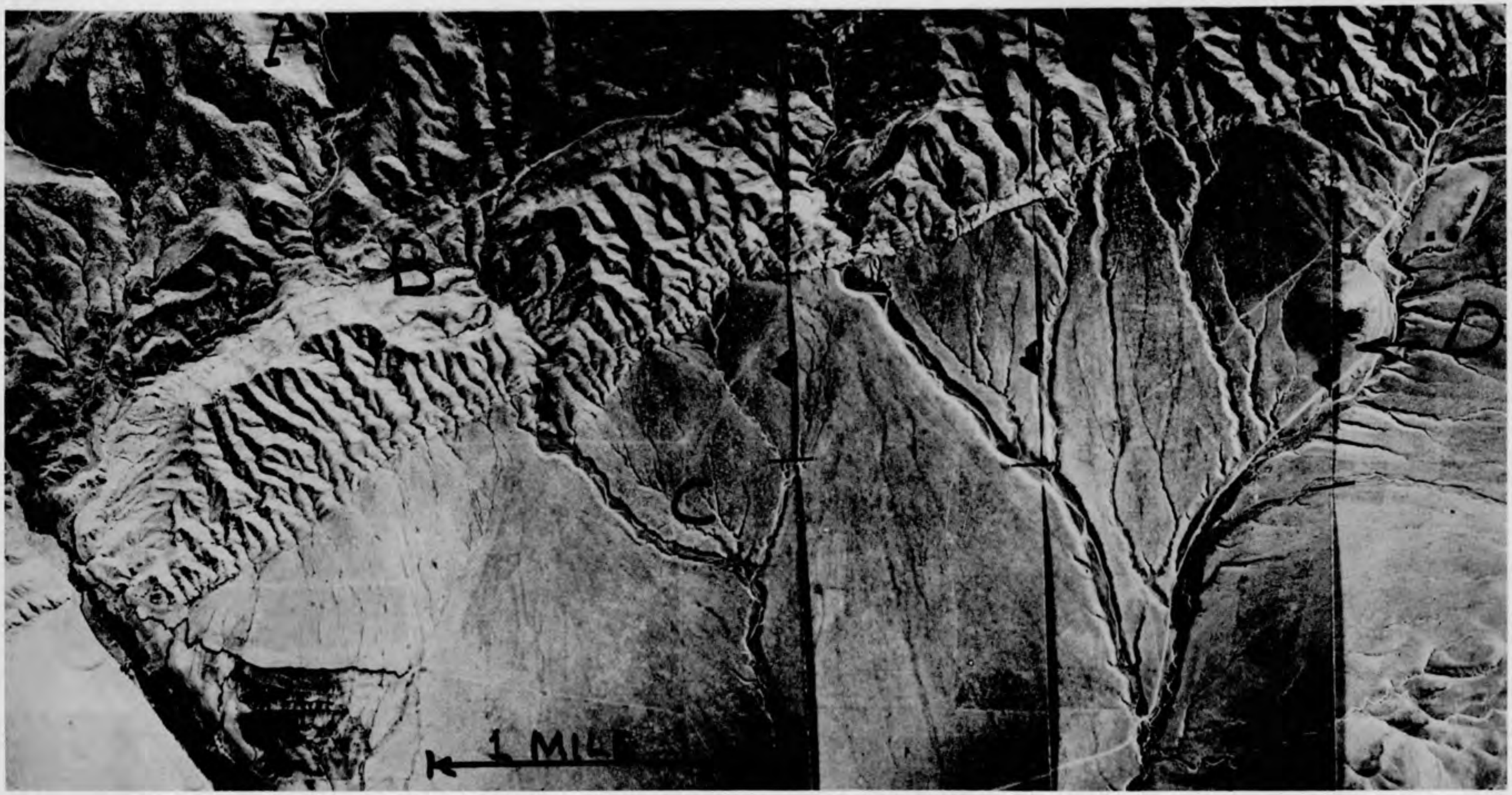


Fig. 3-15 THREE CONTRASTING SOIL PARENT MATERIALS IN THREE DIFFERENT GEOMORPHIC UNITS (MONTANA)

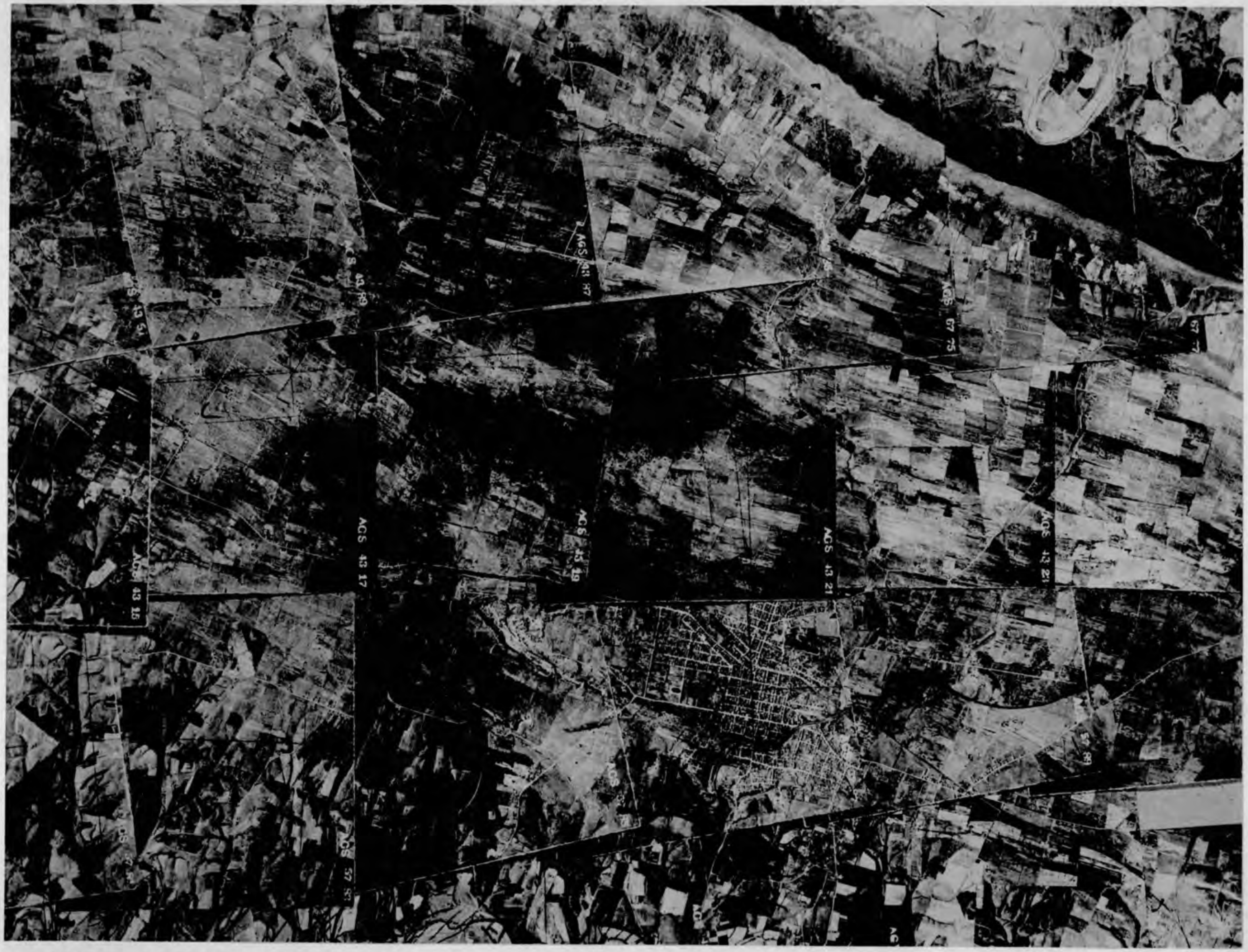


Fig. 3-16 **TILTED SANDSTONES, SHALES, AND LIMESTONES (MARYLAND)**

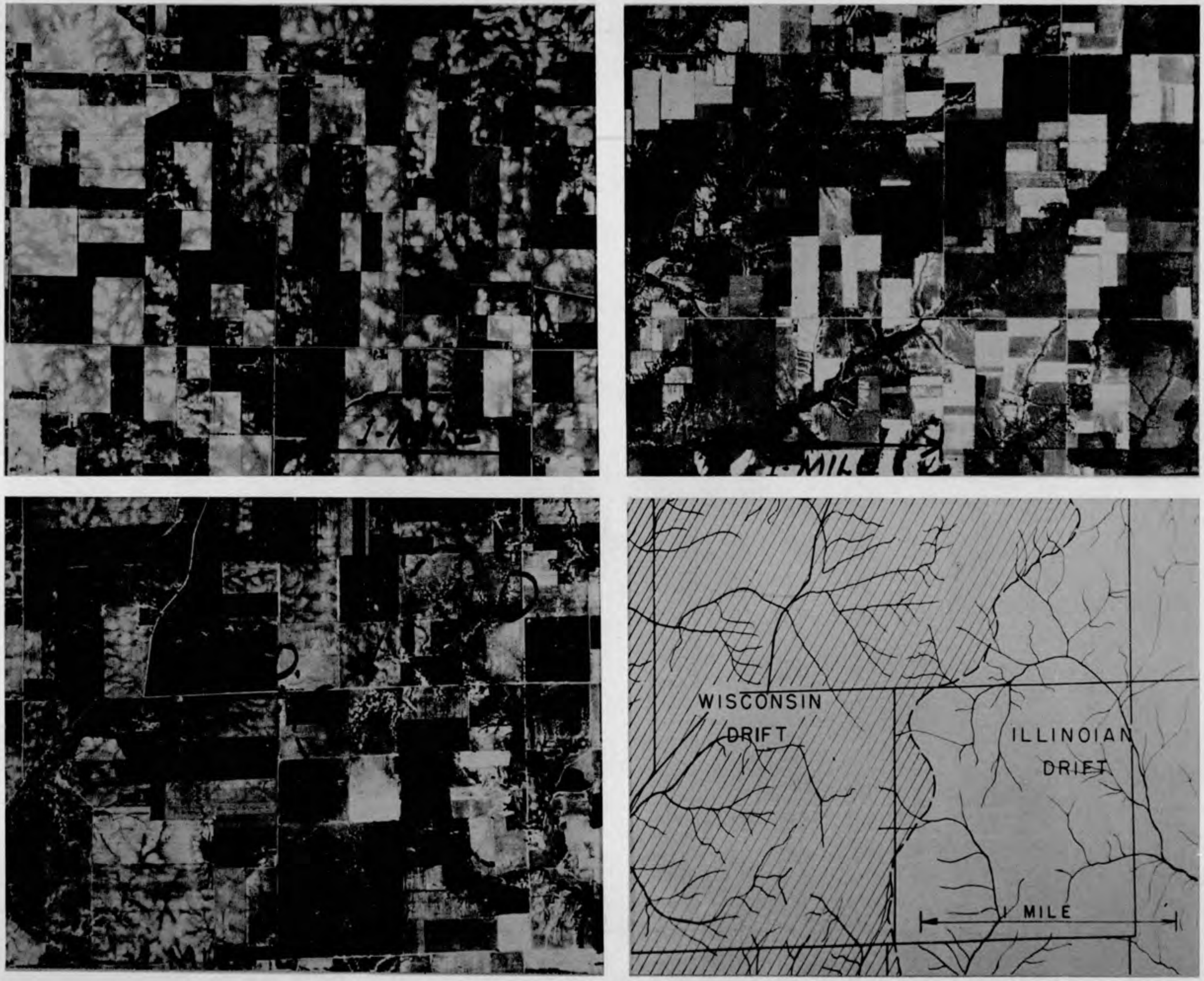


Fig. 3-17 STANDARD PATTERNS CAN BE SEPARATED MERELY BY OUTLINING MAJOR PATTERN DIFFERENCES (INDIANA)

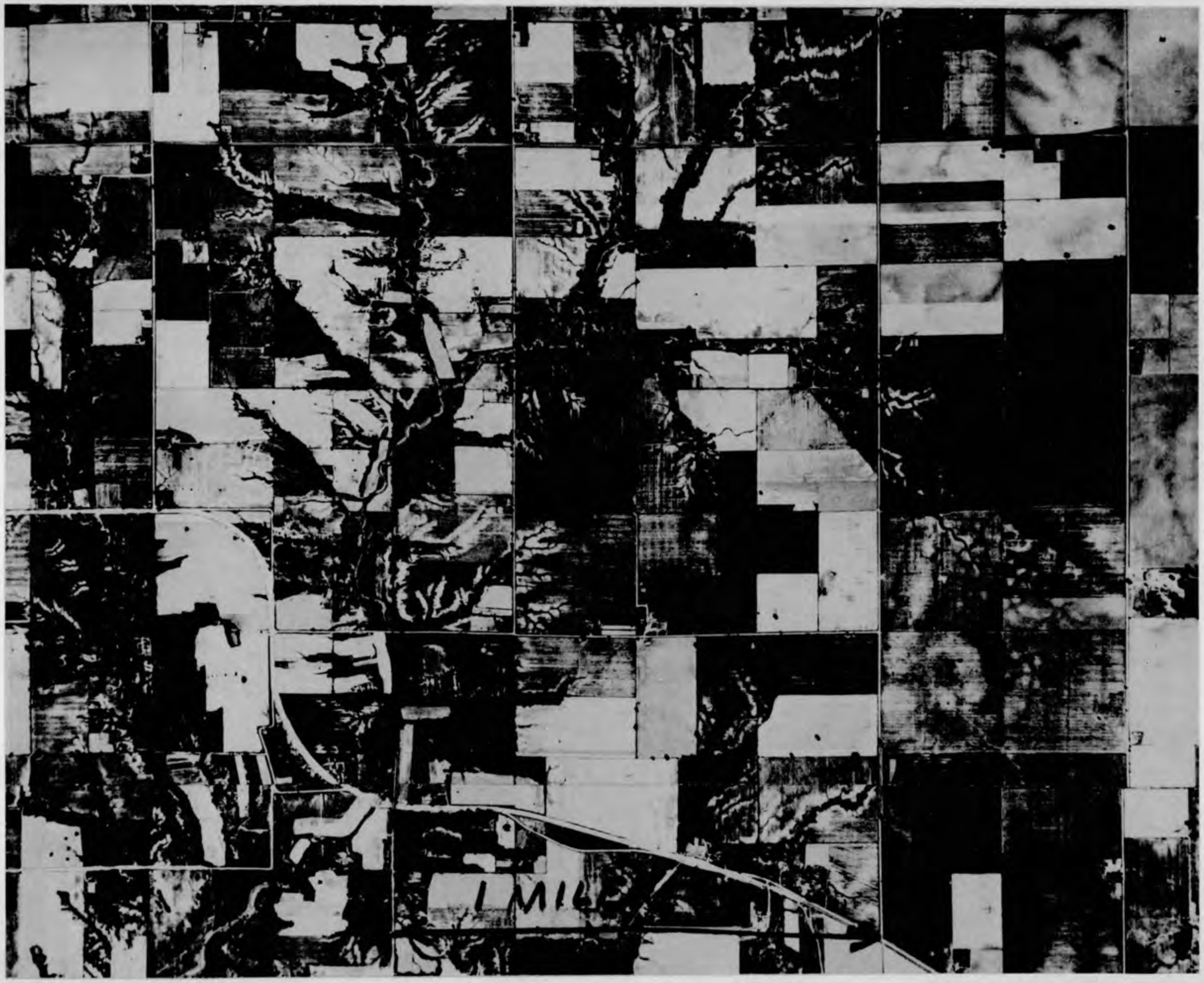
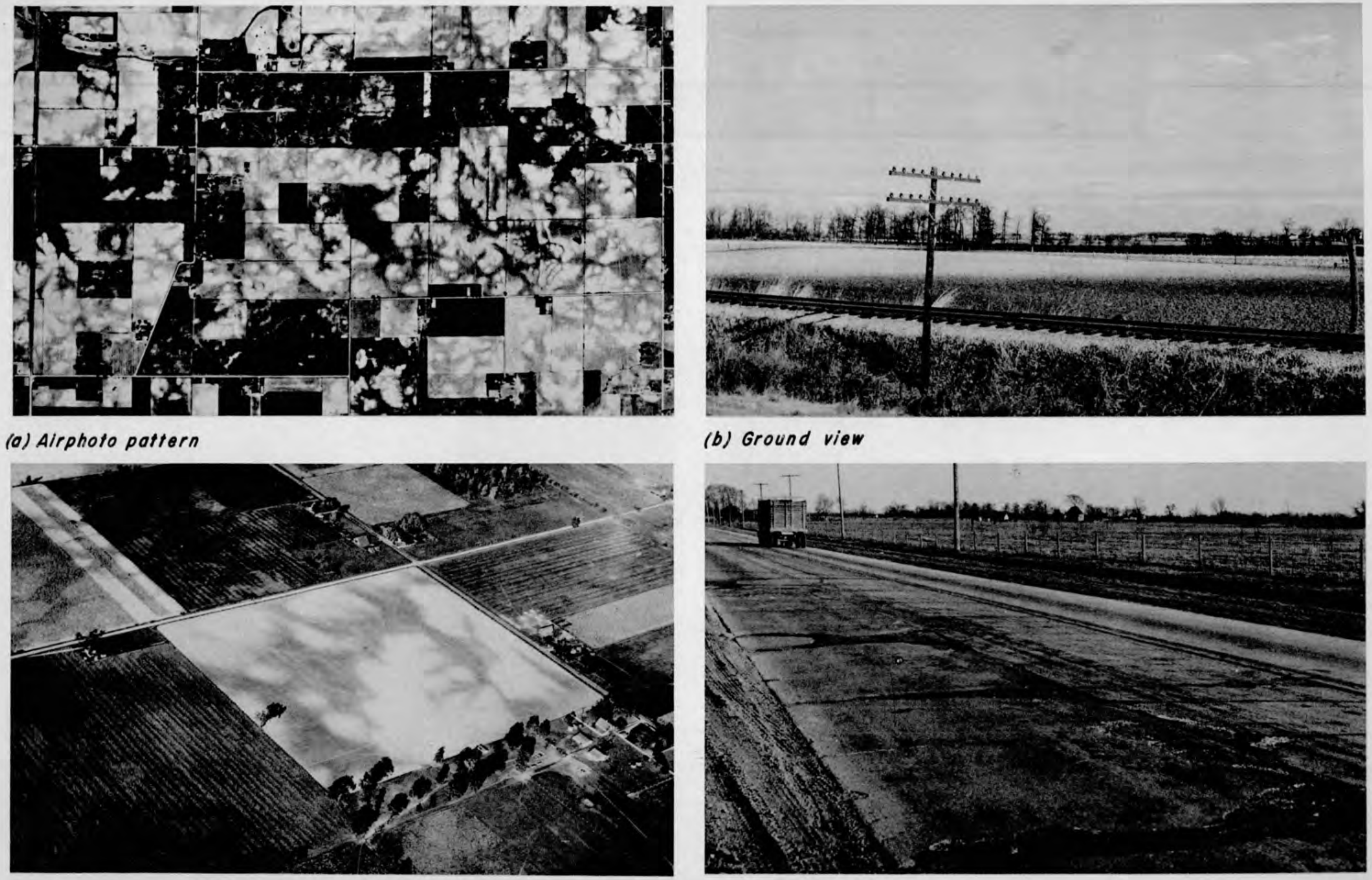


Fig. 3-18 COMPLEX PATTERNS NEED DETAILED INSPECTION OFTEN COUPLED WITH FIELD CHECKING (INDIANA)

273-c
14218

8760
9598



(a) Airphoto pattern

(b) Ground view

(c) Low ultitude oblique photo

(d) Performance

Fig. 3-19 THE ENGINEERING SIGNIFICANCE OF SOILS (INDIANA) ments are quoted *(145, p. 16-17):* "An empirical description of a region is one which uses simple commonplace expressions, with no attempt at explanation. Hills, valleys, mountains, and other features of the landscape are described in terms of shape, size, position, and color. The picture thus presented to the reader is a difficult one to carry in mind because it involves a mass of detail with little apparent relationship between the different facts." In his discussion of explanatory descriptions of land forms, he says *(145, p. 16-17)*: "Explanatory descriptions employ terms which are much more precise in character than are empirical terms and which convey some idea concerning the genesis of the form in question. Whereas the term HILL is empirical, the term DUNE is explanatory. A dune is a hill of specific type whose origin is dependent upon wind action. In a similar manner such terms as DRUMLIN, KAME, ESKER, CINDER CONE, MORAINE are all explanatory terms descriptive of hills of various methods of origin. Such terms, too, convey more than the simple fact of origin, for they connote also much regarding the matter of shape, size, composition, as well as location with relation to other forms."

The land form of an object can often be determined by stereoscopic study of photos if the photographs have been obtained in stereoscopic sequence and have been obtained at a satisfactory scale. It is possible to determine, by detailed stereoscopic study, whether a particular land form is rounded or angular, has vertical or sloping faces, is flat-topped or rolling. An example of some of the simplest land forms are terraces, sand dunes, eskers, limestone plains, and cinder cones. Figures 3-20 and 3-21 illustrate some of the simple land forms. In many regions, particularly in the western United States, land forms are of such magnitude as not to be contained in one or two photos. In such instances, study of a region by using an airphoto index sheet will usually make it possible to trace the extent of the major features. Stereo-study of photos of the transition zones will confirm previously made predictions.

An understanding of land forms and their origin makes it possible to bound areas of like materials and to predict textures and physical characteristics of the materials that make up the deposits. Of all the natural elements of the pattern, the land form is probably the most important because it is so closely associated with origin of the material and the subsequent erosional history.

Regional Drainage. Second in importance in evaluating patterns is the areal drainage of a region. As an element the drainage pattern gives a clue to general porosity, dip of the rock, type of rock and relative depth of soil mantle. Detailed analysis of the areal drainage pattern gives a clue to areal soil textures. When airphotos are examined stereoscopically, the terrain under inspection stands out in relief. Streams can be located more or less easily, depending on the roughness of the countryside. It is a simple matter to outline the stream systems on the photographs with china marking crayons *(28, p. 25)*.

Drainage is a direct function of soil permeability and ground slope. Porous sands absorb the rainfall and a surface drainage does not develop while clays and silty clays resist the rainfall penetration which gives rise to surface runoff and the development of a surface drainage pattern *(29, p. 588)*. A complete absence of a surface drainage pattern may mean a porous material while a highly integrated surface drainage pattern indicates an impervious material. The latter, when occurring on flat-lying soils may indicate to the engineer that the soils will be difficult to drain internally and the need of an adequate base course *(29, p. 588)*.

In his study of drainage patterns from aerial photos, Parvis has grouped patterns into six basic or elementary patterns *(55, p. 91)*. These are as follows: dendritic, trellis, radial, parallel, annular and rectangular. There are many variations of these six types, and it is difficult to find ideal situations where a particular type predominates. See Figure 3-22. Drainage patterns are discussed in detail by Zernits *(184)*.

Flat-lying rocks and areas of generally impervious soils create a dendritic pattern. The drainage pattern of folded, faulted and tilted rocks is trellis in form. A radial drainage pattern occurs in areas having a prominent peak or dome with the drainage features radiating outward from a central point or area. Parallel drainage is developed on gently sloping rock areas which are of sufficient resistance to permit drainage features to flow parallel down the slopes with little lateral influence. Annular drainage patterns are developed in connection with certain igneous and sedimentary material when associated with domes. Rectangular drainage patterns indicate angularity produced by rock joints or changes in rock materials for flat-lying rocks. A complete absence of drainage channels usually suggests a porous material, particularly in a humid region. Figure 3-23 illustrates the six basic types by showing the corresponding airphoto patterns.

Erosional Features. Soil textures and profile features can be interpreted directly from a detailed study of gully systems and gully characteristics. Gullies with a non-uniform cross-section and an interrupted gradient reflect stratified soil conditions or soils having a developed profile consisting of contrasting soil horizons.

In general, there are three basic gully characteristics which are associated with three major soil textural groups. See Figure 3-24. Granular soils develop sharp V-shaped gullies having a short, steep gradient. Non-granular, cohesive and plastic soils produce a gully whose cross-section is a broad, softly-rounded saucer shape and whose gradient extends well back into the upland. Loess soils and sand-clays exhibit a gully whose cross-section is U-shaped; such soils are removed by headward erosion through flat-bottomed gullies with a low gradient. Figures 3-25 and 3-26 illustrate gully characteristics for typical soil types.

Gully systems, or the local arrangement of the erosional features, are closely associated with particular soil types and are rarely duplicated in unlike soils. An example of this can be seen in the pinnate gully system of loess, the white-fringed gully system of Illinoian glacial drift, and the meandering gully system of certain lacustrine soils. See Figure 3-27. In densely wooded areas, it is seldom possible to see such details as shape and gradient when viewed through stereoscopes. In such areas, soil determination must be made from study of other elements with particular emphasis placed on land form and regional drainage.

SOIL COLOR TONES. Next in importance of the elements and one which may be misleading at times is soil color tone. In aerial photographs, soil color tones are represented as a series of gray scale values ranging from white to black. These gray scales, in addition to indicating soil color tones, may at times indicate contrast in soil textures, contrast in moisture content, and a difference in elevation. Soil color tones on photographs range from extensive areas of one color, where the areal distribution of a soil type is great, to a minute speckled effect created by variations in texture and thickness of top soil (or soil horizons) occurring in extensive areas of uniform soil parent materials. Figure 3-28 illustrates various tone patterns.

As was pointed out in the discussion on limitations, the element photo-soil color tones can be unreliable if the interpreter has failed to evaluate properly the climatic conditions. In densely wooded areas, soil color tones cannot be seen and differences of soil moisture or soil type often are shown in contrasting vegetation types.

VEGETATION. As far as engineering interpretation is concerned, the interpreter should learn that contrasts in vegetation usually reflect a change in the natural and environmental conditions for plant growth. It is up to the interpreter to decide whether or not these conditions are natural or artificial, and whether or not they are associated with soil texture, soil moisture, or with topography. Study of vegetation in conjunction with the other elements will aid in such determinations.

Concerning vegetation, Belcher *(29, p. 596)* states that types of trees are difficult to identify but drastic changes in soil conditions create contrasts in vegetative patterns that mark the boundary between soil areas. Forest fires and lumbering operations tend to influence the pattern. He further states that *(29, p. 591):* "In general wet and dry positions are distinguishable by the vegetation that they support, giving the observer a general impression of cover type. Although the presence of poplar indicates dry ground, jack pine implies sand and gravel beds; tamarack, muskeg, and willow, wet ground. It is also true that many species such as white pine and aspen are tolerant of drainage and soil conditions and will grow on sandy as well as clay soils and in wet or dry positions."

When airphotos are made to a scale which is suitable for engineering soil evaluation (1:18,000 or 1:22,000), it is difficult to distinguish individual trees or tree types. Spurr *(21, p. 190),* in his book on airphotos in forestry says that groups of species may be recognized on aerial photographs and that the occurrence of a group of trees on a given topographic site is frequently sufficient to permit the identification of the underlying soil.

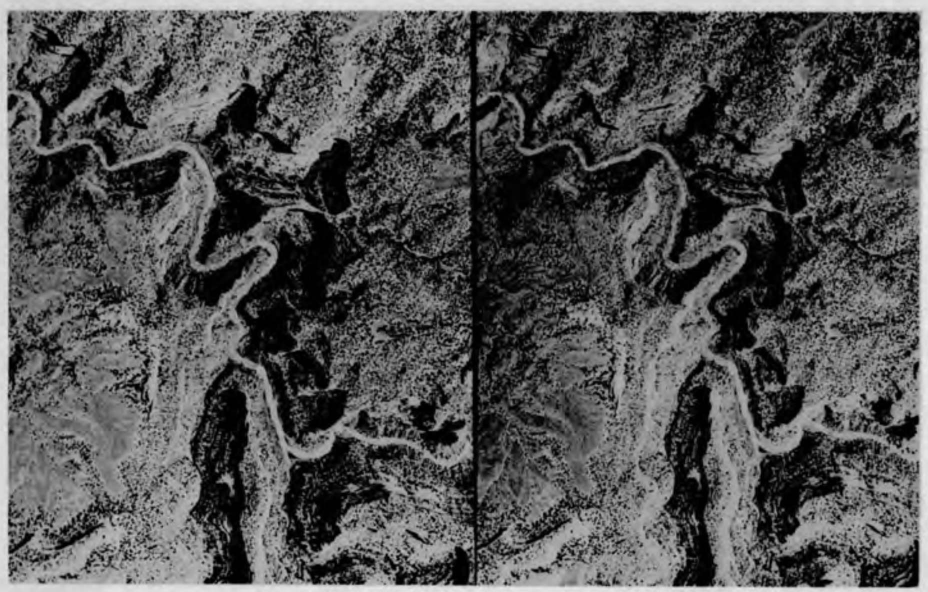
SPECIAL ELEMENTS. There are many elements that are used often in soil identification which are characteristic of a particular rock type, soil type, or rock-soil mixture. These elements usually depend on some inherent quality of the material. Some of these are very difficult to see even on the best of aerial photographs with the best of optical instruments because of their small size or because of a dense mat of vegetation. Figure 3-29 illustrates a few of the special elements. Windblown silts have the ability to occupy vertical slopes in their erosional features. In windblown silt areas, such erosional features as "cat steps", "terracettes", and "silt pinnacles" are found. In the airphotos, "cat steps" or "terracettes" appear as a series of disconnected and discontinuous minute steps on hill slopes. They are not to be confused with "cattle trails" which often spiral a hill and which are continuous and connected. Cattle trails are governed in extent by fence lines and field patterns. They are not to be confused with land slides which usually occur in shale bedrock areas and which slides form a definite local slide pattern.

Sinkholes, solution valleys, "hay stacks", natural bridges, and other karst features are characteristic of soluble rocks, particularly limestones. Basalt patterns often are characterized by minute polygons which can be seen in the scabland regions where vegetation is absent. Often it is possible to see basalt columns in the major gullies or coulees in sharp and clear photographs. The flow pattern of some of the lavas form a distinctive pattern in volcanic regions.

Many of the water-deposited materials likewise have soil pattern elements which possibly should be considered as "specials" since they do not logically fall into one of the other element groups. Common among these are markings produced by current activ-

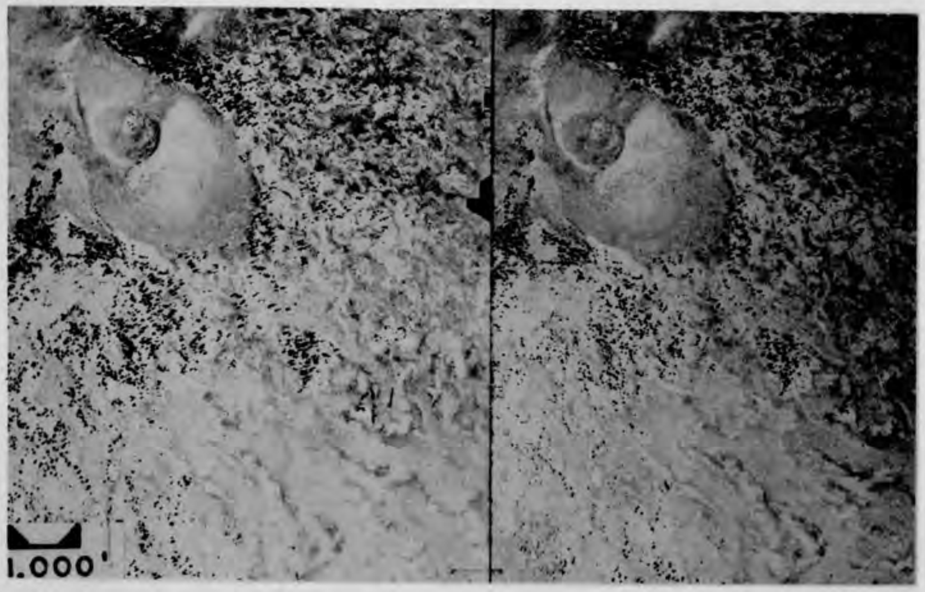
7441
18445

18444
18446



(a) Mesa (Colorado)

(b) Terrace (Indiana)



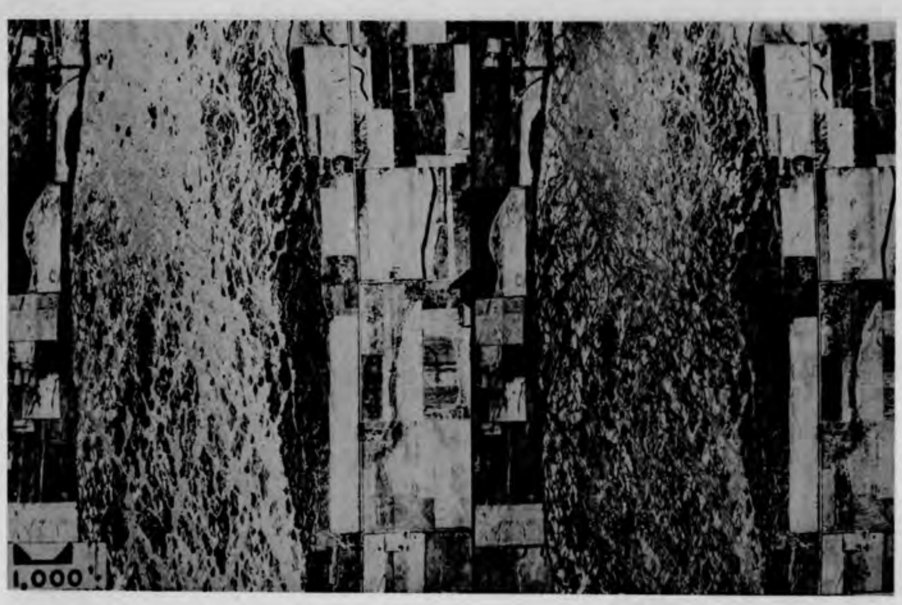
(c) Cinder cone (California)

(d) Dune (Washington)

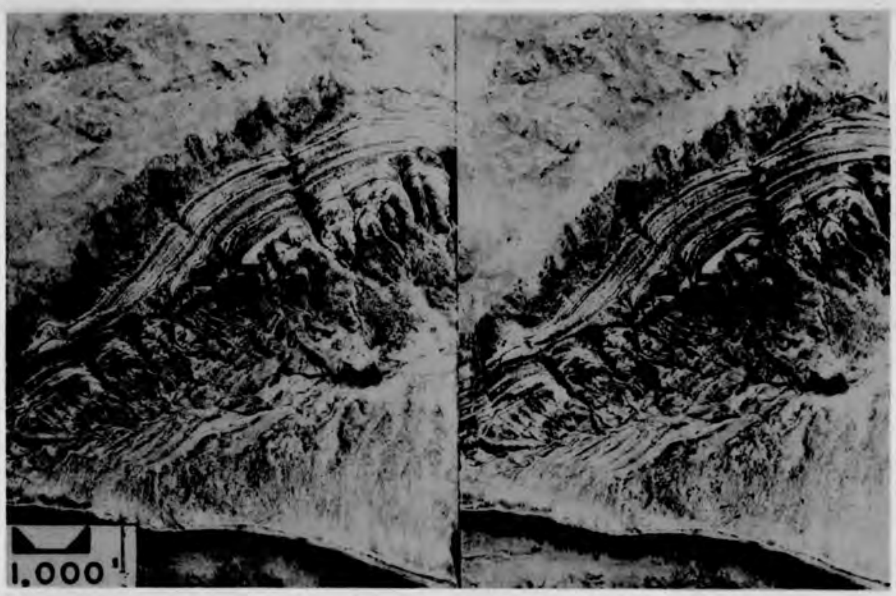
Fig.3-20 STEREOPHOTOS OF A FEW OF THE SIMPLE LAND FORMS

18447
18449

18448
18450



(a) Flood plain (Nebraska)



(b) Hog back ridges (Wyoming)

(c) Eskers (Minnesota)

(d) Sinkhole plain (Indiana)

Fig. 3-21 A FEW OF THE SIMPLE LAND FORMS

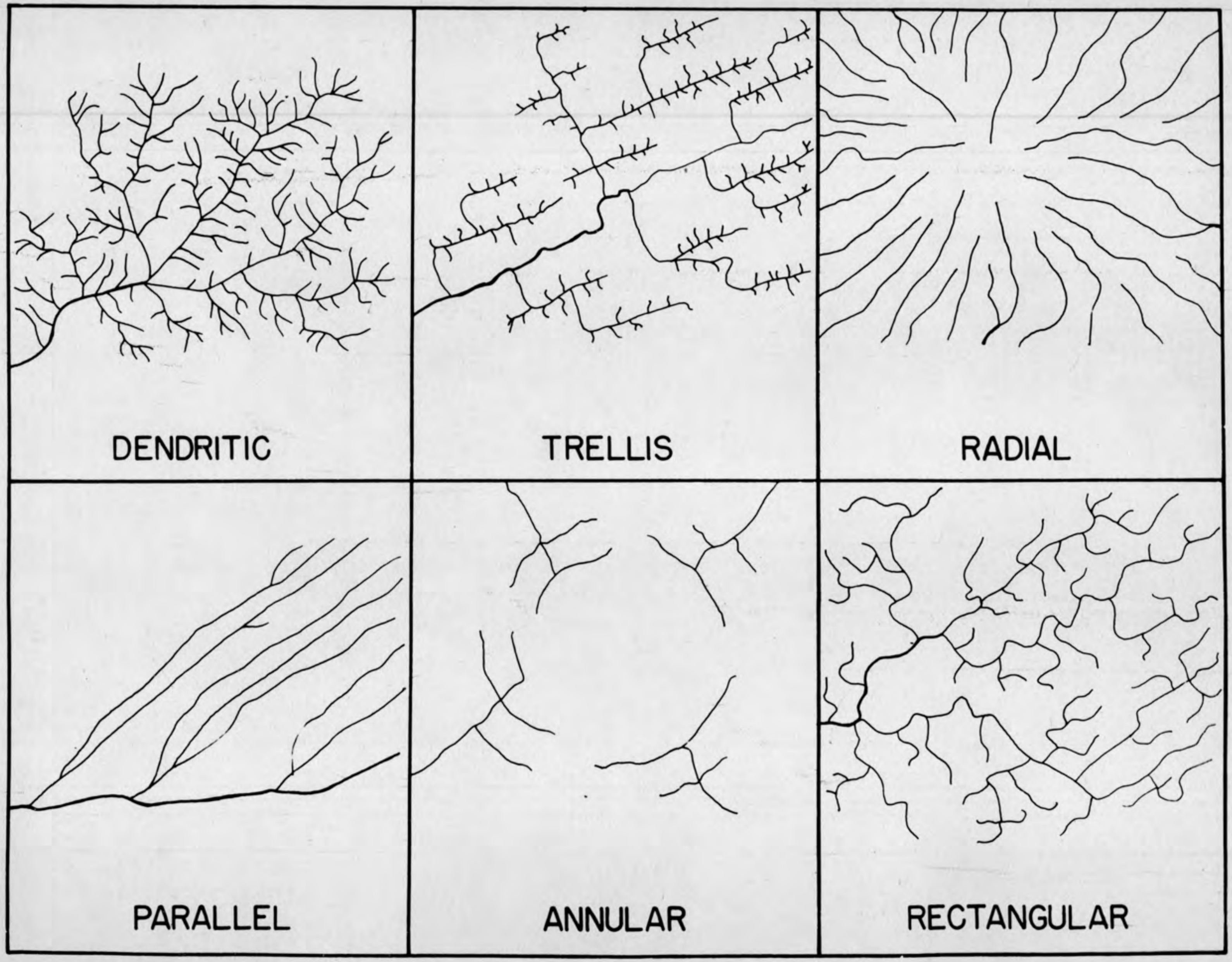
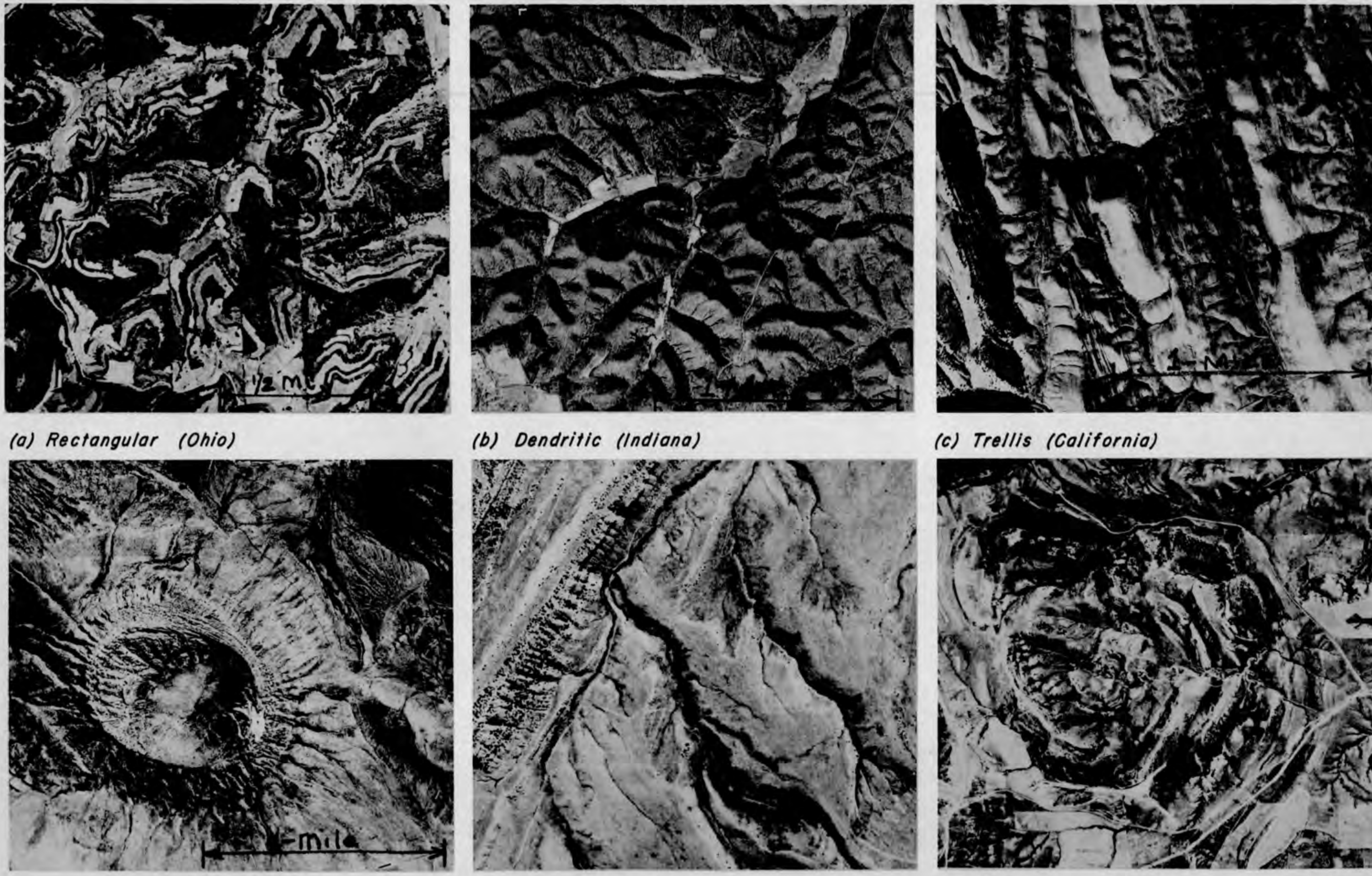


Fig. 3-22 SIX BASIC DRAINAGE PATTERNS

7274
7315

8560
7448

7309
14767



(a) Rectangular (Ohio)

(b) Dendritic (Indiana)

(c) Trellis (California)

(d) Radial (Idaho)

(e) Parallel (Wyoming)

(f) Annular (Montana)

Fig. 3-23 AIRPHOTO PATTERNS TYPICAL OF THE SIX BASIC TYPES OF DRAINAGE SYSTEMS

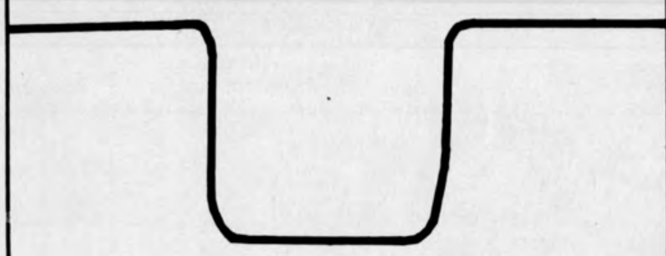
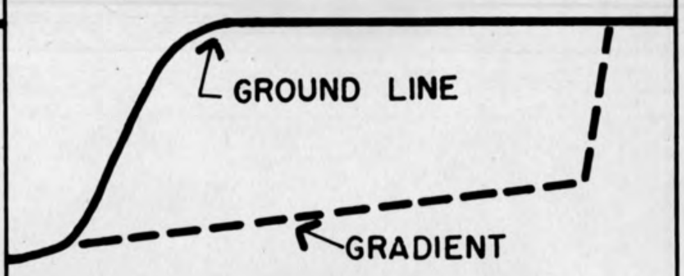
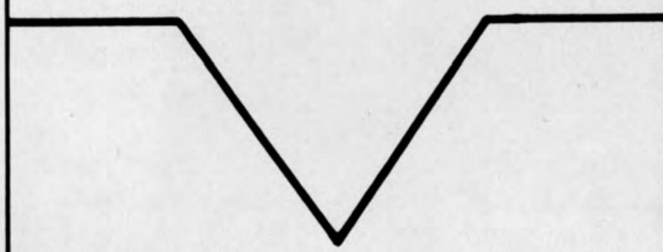
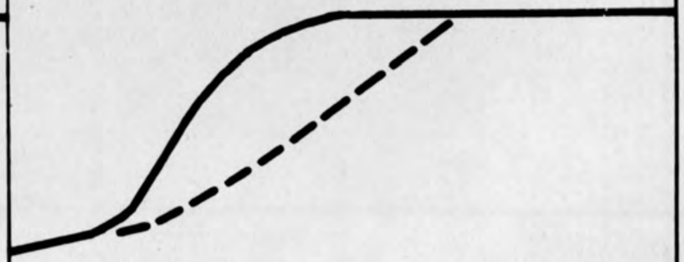
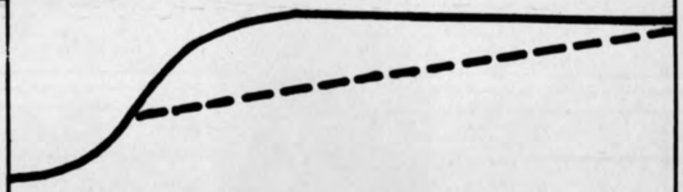
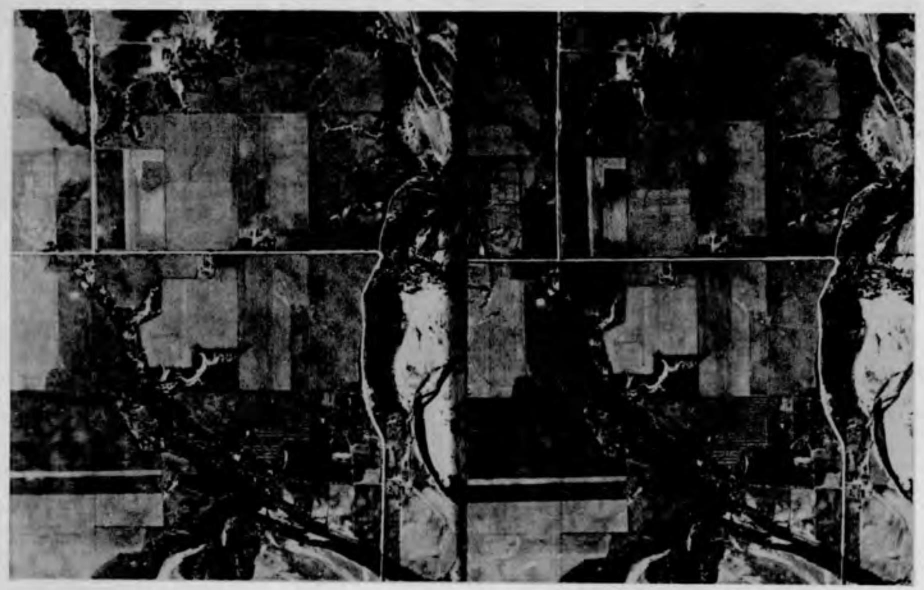
SOIL	CROSS-SECTION	GRADIENT
SAND - CLAY LOESS (SILT)		
NON-PLASTIC SEMI-GRANULAR NON-COHESIVE SANDS GRAVEL COMBINATIONS		
NON-GRANULAR COHESIVE PLASTIC CLAY SILTY CLAY		

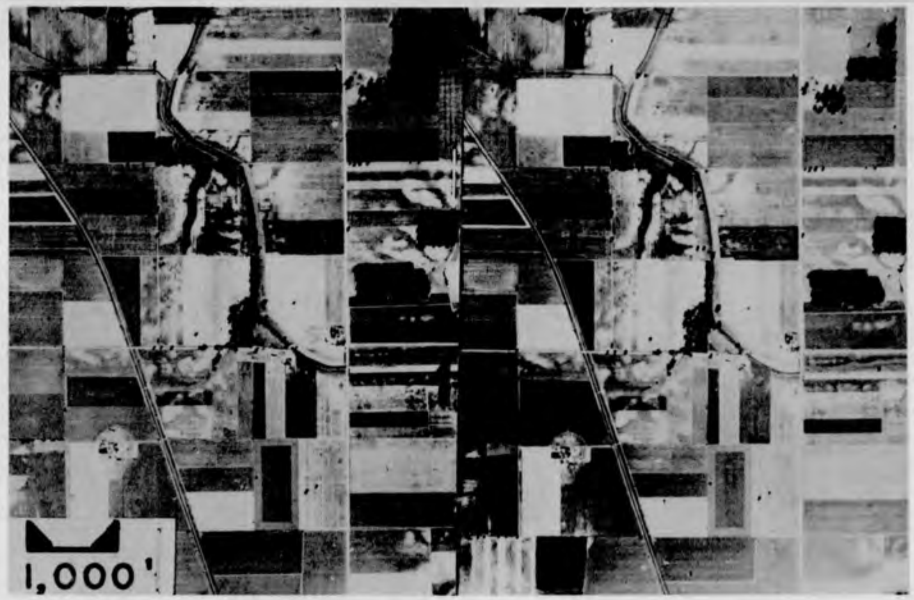
Fig. 3-24 TYPICAL GULLY CHARACTERISTICS

7198
8424

18451
6582-6581



(a) Granular soils



(b) Clays and silty clays

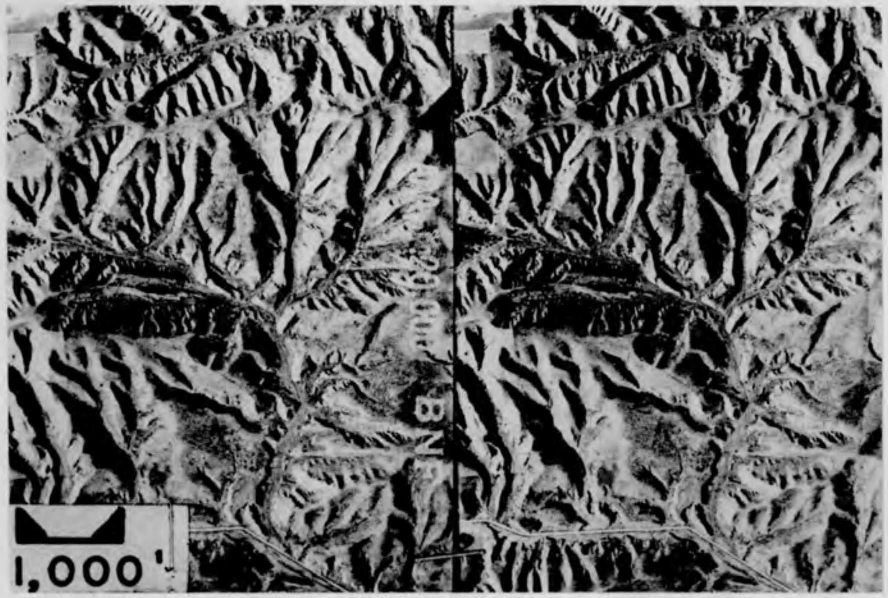
(c) Granular soils

(d) Clays and silty clays

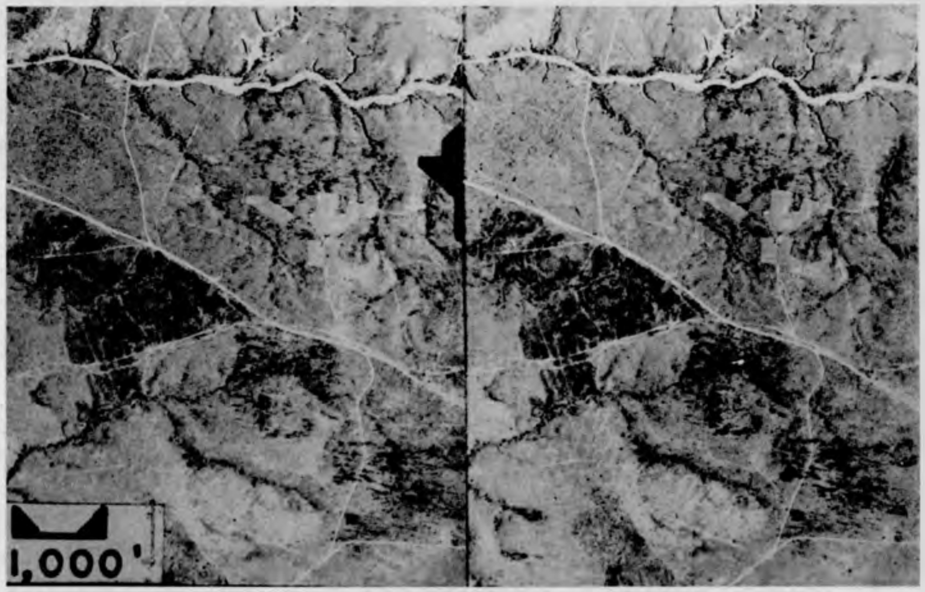
Fig. 3-25 ILLUSTRATIONS OF GULLY TYPES (INDIANA)

18452
9543-9544

18453
8125-8126

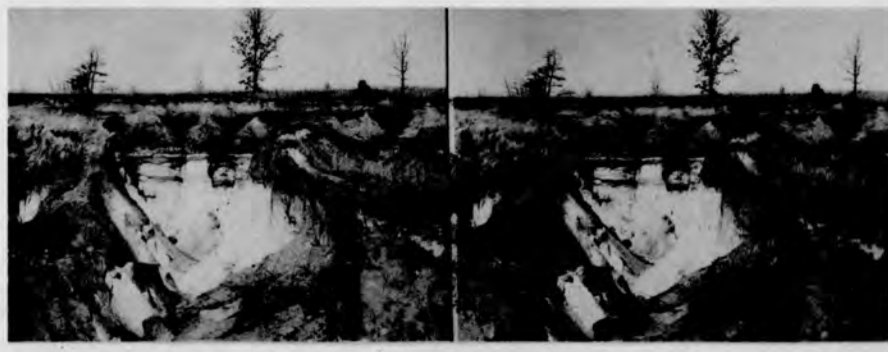


(a) Loessial soils (Nebraska)



(b) Sand clays (Alabama)

(c) Loessial soils (Indiana)



(d) Sand clays (Tennessee)

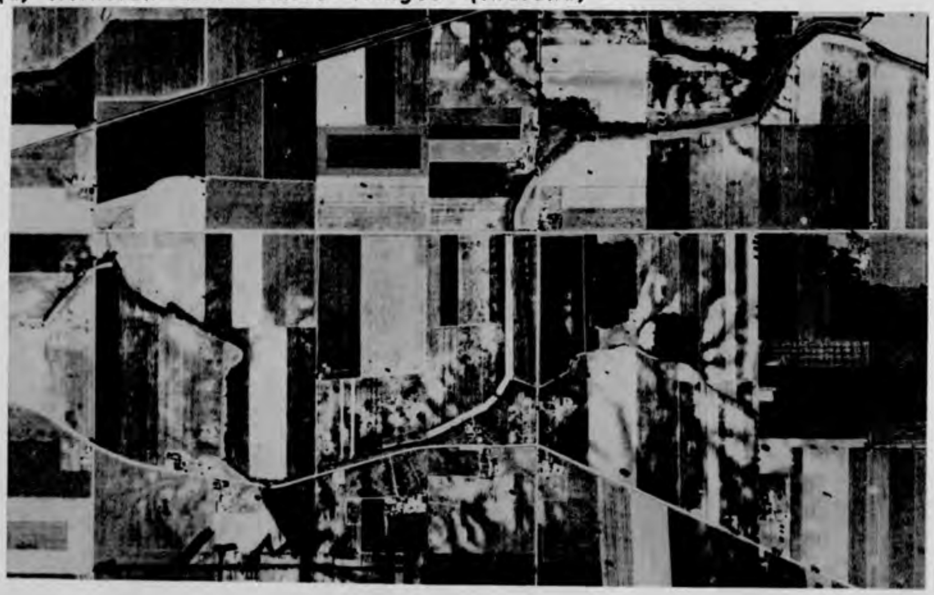
Fig. 3-26 STEREOPHOTOS OF TYPICAL GULLY TYPES

8555
7310

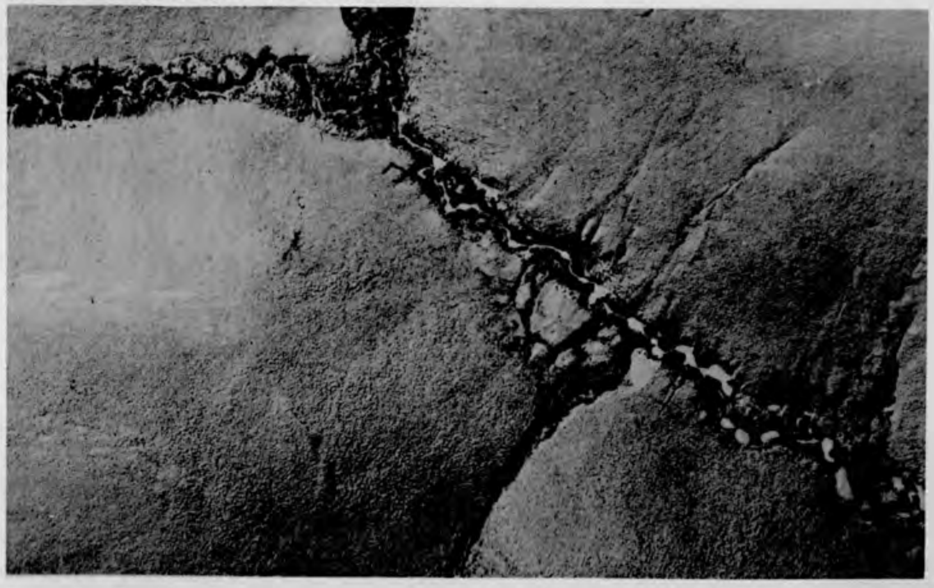
7297
18516

(a) Illinoian drift-white fringes (Indiana)

(b) Loess-pinnage (Nebraska)



(c) Lakebeds-meandering (Indiana)



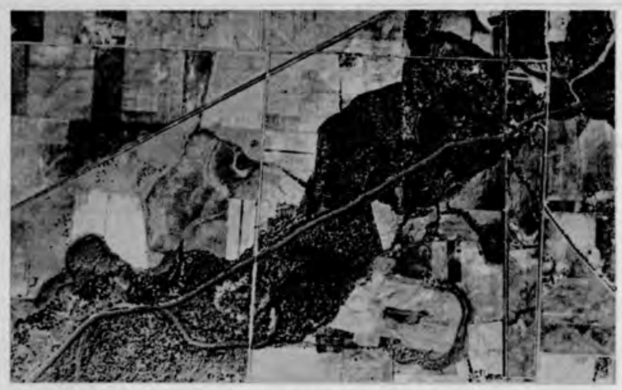
(d) Permafrost-button type (Alaska)

Fig. 3-27 EXAMPLES OF GULLY SYSTEMS

14796
855@
7196

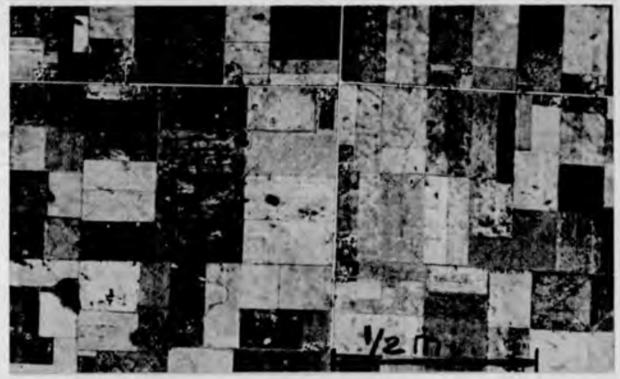
301-c
14783
7519

7313
7285

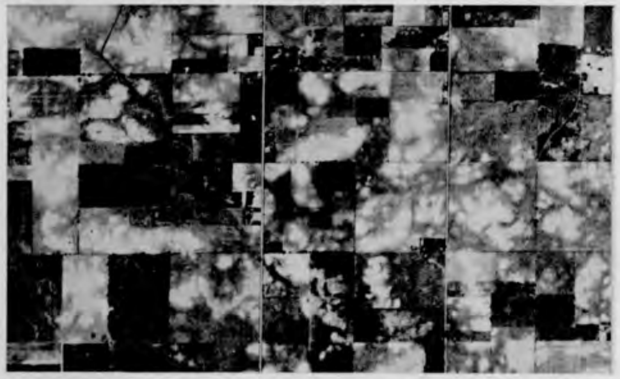


(a) Uniform-gray (Indiana)

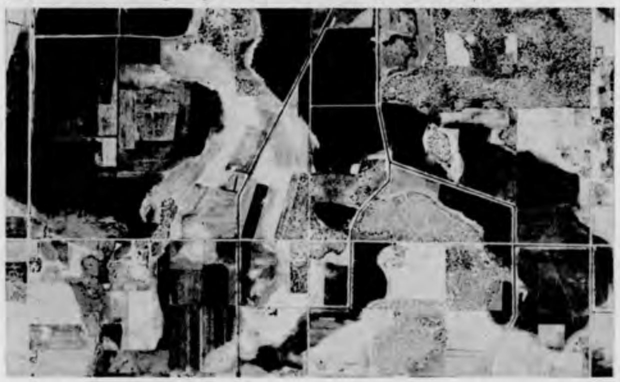
(b) Ashen gray to white (Indiana)



(c) Finely mottled (Indiana)

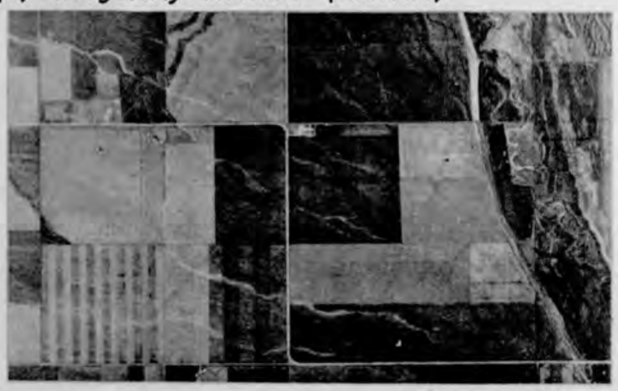


(d) Irregularly mottled (Indiana)

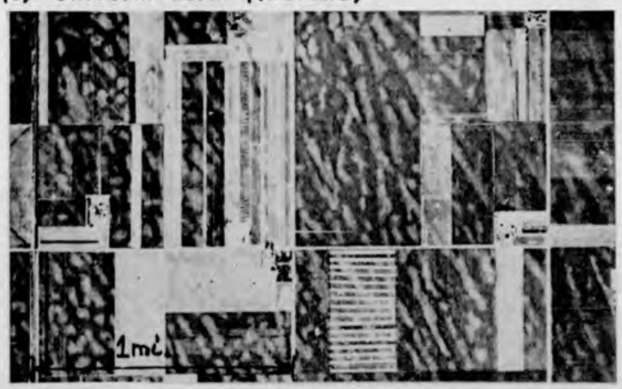


(e) Uniform-dark (Indiana)

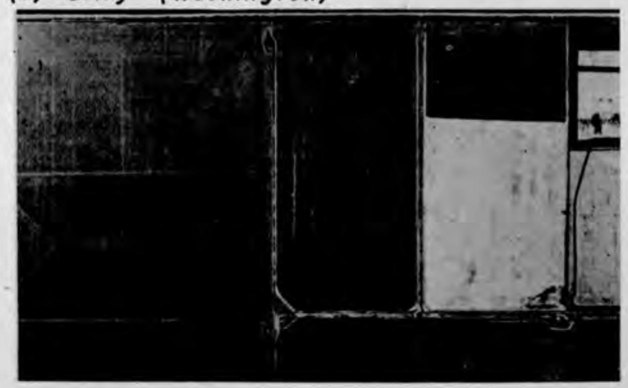
(f) Silky (Washington)



(g) Current mottling (Montana)



(h) Uniform gray-light streaks (North Dakota)

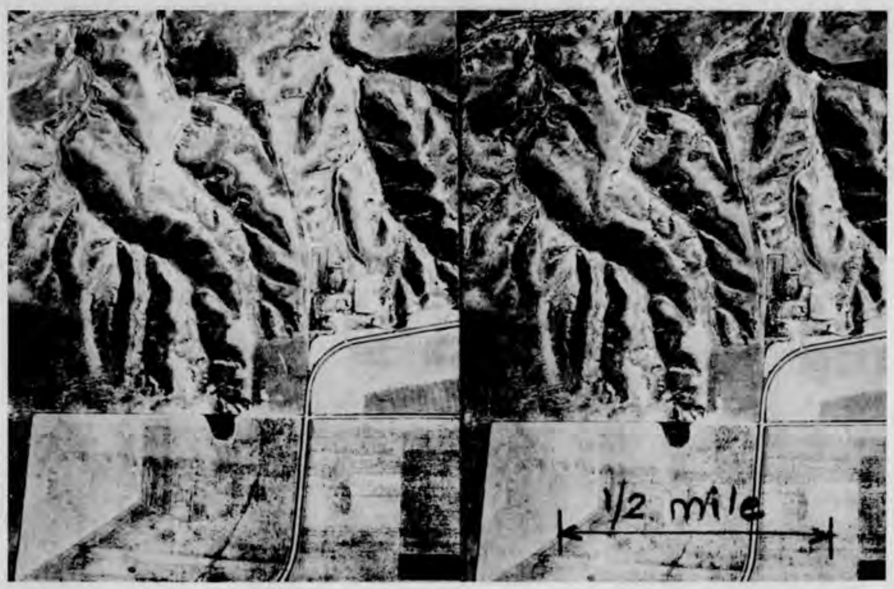


(i) Uniform-gray (California)

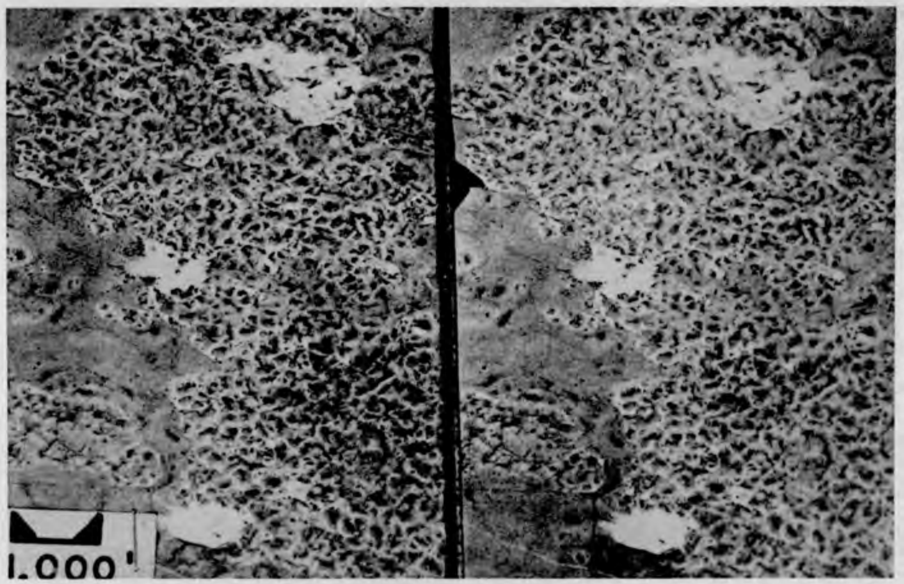
Fig. 3-28 EXAMPLES OF PHOTO-PATTERN COLOR TONES

7471
15035

18454
18455

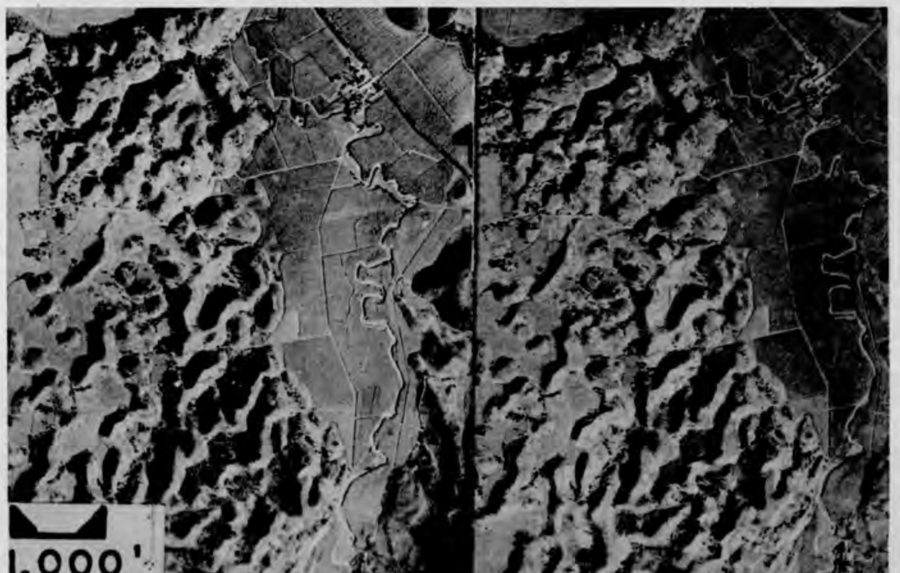


(a) "Cat steps" in loess (Nebraska)



(b) "Blow outs" on sand dunes (Nebraska)

(c) Beach ridges (Indiana)



(d) "Haystacks" in limestone (Puerto Rico)

Fig. 3-29 EXAMPLES OF SPECIAL ELEMENTS

ity. These markings vary in extent, size, and shape from massive sweeping bands (similar to those in the Louisiana Bayous) to minute rippling marks of many of the glacial outwashes. In some instances, these marks can be seen clearly by ordinary visual inspection; in some instances, they must be determined by studying the arrangement of the vegetative cover. The rippling effects of water deposition are distinctively different than the rippling effects produced by wind activity. Water markings create a network of interconnected multi-directional markings while wind markings are very uniform and are usually uni-directional. Sand dunes occasionally exhibit a distinctive and special element, that of "blowouts". These features are only associated with sand-sized materials.

In the Arctic and Subarctic, the presence of soil polygons, pingos, certain types of soil-rock flow markings, and minute "mud boils" are distinctive and characteristic elements of certain airphoto patterns. Of these few, the element soil polygons definitely can be associated with frozen soils.

MAN MADE ELEMENTS. Some of the most confusing and perhaps the most interesting pattern elements are those which are related to man's activity. Most of these, whether from the standpoint of engineering, agriculture, conservation, reclamation, erosion, or others can be traced directly to the dictates of nature. They may be related to topography, soils, rock, climate or some other natural element, and they usually represent man's desire to develop his inherited earth. Figure 3-30 illustrates some of the common man-made elements.

In humid regions where there may be a surplus of water, the airphotos may contain such elements as dead furrows, tile drainage, field ditches, levees, flood walls, ponding areas and others. Some of these, such as buried farm tiles and dead furrows, are visible only under certain moisture conditions (at the time of photography); however, even though these may exist, they cannot be detected if the photos were made during dry weather. Such elements are important clues to soil texture, drainage, and ground-water conditions. Such elements as contour plowing, terracing, and strip cropping provide indications of erosion characteristics. In areas where dry farming and other methods of moisture conservation are practiced, the photos show alternate cultivated and uncultivated fields. Orchards require well-drained soils and when occurring on flat ground, particularly in humid regions, they usually suggest porous soil conditions. Contrasting field patterns as well as contrasting natural patterns often indicate contrasting soils.

Some of the engineering practices are equally interesting as airphoto pattern elements because of the influence of topography, rock, soil-type and climate on engineering structures. Rather than being direct identifying elements, most man-made features are of indirect significance, and the interpreter can often check conclusions made from previous study of the natural elements. For example, in humid regions, because a terrace occupies an elevated topographic position, is flat, is easily cultivated, is well drained, and contains a relatively rich top soil, it may be farmed extensively in one crop type. The field pattern will be vastly different from that of either the upland on one side or the recent alluvial flood plain on the other. In the alluvial areas, the field pattern is controlled largely by current deposited ridges, old channels, or slack water areas; in the upland areas, the field pattern is controlled largely by relief.

Dominating and Supplementary Elements

Often it is possible to make reasonably accurate soil determinations, or soil-rock determinations, on the basis of one or two elements. When this is the case, those elements can be thought of as being dominating elements of the pattern. The standard, or simple pattern which represents widespread uniform materials, usually has one or two dominating elements. For further substantiating evidence for an engineering evaluation, the interpreter must use the remaining, or supplementary, elements. In complex soil areas, or rock-soil areas, dominating elements rarely occur and the interpreter must correlate by inference made from all elements.

There are only a few patterns in which the dominating elements may be used with reasonable assurance. For one particular type material or deposit, the dominating element may be land form such as the crescent-shaped land form of barchane dune. In another instance, the arrangement and contrasts of the element color tone of Wisconsin glacial drift soils, particularly the till plains, can be thought of as the dominating element. Likewise, the color pattern of some granular soils can often be considered as a dominating element. The pinnate gully system of windblown silt is the dominating element for windblown silts of the Great Plains; however, it is not the dominating element of windblown silts in the Palouse Region of Washington. The white-fringed gully system of Illinoian drift soils is dominating for that particular glacial deposit. The sink-hole-studded plain is the dominating element of certain flat-lying limestones. In many water deposited materials, particularly granular flood plains, the element flow marking is dominating.

It can be seen that dominating elements are those which stand out in the observer's mind, those which create a first and lasting impression. In any event, regardless of how dominating an element is, detailed study of the other elements should always be made to substantiate earlier predictions.

PROCEDURES FOR SOIL INTERPRETATION

For the most part, the procedures followed in learning to identify soil patterns from aerial photographs are relatively simple and straight forward. There are two basic methods of approach, the use of which depends on whether or not the interpreter has advance knowledge of natural conditions in an area. Selection of his approach also depends on whether or not the area is unknown and relatively inaccessible to field checking. For the purpose of this discussion, these two methods will be discussed as "Procedures in Accessible Areas" and "Procedures in Unknown or Inaccessible Areas."

Procedures in Accessible Areas

The rapidity, accuracy, proficiency and reliability of a survey made from aerial photographs lies within the province of the interpreter. His skill is governed by his constant use of aerial photographs not only in the office and in the field but by constant correlation of predictions with literature, with actual sample data, and with engineering performance data. Assuming the interpreter is to make a study of soil conditions in an accessible area and in one of which he has a set of photos, the following procedures are suggested. For purposes of demonstration part of the following is concerned with an area in Switzerland County, Indiana in which the soils are Illinoian Drift on limestone and shale.

ASSEMBLE MOSAIC. Using an index sheet (Figure 3-31) as a guide, the interpreter should assemble the alternate contact photos into an uncontrolled mosaic; this can be done by stapling the photos on celotex sheets. It is only necessary to mark the soils (Figures 3-32) and other information on the assembled set leaving the other set of photos unmarked. The remaining photos are set aside for later use in stereoscopic study.

FIRST IMPRESSION. The chief advantage of assembling the photos into some type of mosaic lies in the fact that the observer gains an overall picture of the area in which he is working. By viewing the mosaic from a distance, the observer gains a first and sometimes lasting impression. He should study the area as an entire unit—noting the major items, those of such magnitude either by color contrast or by configuration of lines and units which create an outstanding pattern. This may be in the form of a braided stream crossing the area; it may be a plunging fold or a series of parallel ridges or hogbacks characteristic of a region of tilted rocks; it may be clusters of crescent-shaped sand dunes which appear to be migrating across the area.

In the example in Switzerland County the contrasting airphoto-soil patterns have been separated as shown in Figure 3-32. In Figure 3-32 no attempt has been made to mark minute details—rather the major soil parent materials have been separated. The details should be supplied using stereovision.

STUDY MAJOR FEATURES. The observer should study each major feature of the area stereoscopically. This can be done by using the matched prints either in place, on the board or it can be done by removing the prints containing the object and matching them with the proper photo-stereo-mates for study at a desk or table. The elements of the pattern should be noted and tentative predictions of soil texture or of rock type should be made. Each element should suggest a particular material and all should agree.

In the example contained in Figure 3-33 the details of the soil parent material border have been worked out by stereo-vision. Note that such items as gully pattern, soil color tones, field patterns, and apparent topographic features of the two materials have been separated and grouped. These should be labeled on the photos which were assembled into the uncontrolled mosaic. A red china marking pencil is satisfactory for this use since the red marks can be erased with art gum or they can be removed by a cloth moistened with carbon tetrachloride without damaging the photo emulsion. The use of an electric eraser will destroy the photo emulsion.

LOCATIONS FOR FIELD STUDY. Undoubtedly the best method to gain proficiency is to mark areas for field study and then visit those areas and at the same time compare earlier predictions with actual field conditions. Locations which are considered typical of each major parent material should be marked.

LITERATURE SURVEY. After the interpreter has mapped the area and has gained some idea of the various parent materials using airphotos, he should conduct a literature search which should include the fields of geology, pedology, and soil survey. From a study of existing maps, the interpreter should note bedrock boundaries or soil boundaries and compare them with the boundaries which have been marked on the aerial photos. Predictions can be verified from a study of the soil and rock descriptions in the literature. There is a definite advantage to be gained by the interpreter when he studies an area from the photos in advance of any field work or literature survey since the interpreter gains a feeling of confidence and of self assurance which is of great value to him when studying unknown or previously unexplored areas.

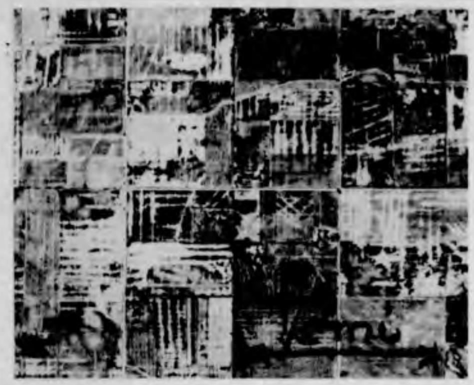
Figure 3-34 is a photo copy of an airphoto and an agricultural soil survey map of an area in Switzerland County, Indiana *(185)*. The letters on the agricultural soil survey map refer to agricultural soil names. The area covered by the photo and by the map is one developed from thinly bedded limestone and shale (Ordovician in age). The bedrock soils have been named Fairmount and Switzerland while the alluvial soils are Huntington and Wheeling (Soil

7503
7491
7487

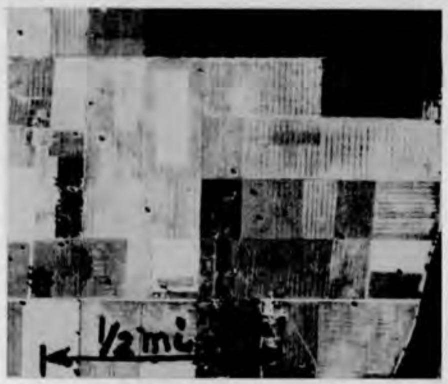
7499
7494
7496

7513
9321
7514

7507
7516
7501



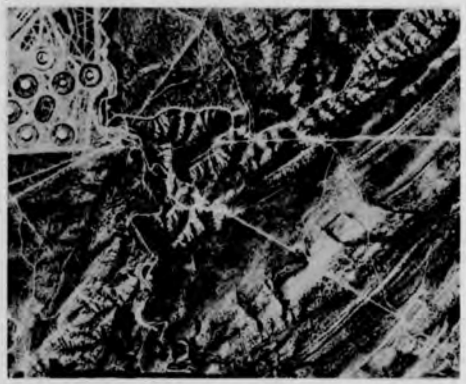
(a) Buried farm tile



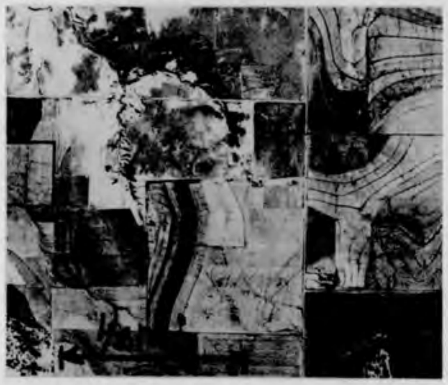
(b) Dead furrows

(c) Surface ditches

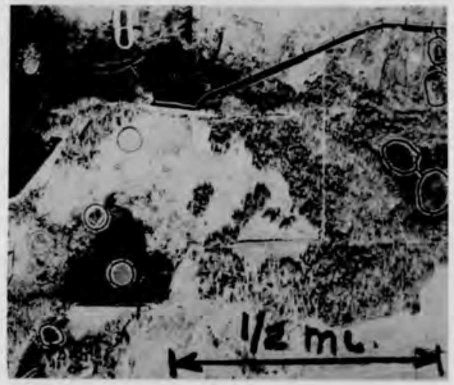
(d) Contour plowing



(e) Pipe lines



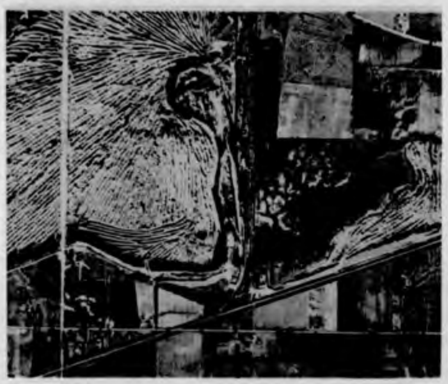
(f) Terracing



(g) Fish hatcheries

(h) Irrigation

(i) Tree plantings



(j) Strip mines

(k) Power line

(l) Erosion control

Fig. 3-30 EXAMPLES OF MAN-MADE ELEMENTS

Fig. 3-31 INDEX OF PHOTOGRAPHY OF SWITZERLAND COUNTY, INDIANA

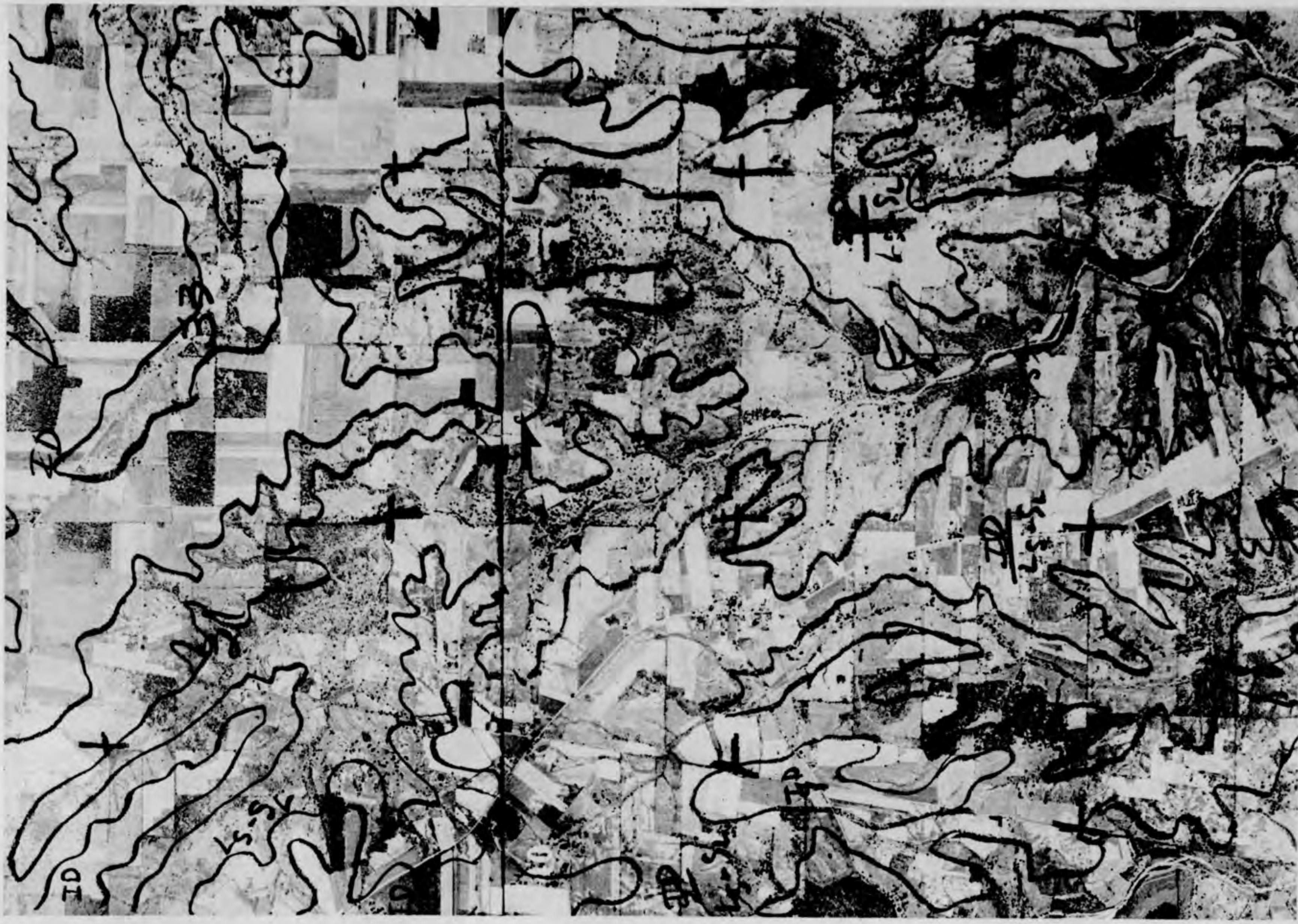


Fig. 3-32 GENERALIZED SOIL-PARENT MATERIAL BORDER MARKED ON CONTACT PHOTOS

Fig. 3-33 DETAIL BOUNDARY MARKINGS

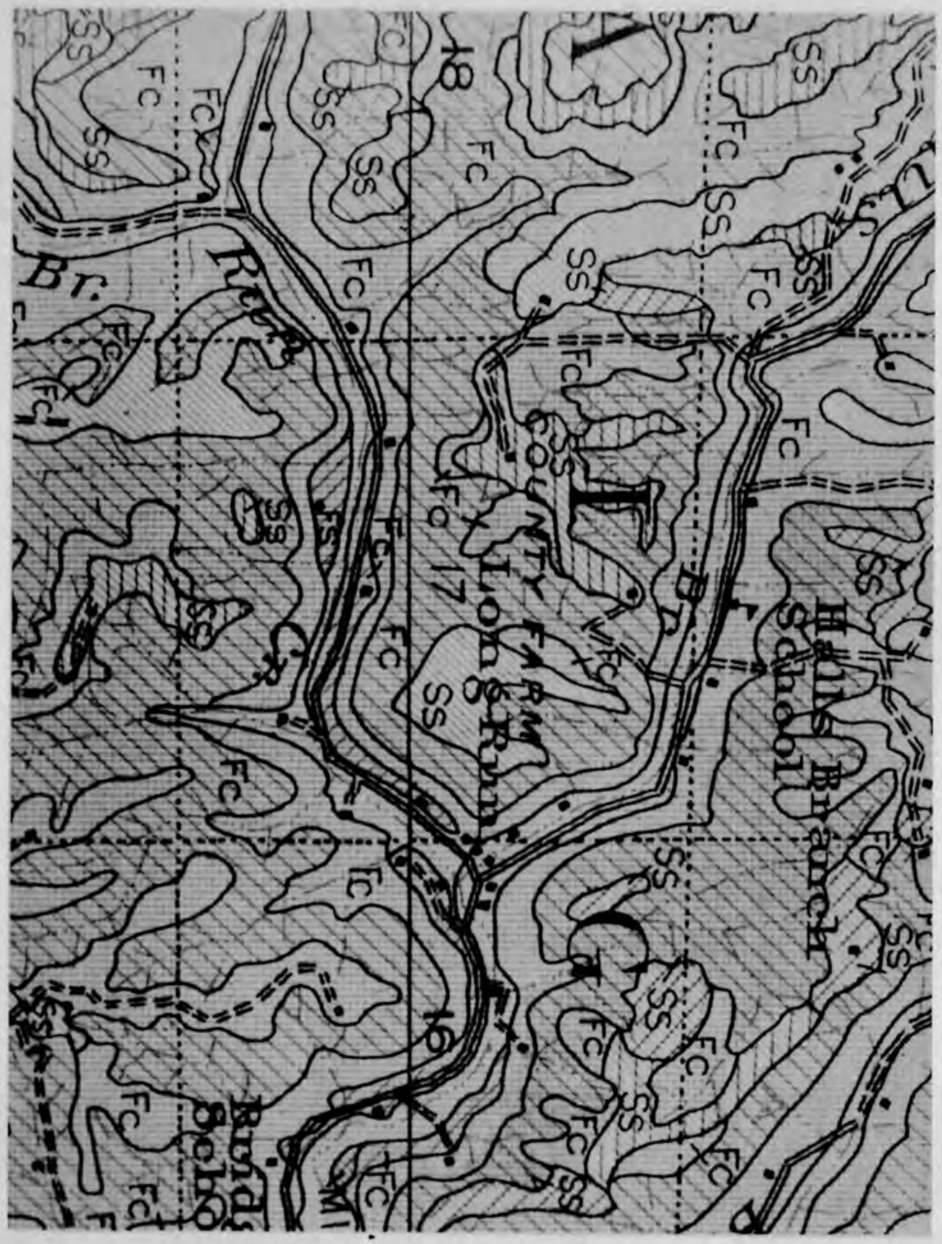


Fig. 3-34 AIRPHOTOS AND AGRICULTURAL SOIL SURVEY MAP OF THE SAME AREA

Survey of the Department of Agriculture). In the example, the Switzerland soils (S) occupy the hill tops and upper hill sides, the Fairmount soils (F) occupy the steep slopes (colluvial soils), the Wheeling soils (W) occupy terraces and benches, and the Huntington soils (H) occupy the flood plains or first bottoms. From an engineering standpoint these general classifications of hill tops, hill sides, terraces, and flood plains for soils of this region suffice. By stereo-vision they can be readily delineated on the photos.

FIELD STUDY. Following the literature survey and inspection of the photos, the observer should take the photographs into the field in order that first-hand verification of his predictions can be made. If convenient, it is best to divide the mosaic into small groups of mosaics each of which can be stapled to a small celotex board. If it is not possible to use groups of photos mounted on boards in the field, a map or index sheet can be used which will show the locations of photos for field checking from the proper photo index number. At each location marked on the photos, the observer should check the photo elements by stereoscopic study at the particular spot of interest. In this way, elements both on the photos and on the ground can be observed—thus making it possible to compare actual ground features with their pictorial representation on the photos. Figure 3-35 shows an airphoto—ground photo combination of shallow Illinoian drift on thinly bedded limestone and shale in Switzerland County.

In areas of rolling topography, the study of highway and railroad cuts will give the interpreter an opportunity to view soil profiles. In areas of flat topography, a soil auger should be used to obtain samples representative of the soil profile. A profile sample should consist of samples representative of the "A" horizon or the top soil, of the "B" horizon or weathered zone, and of the "C" horizon or unaltered parent material. Samples need only to be taken for ordinary classification tests. In order to prove that soil patterns and related engineering problems are repetitive in nature, the interpreter should sample areas of similar airphoto patterns in different areas, often separated by considerable distance.

PERFORMACE STUDY. The correlation of the performance of a structure with soil types is of utmost importance. Particular attention should be given to variations in performance between cut and fill sections and to locations where varying soil horizons are crossed. In concrete pavements, this may be shown in the form of differential cracking of the pavement slab between cut and fill sections, diagonal cracking characteristic of frost heaving, settlement at joints or cracks which is often indicative of pumping or other subgrade disturbances, and discoloration of the pavement at joints and cracks which may be caused by pumping action. In bituminous pavements, this may be shown in the form of general subgrade failures, alligator cracking, and chuckhole development. In certain soil-rock areas, it is possible to predict landslide difficulties.

Figure 3-36 shows a landslide condition in thinly bedded limestone and shale in Switzerland County, Indiana. The arrows in part A point out landslide markings on the airphotos. Part B shows the topography typical of the limestone and shale of the region. Note the change in slope below the timber. This change roughly delineates the change from rock-in-place to colluvial slide rock. The photo in part C shows the start of a slide in a side hill cut and fill section. Part D shows a small slide on the side slopes of a limestone and shale hill. Note the changes in slope as well as the "wrinkled appearance" of the hill side.

By the correlation of the performance with soils and with the corresponding airphoto patterns, the interpreter becomes fully aware of the major engineering significance of this method of survey and he will realize how it can be used to advantage in design and construction of engineering structures.

PHOTOGRAPHIC RECORD. In learning this method of survey, the interpreter should obtain ground photographs of many of the pattern elements to which he can refer later when making a soil survey analysis or when illustrating reports. He should build up a collection of ground photos and low altitude obliques of as many patterns and variations in pattern as possible. Often, it is difficult to show some of the elements in ordinary photographs, and the observer may want to take ground photos in stereo-pairs. This can be done by taking one photograph and then stepping over a few inches and taking a duplicate photo being careful to include exactly the same field of vision and being careful to have the horizon in exactly the same portion of both photographs. It will be found that such photos, when matched and viewed under the stereoscope, will make it possible to study relief and gully shapes much better than by using ordinary photographs. In general, it should be remembered that, if the object to be shown in relief is relatively close to the observer (within 100 to 200 feet), the camera need only to be moved two or three inches; for greater distances, the center of the pictures should be much farther apart. For scenes such as distant mountain ranges where the object is a matter of miles away, the camera can be shifted laterally 10 or 15 feet; however, the observer must be careful that there are no objects in the foreground which will come into the view of either picture since this will result in confusion to the viewer.

FINAL OFFICE STUDY. Upon completion of the field reconnaissance and sampling, the observer will want to reassemble the photographs into a mosaic for additional study of the area he has visited. He may wish to study the literature again and correlate certain features as shown on published maps with his interpretation as indicated on the photos.

Procedures in Unknown and Inaccessible Areas

By gaining earlier experience in known and accessible areas, particularly where literature about these areas is available, the observer will have established a definite method of attack. However, it is not always possible to gain access to an area conveniently and often a survey must be made of an area for which there is no literature. In such cases, the interpreter must rely on judgment, imagination, and processes of logical reasoning in order to make a reasonably accurate soil survey. Based on the fact that advance knowledge has not been supplied with the photographs, the following procedure will be helpful in conducting such a survey.

DETERMINE PHYSIOGRAPHY. First, the interpreter should determine the general physiography of the region. It should be decided whether the area is a plateau, a lowland, a coastal plain or some other major or standard physiographic type or province. This can be determined by a study of a large number of photos preferably assembled in index form; this will enable the observer to view the entire area, or a large portion of it. It can also be done to a limited extent by study of a series of tri-metrogon strips including the right, left, and vertical photos. However, the tri-metrogon strips should cross a physiographic region. Photo coverage in any event should cross a physiographic boundary. Determining the physiographic region is largely accomplished by a study of the land forms and their areal extent. Determination of the physiographic province type limits to a certain extent the type of materials to be found.

DETERMINE GEOLOGY. It is important that the interpreter determine whether or not the particular region is composed of ice laid materials, water worked and water laid materials, wind worked and wind laid materials, or whether the area is composed of rock materials. It is not important from the standpoint of engineering soils that the interpreter determine or even know the geologic age or period. It is of more importance that he be able to tell the general type of material and that he be able to differentiate between the various major parent materials. Determining the geology of the region is done by observing the regional aspects, the configuration of drainage lines and other surface markings, and by making a study of land forms. Determining the geology also limits the type of material expected to be found.

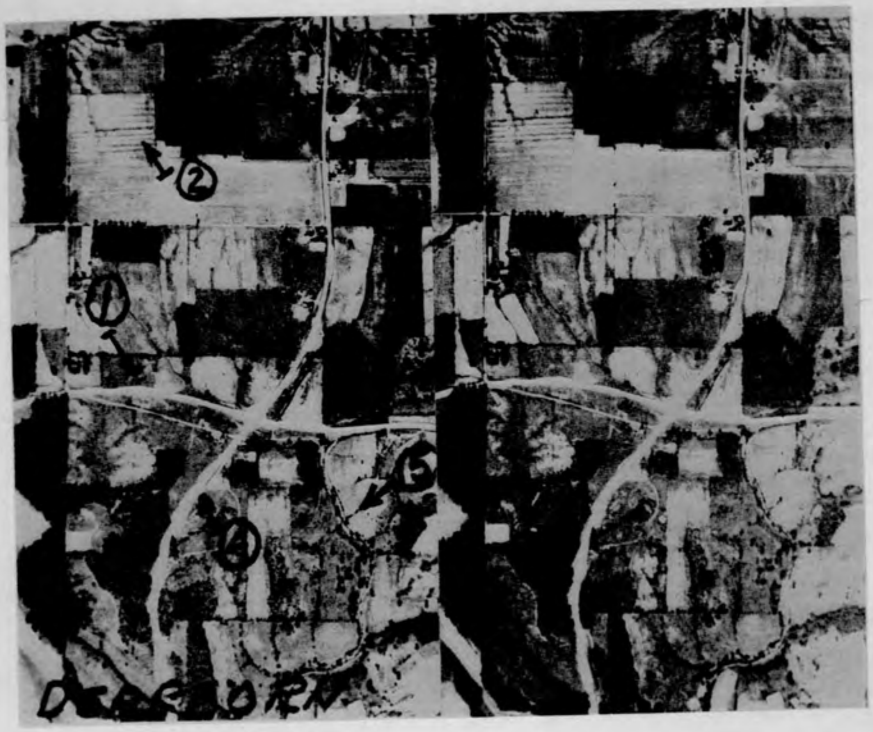
DETERMINE REGIONAL DRAINAGE. It is of importance that the observer determine the regional drainage of the area since drainage patterns are closely related to physiographic and geologic conditions. Regional drainage gives the interpreter an indication of the relative depth of the overburden and the relative hardness or softness of the soil or rock-soil materials. Drainage study also makes it possible to determine uniformity of the parent types of changes in parent type within any physiographic region. Drainage is best observed from study of a large number of photos such as an index sheet or from study of a mosaic. To a limited extent drainage can be interpreted from strips of tri-metrogon photos. The overall drainage reflects the overall soil texture and porosity.

DETERMINE CLIMATIC ZONES. Perhaps one of the most important features in soil development is the influence of climate which often is clearly shown on aerial photographs. The general climatic region can be identified by vegetation, distribution and contrasts in vegetation types, drainage pattern, and erosional features. Knowing the general climatic conditions under which the area has existed and under which the soils have formed gives additional clues to the type of soil and to the relative profile development.

DETERMINE LOCAL FEATURES AND LOCAL DRAINAGE CONDITIONS. A detailed study of local drainage features and the individual gully systems makes it possible to identify soil textures. A study of erosional features in the light of climate will make it possible to determine whether erosion is relatively old in nature or is relatively recent, thereby establishing the degree of reliability to be placed in gully characteristics. Local conditions of vegetation and man-made features should also be determined. Vegetation reflects climate, soil texture, soil moisture, and soil fertility and aids in making engineering soil predictions.

APPLY ELEMENT TESTS. After the interpreter has pieced together all bits of evidence gleaned from detailed study in light of the various natural sciences, a thorough and detailed study of the elements of each pattern represented on the photograph should be made. When the sequence of natural events have been traced from original deposition through the erosional history to the present and when all of the elements agree and check each other, then the interpreter can predict engineering soils data with a reasonable degree of accuracy. It follows then, that knowing the engineering soils of a region makes it possible to predict certain engineering problems which will influence location, design, construction, and maintenance.

7026



6704

Fig. 3-35 AIRPHOTO-GROUND PHOTO OF SHALLOW ILLINOIAN DRIFT ON LIMESTONE AND SHALE

18459
6688-6689

9813
6697-6698

Fig. 3-36 A LANDSLIDE CONDITION IN LIMESTONE AND SHALE