in contrast to other textural combinations found in association with them. At the other extreme, the dry climate of northern interior Alaska includes areas having a wet soil-climate regardless of texture. These are coincident with the areas of perennially frozen ground, and here vegetation changes accordingly. Consequently, in areas where the ecologic balance is undisturbed, vegetation will reflect subtle changes in the soil moisture conditions.

The amount and type of surface drainage on these land forms is related to slope and permeability of a land mass. Where there is a large amount of surface drainage on level to undulating relief, the soil material can be expected to be relatively impervious, while a lack of surface drainage indicates a porous land mass. Recent alluvium is an exception since it is periodically refreshed by overflow.

Combining these various elements of the soil pattern and interpreting them in the light of experience and principles that are universally applicable, makes airphoto interpretation a medium of obtaining and presenting information regarding the physical properties and conditions of surface and subsurface deposits. As usage increases and experience is developed, numerous organizations are finding that engineering costs are less and a better quality of work results when full use is made of aerial photography.

PHOTO-INTERPRETATION IN MILITARY GEOLOGY[1]

John T. Hack

INTRODUCTION

MILITARY geology is a field of military science and of geology concerned with the application of geologic knowledge and techniques to various military tactical and strategic problems.

It has a great variety of uses in military terrain intelligence. The most common application is in predicting soil and foundation conditions at proposed sites for military installations, such as airfields, roads, bridges, piers, tunnels, water wells, and other large works whose location and design depends upon the terrain. Geology is also applied in studies of terrain appreciation which involve predicting ground conditions affecting ease of movement. All of these applications depend on knowledge, observed or inferred, of the structure, texture, porosity and other physical properties of the rock and soil on the surface and at depth.

Aerial photographs are an aid in this field just as they are in many other fields of military science and geology. Because they show the details of topography, drainage, vegetation and cultural patterns, they may be used as base maps or for the construction of base maps. Aerial photographs may also be used in interpreting geology or in extending a geologic map from a geologically mapped area into an adjacent area where the geology is unmapped. Much has been written about the great value of aerial photographs in interpreting geology, and some make the claim that aerial photograph interpretation may be used as a substitute for geologic field work. It is true that aerial photographs are an especially valuable tool in military geology when detailed information is required because they are often the only available source of such information, but they are not a substitute for geologic maps and reports resulting from detailed and careful field observation. I wish to describe in the following pages some of the methods of applying photo-interpretation to geology and to point out some of the limitations of these methods.

[1] Published by permission of the Director, U. S. Geological Survey.

USE OF AERIAL PHOTOGRAPHS AS SOURCE MATERIAL IN MILITARY GEOLOGY

General Statement.

The source material of military geology is varied, and the nature of the material which can be used depends on the extent of published scientific data available, on the accessibility of the area, on the kind of report to be prepared, and on the time available for study. Aerial photographs are the most valuable source material when detailed information is needed, when the area under study cannot be visited, and where detailed geologic maps and other more precise data are lacking. They are especially useful in enlarging and refining small scale geologic maps when greater detail is needed than can be interpreted from geologic maps alone. Except in a few parts of the world, this latter situation is the most common one.

In some areas it is possible to interpret the geology from aerial photographs alone. More generally, the photos supply only indirect evidence of the geology, and if detailed analysis of small areas is necessary, the military geologist uses aerial photographs to supplement and to refine the available information based on ground observation. Many sources of information are useful. Generally some kind of geologic map is available, although it may be on a scale of 1:1,000,000 or smaller; but even such a map is helpful. Valuable clues to the geology may also be obtained from geologic reports without maps, from scientific reports other than geologic reports, from accounts of travels, and from ground photographs. These sources of information, when used in conjunction with aerial photographs enable the geologist to form a "hypothetical" geological map of the area.

The most common kinds of evidence furnished by aerial photographs are the following: (1) the appearance of the geologic deposits themselves, (2) the topographic form of the terrain, (3) the pattern and completeness of drainage, (4) the vegetation and its patterns, (5) adjustment of cultural patterns to the terrain.

Appearance of geologic deposits on aerial photographs.

Most depositional features have a unique and characteristic appearance, and are recognizable if formed in recent time. Dunes, bars, spits, beaches, glacial moraines of recent origin, stream terrace deposits, active alluvial fans, and some volcanic deposits can be recognized especially in dry or cold climates where vegetation does not obscure them. Conditions of drainage, stability, and factors influencing movement can generally be predicted for any of these deposits.

Sand dunes are a widespread terrain feature. It has been estimated that in the United States they occupy about 10 per cent of the land area. They are readily recognized and can be delineated on aerial photos because they have a characteristic form commonly consisting of alternate hollows, and bow-shaped hillocks; they impede drainage and are dry, having a sparser vegetative cover than surrounding terrain. The form of dunes, however, may eventually be destroyed by erosion so that the areas of sand are unrecognizable on aerial photographs even though still an important factor affecting ground conditions for military operations.

Glacial moraines have a characteristic appearance, as do the outwash trains which extend down-slope from them. Stream terrace deposits and alluvial flats are easily identified, and where the vegetation is sparse, even the texture of these deposits may sometimes be inferred by a skillful interpreter. Depositional coastal feature such as beach ridges, spits and bars are readily indentified. In general, the features found along coasts are favorable for photo-interpretation because they are free of vegetation. The largest part of the land area, however, is underlain by older sedimentary and igneous rocks, and their interpretation can rarely depend on characteristic features of the deposits themselves. Correct interpretation of rock type and structure must depend on basic geologic data aided or refined by clues seen on photos.

Topographic form.

Topographic forms are influenced by rock types, and by the geologic history of a region and can be used in interpreting geology. Hard crystalline rocks are carved into more rugged topography than softer sedimentary rocks. Relatively hard sedimentary beds, such as limestones and sandstones, commonly form plateaus or ridges which are topographically higher and flatter than areas underlain by softer rocks. Thus, in a region of moderate relief, hard sandstones and limestones can be expected to form rather smooth-topped table-lands or flats, edged by bluffs or scarps, whereas shales and other soft rocks will form hilly undulating terrain with sharper crested divides. Limestone areas are generally pocked with sink-holes or incipient sink-holes.

These features are most successfully interpreted when the aerial photographs can be compared with a geologic map, even though the map may be small in scale. The map may enable the geologist to identify a certain kind of topography with a specific geologic formation or with a group of formations so that the small scale geologic map can be refined and enlarged.

The pattern of drainage.

The dependence of drainage patterns on underlying rock structure is a phenomenon familiar to all geologists. Areas of folded rocks commonly have trellised drainage patterns with the streams following longitudinal valleys carved in the softer rocks. Areas of flat-lying sedimentary rocks have branching tree-like patterns. Igneous rocks often produce rectangular patterns dependent on the joint systems of the underlying rocks. Drainage ways are apt to be denser in shales and other impervious rocks than in porous rocks such as limestone and sandstone. Poor drainage in the lowlands and numerous channels for runoff on slopes are identified with rocks of low porosity and strength. As in the case of topographic form, however, drainage patterns can be used only to provide clues in interpreting geology and are most successfully used when geologic maps are available for comparison.

Vegetation.

Natural as well as cultivated vegetation commonly, but not always, reflects ground conditions. Certain plants and associations of plants are indicators of drainage conditions, or of rock types, and often can be recognized and delineated on aerial photographs. Photo-interpretation of vegetation is a promising field for research in military photo-interpretation, but, as in the case of other terrain features, vegetation can only provide clues to terrain conditions. The factors which influence the distribution of vegetation in a given area must be related to the regional geology and topography before the vegetation can be used. Considerable research was done on this subject during the war and a number of photo-interpretation manuals were prepared which provided keys to the identification of vegetation of military significance. Certain plants like the

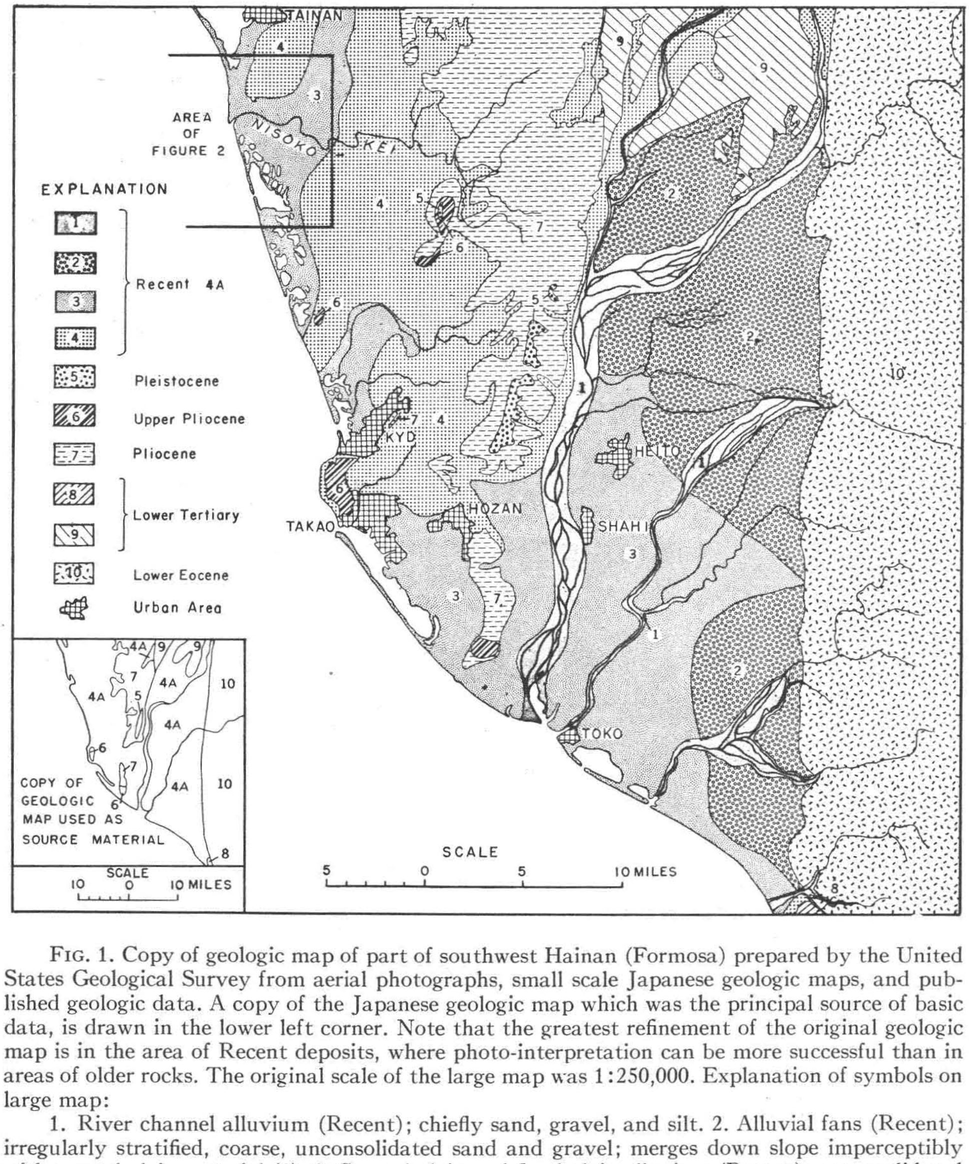

FIG. 1. Copy of geologic map of part of southwest Hainan (Formosa) prepared by the United States Geological Survey from aerial photographs, small scale Japanese geologic maps, and published geologic data. A copy of the Japanese geologic map which was the principal source of basic data, is drawn in the lower left corner. Note that the greatest refinement of the original geologic map is in the area of Recent deposits, where photo-interpretation can be more successful than in areas of older rocks. The original scale of the large map was 1:250,000. Explanation of symbols on large map:

1. River channel alluvium (Recent); chiefly sand, gravel, and silt. 2. Alluvial fans (Recent); irregularly stratified, coarse, unconsolidated sand and gravel; merges down slope imperceptibly with coastal plain material (3). 3. Coastal plain and flood plain alluvium (Recent); unconsolidated sand, gravel, silt, and clay; finer constituents most common near shore. 4. Piedmont alluvium and stream terraces (Recent); unconsolidated gravel, sand, silt, and clay, generally coarser and better drained than coastal plain alluvium. 5. Bench gravels (Pleistocene); well-sorted red clay, sand, and gravel; generally covered by ferruginous red soil; thickness, few feet to 200 feet. 6. Ryukyu limestone (Upper Pliocene?); hard, compact, fossiliferous limestone. 7. Shokozan formation (Pliocene?) and Byoritsu formation (Pliocene); Shokozan formation is chiefly conglomerate, interbedded with sandstone, shale and limestone; Byoritsu formation is chiefly sandstone, interbedded with shale and marl; becomes coarser southward. 8. Koshon conglomerate (Miocene to Upper Eocene); sandstone and conglomerate. 9. Arisan formation: (Miocene to Upper Eocene); chiefly sandstone and shale. 10. Hori slate and crystalline schist (Eocene); hard metamorphic slate, schist, and gneiss, intruded by igneous rocks.

nipa and sago palm of the southwest Pacific are distributed over wide areas and wherever found are good indicators of poor drainage conditions and are thus particularly valuable in photo-interpretation. Most vegetation, however, is either less selective of soil conditions or impossible to identify on aerial photographs. In southern Maryland, for example, where large areas are underlain by poorly drained silt with interspersed areas of well drained sand and gravel, ground conditions should be expected to influence the vegetation cover. The vegetation pattern, however, does not reveal the nature of the ground. The common holly, which is very abundant, appears to be an indicator of soils with a high clay or silt content and rarely grows on dry sandy or gravelly soils, but the dominant trees of the upland forest which are jack pine and white oak completely shade the holly and are less selective. They grow well on both silty soils and on dry sand and gravel and their distribution is dependent on the history of land utilization rather than on the properties of the soil.

Studies made by H. M. Raup and C. S. Denny (as yet unpublished) along the Alaska Highway have shown that, although several forest types in that area can be recognized on aerial photographs, their use in interpretation of geology is complicated by the fact that the forest composition is strongly influenced by past forest fires. The vegetation can be used to interpret the simpler geologic features, but methods of interpretation cannot be refined without a thorough understanding of the plant ecology of the region.

As in the case of topography and drainage patterns, a geologist may use the vegetation as a clue in photo-interpretation in some areas if he has a geologic map for comparison with the photos. He may then discover relationships between rock formations and kinds of vegetation, or he may discover that the forest or cultivated fields are more lush on one formation than on another, and thus be able to trace boundaries in greater detail than on the geologic maps available to him. The detailed map shown in Figure 2 was prepared largely by interpretation of vegetation patterns. It represents an area of recent alluvial deposits in which the distribution of cultivated vegetation, mostly sugar cane, rice, and potatoes is strongly influenced by drainage conditions.

The location of roads, railroads, houses, cultivated fields, ditches and other man-made structures are very commonly controlled in part by the kind of ground. Examples are numerous. In western Minnesota, farm houses and country roads are strung out along the old sand and gravel beach ridges of ancient glacial Lake Agassiz. Roads, railroads, and settlements generally avoid poorly-drained areas if areas of better drainage are nearby. If the soil and underlying rock are unstable and "heavy," cultivated fields are apt to be oriented with their long dimensions at right angles to the slopes. If the soil is coarse-grained and stable, orientation of fields is apt to be random, or controlled by some other factor that the terrain. The presence of drainage ditches indicates poor drainage. Retaining walls on low slopes indicate unstable bedrock or soil. Thus many useful clues can be obtained by observing the works of man and relating them to known geologic features.

INTERPRETATION AND ASSEMBLING SOURCE MATERIAL FOR MILITARY GEOLOGIC REPORTS

Nearly all military geologic problems require for their solution the construction of a geologic map. Even though the objective may be to describe foundation conditions at only one spot, these conditions cannot generally be ascertained without knowing the relation of the deposits at one place to other deposits in the region which may lie underneath them at shallow depth and crop out a short distance away. In preparing a geologic map, the interpreter uses the same procedures as a field geologist working on the ground, but his evidence is derived from inferences based on reading the aerial photographs rather than from ground observation. The biggest handicap is that he cannot observe rock textures and measure thicknesses of strata, and he is thus often unable to work out the structure of the rocks unless the structure is simple and the evidence on the photographs clear.

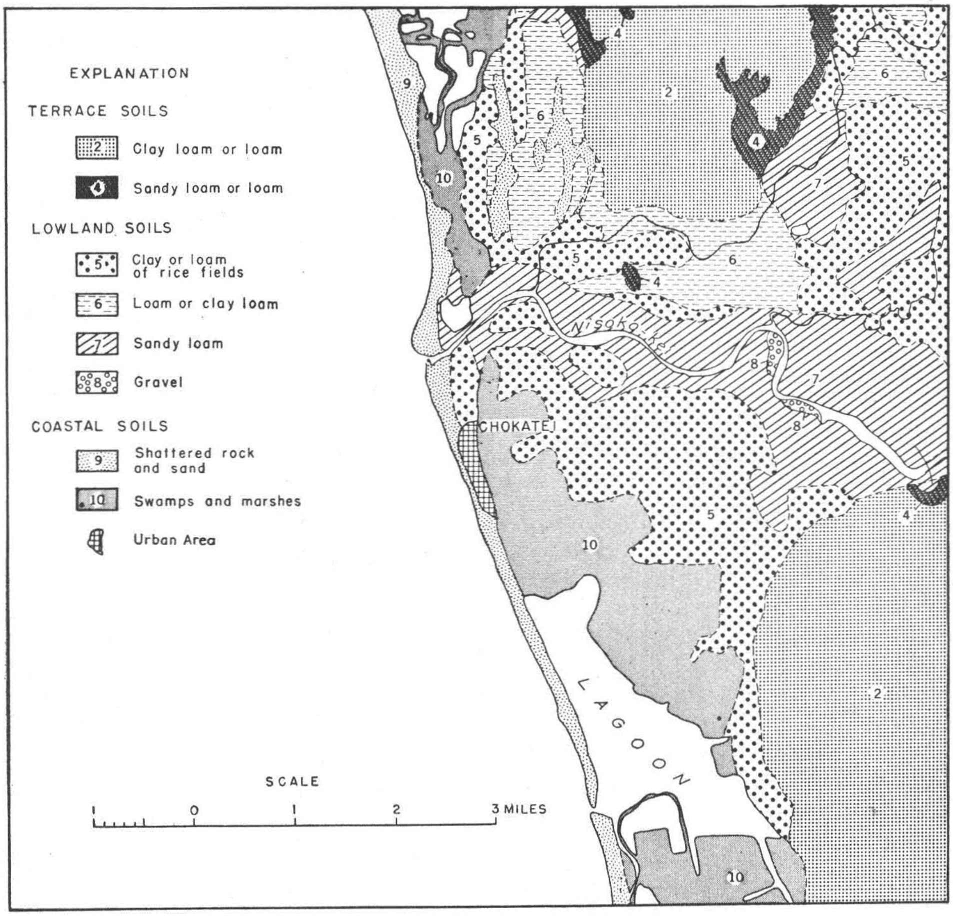

FIG. 2. Detailed soil map of part of the alluvial plain of southwest Hainan (Formosa) prepared by the United States Geological Survey using aerial photographs as the principal source material. For location, see Figure 1. The original scale of compilation was 1:50,000. The interpretation of soils is based on detailed interpretation of geology and was executed by a soil scientist working in collaboration with a geologist. In compiling this map, photo-interpretation of cultivated vegetation and topographic form were relied upon heavily. Explanation of map symbols:

2. Clay loam or loam on terrace surfaces; dark-gray or brown; moderately plastic, generally well-drained. 4. Sandy loam or loam of terrace slopes; commonly gravelly, well drained; friable or plastic. 5. Clay or clay loam of rice fields; dark-gray or dark-brown; poorly drained; plastic. 6. Loam or clay loam; gray or brown; plastic. 7. Sandy loam or gravelly sandy loam; light-gray, brown, or yellow; plastic or friable; generally on natural levees. 8. Gravel; surface few feet well drained, but water table near surface. 9. Shattered rock and sand of coastal beaches and dunes; non-plastic; well drained. 10. Low, wet or marshy ground; tidal flats, fish ponds, salt-drying flats; crossed by dikes and tidal channels.

During the planning of the invasion of Okinawa, a military geologic report was prepared on the foundation conditions to be expected at a proposed site for a large pier on the southern part of the island. In this area the rocks consisted of a limestone formation and an underlying formation of alternating beds of sand and clay. The only geologic map available was small scale and inadequate for the solution of the problem, as it showed only generalized boundaries of the rock formations and presented little information on rock structure. It was easily determined by examination of aerial photographs that the rock on the shore at the pier site was a limestone, as this formation proved to have a number of distinguishing characteristics: (1) it generally supported pine trees rather than broad-leaved trees; (2) crops were less lush than in shale areas; (3) it tended to form bluffs along the shore; (4) it had more level but rockier topography than the clay areas. The remaining problem was to determine the thickness of the limestone at the shore so as to determine whether it formed the floor of the harbor or whether the underlying soft beds formed the floor. This problem was partially solved by mapping the geology of the area back from the shore on aerial photographs. The map permitted determination of the elevation of the limestone bed at various points and the construction of a cross section toward the shore which showed the inclination of the limestone and its thickness within rather wide limits of error. It was suspected that the rocks were faulted and that the presence of faults possibly could not be detected on aerial photographs. The cross section indicated that the limestone was probably thin and probably nearly horizontal, so that the bottom of the harbor could be expected to be underlain by soft clay or sand. The reliability of this estimate was poor owing to the possible existence of undetected faults. Had a good geologic map been available, an estimate of very high reliability could have been made as the map would have provided precise data on the thickness of the strata, their inclination, and the location of faults.

Generally, the information required in military geology is more complex and involves predicting or mapping ground conditions over a wider area than given in the above example from Okinawa. Frequently, in addition to the kind of bedrock, soil conditions must be worked out and the geologist must work in collaboration with specialists in soil science.* Whether the problem is simple or complex, the solution requires the same kind of judgment as in possessed by skilled field geologists and their collaborators.

GEOLOGIC MAPS AS SOURCE MATERIAL

As discussed above, some kind of geologic map made from data obtained by ground observation is almost indispensable for the solution of most military geologic problems. If these maps are sufficiently detailed, they are far more useful than aerial photographs for geological purposes, and the principal use of aerial photographs becomes merely that of aiding in the location of areas for study and relating the geology to details of culture. Detailed geologic maps often allow the trained user to draw the same conclusions as could be drawn from a time-consuming survey on the ground. They commonly provide enough structural data to make possible the accurate prediction of foundation and trafficability conditions.

To be useful for this purpose, geologic maps must be made in considerable

* A discussion of methods of photo-interpretation of soil conditions has been published by J. G. Cady, M. M. Striker, and V. P. Sokoloff, Application of soil science in terrain intelligence studies, *Soil Science Society of America Proceedings*, Vol. 10, 1945, pp. 371–374.

detail and must be on a scale of about 1:50,000 or larger. Such maps, however, are available in very few areas. Less than 10 per cent of the United States, for example, is mapped geologically on scales adequate for effective military planning. Only a few countries, notably England, Germany, and France, are nearly adequately mapped. Central and western Germany is an example of such an area. Large parts of this region are mapped geologically on the scale of 1:25,000, and easily read, colored, published maps are available.* These maps contain a wealth of detailed information on soil, geology, and topography, and they are supplemented by reports which describe the physical properties and structures of the soils and rocks delineated. In preparing a geologic report on an area included on one of these maps, very little research is necessary. The task of the military geologist, when this kind of data is available, is simply to translate the geology into terms of its effect on the military operations contemplated, so that the report is usable by the officers concerned with the problem. Without question, a military geologist can today advise on geologic problems with far less effort for areas in this part of Germany than he can for most areas in the United States, where he must resort either to surveys on the ground, or, if they are too costly for the purpose, to study of aerial photographs.

ORGANIZATION OF PHOTO-INTERPRETATION IN MILITARY GEOLOGY

It is apparent that, to get the most out of photo-interpretation, a geologist should be as familiar as possible with the geology of the area being studied in order to evaluate the terrain features seen in relation to geology. He should also be as familiar as possible with other elements of the terrain, such as the natural and cultivated vegetation, so that he can recognize what he sees in the photographs, separate the landscape into its various elements, and use them as evidence for interpretation of the geology. Even the most experienced interpreters frequently encounter new or unusual features that cannot be explained and are tempted to jump to conclusions as to their nature. To borrow an example from another field; I recall that, during the planning of the invasion of Okinawa, a number of interpreters working on enemy military installations interpreted as anti-aircraft gun emplacements, numerous perfectly circular structures of unknown origin, until someone saw a ground photograph of a primitive Okinawan sugar mill and realized that this was the typical gun emplacement! The same kind of error can be made in geology. These sugar mills might with some logic have been interpreted by a geologist as animal-powered water pumps. The temptation would have been strong, for the location of wells would indicate a great deal about the location of underground water, and the distribution of water-bearing rocks.

Successful geologic photo-interpretation is a complex technique of scientific research, and an interpreter working with aerial photos alone is severely handicapped unless he knows the terrain intimately. The most effective geological photo-interpretation for military intelligence purposes is done by teams of well-trained scientists, each of whom is thoroughly experienced in geology or one of the related fields, such as soil science, ecology, and forestry. A sound basis in the fundamentals of geology, experience in the field, and ability to use the geologic literature of foreign countries are the best possible background for a military geologist. A working knowledge of the use of aerial photographs can be acquired in a few weeks' time, and, in fact, it is now a knowledge that most

* Preussische Geologische Landesanstalt, Geologische Karte von Preussen und benachbarten Bundestaaten, 1:25,000.

field geologists acquire as a part of their normal experience. But an understanding of geology and its relation to terrain features can be acquired only through many years of training and experience. Research teams composed of geologists and scientists in related fields can do a better job working together than as individual workers, for the experience and ideas of each contribute to the success of the whole group. Consultation and exchange of ideas are valuable in this field in which so much depends on the recognition of complex and extremely varied relationships.

CONCLUSION

Photo-interpretation is a valuable technique in military geology, especially so, because, in military geology, it is often impossible or impracticable to visit the area under study. What can be accomplished by photo-interpretation is limited by the knowledge of the interpreter, however acquired, of the geology and geography of the area being studied. Photo-interpretation as a technique is deserving of attention during peacetime as a fruitful field for research. Nevertheless, our major effort should now be spent in acquiring and organizing for ready reference as a much fundamental scientific knowledge as possible of the world's geology and geography based on field investigations.

INTERPRETATION OF MILITARY INSTALLATIONS FROM AERIAL PHOTOGRAPHS

Thad Jones, Air Research Unit, Library of Congress

IN ATTEMPTING to find an adequate approach to a discussion of interpretation of military installations from aerial photographs, it is necessary, in the writer's opinion, to consider the technique primarily as a military procedure rather than as an independent technical operation.

The first problem encountered in identifying military installations from aerial photographs, is what military situation exists. Before photography can be obtained for interpretation, it is necessary that the area to be photographed be determined, then the type and scale of photography must be determined. The photographic interpreter next considers the general military situation in the selected area from the point of view of the enemy. The general type of military installations that may be sited in the area are thus established. The military photo interpreter knows, before he looks at his photographs, that he is going to find, for example, coastal defenses ranging from underwater obstacles, beach obstacles, and infantry defenses to heavy coast-defense installations. Or perhaps it is a different military situation being covered, a situation requiring study of enemy supply installations, or the communication network supporting a tactical front, or the tactical front lines. It is thus seen that the interpretation of military installations consists of much more than just looking at photographs and recognizing thereon all military installations. Actually, this work must be a well organized part of intelligence directing well planned efforts toward many specific objectives.

Military photo interpretation in World War II had several degrees of value, varying in relation to the military situation. There were situations of a nature that severely limited useful applications of photo intelligence, and there were other military situations in which photo intelligence played a primary role in both strategic and tactical results. It is necessary that the influence of these several types of situations on photo intelligence be understood before a satisfactory comprehension of the whole problem can be obtained. Consequently,