Chapter Five

Airphoto Interpretation

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Airphoto interpretation, one of the many tools for recognition of actual or potential landslides mentioned in the preceding chapter, warrants treatment in a separate chapter. This is because the interpretation of aerial photographs for engineering purposes is a relatively new and growing field. It is one, moreover, whose techniques and possibilities are perhaps less known to most than are most other engineering and geologic techniques.

Highway engineers have long been familiar with the use of topographic maps, both in planning and in ground reconnaissance. It was natural, therefore, that when aerial photographs became available, the engineer should make use of them as an additional tool. Aerial photographs present a complete map, as well as a three-dimensional model of the area covered. When properly interpreted, they reveal not only the topography but also considerable information concerning soil, geology, and other natural, as well as manmade, features.

Use of airphoto interpretation in various phases of highway engineering has increased rapidly during recent years. The fact that almost all of the United States and a good part of the world is already covered by aerial photography of suitable scales is an important stimulant. New photography is being added rapidly.[5] In addition, new techniques in production and interpretation processes have continued to extend the advantages of aerial photography.

Advantages

The advantages of using airphotos in the investigation of landslides are summarized as follows:

1. Airphotos present an over-all perspective of a large area. When examined with a pocket or mirror stereoscope, overlapping airphotos give a three-dimensional view.
2. Boundaries of existing slides can be readily delineated on airphotos.
3. Surface and near-surface drainage channels can be traced.
4. Important relationships in drainage, topography, and other natural and manmade elements that seldom are correlated properly on the ground become obvious in airphotos.
5. A moderate vegetative cover seldom blankets details to the photointerpreter as it does to the ground observer.
6. Soil and rock formations can be seen and evaluated in their "undisturbed" state.
7. Continuity or repetitions of features are emphasized.
8. Routes for field investigations and program for surface and subsurface ex-

[5] Detailed information as to availability of existing airphotos may be obtained from: Map Information Service, U. S. Geological Survey, Washington 25, D. C. Prevailing scales of photographs: 1:15,000 to 1:30,000. Price for each photograph, covering 6 to 9 square miles: $0.50 to $0.65. Airphotos taken specifically for highway projects are usually of much larger scale and may be procured through the highway authority concerned.

ploration can be effectively planned.

9. Recent photographs can be compared with old ones to examine the progressive development of slides.

10. Airphotos can be studied at any time, in any place, and by any person.

11. Through airphotos, information about slides can be transmitted to others with a minimum of ambiguous description.

Limitations

Although aerial photography proves a very useful tool for the study of both existing and potential landslides, the highway engineer should be aware of its limitations. Some of these follow.

Personal Experience. — The usefulness of airphotos increases with the individual's experience in interpretation and with his knowledge concerning the area under study. An inexperienced interpreter should be particularly careful in a new, complex area in which he has little background knowledge.

Scale. — The scale of ordinary existing photography (1:15,000 to 1:30,000) is adequate for the study of most terrain and slide problems. However, in geologically complex areas or in areas where landslides are rather small, a scale of 1:5,000 to 1:10,000 would be desirable. Pictures within this range of scale are commonly available when the route has been photographed for photogrammetric mapping purposes. Photography of scales even larger than this is good for detailed examination, but the area covered in each photograph is then limited and, therefore, the over-all perspective is more difficult to grasp.

City Development. — In well built-up areas, natural conditions are altered or concealed by human activities. There, air photography may have special merits in city planning and related purposes, but its usefulness in landslide investigation is greatly handicapped, especially when the landslides are small.

Ground Investigation. — It should be emphasized that the use of airphotos cannot and should not replace ground investigation entirely. Through careful planning with airphotos, however, the surface and subsurface exploration necessary for a landslide study can be profitably reduced to a minimum.

Principles of Airphoto Interpretation

The interpretation of airphotos includes three major steps: (a) examination of airphotos to get a three-dimensional perception, (b) identification of ground conditions by observing certain elements appearing in the photographs, and (c) interpretation of photographs with respect to specific problems by association of ground conditions with one's background experiences. The quality and reliability of any interpretation is, of course, enhanced in direct ratio to the interpreter's knowledge of the soils and geology of the area under study. The acquirement of such knowledge, either by field examination or by study of available maps and reports, should, therefore, be considered an essential part of any photointerpretation job.

Three-dimensional perception can be acquired with a little practice by any person having normal vision. Ability in the identification of ground conditions and the interpretation of them in terms of specific engineering problems grows with one's experience in the use of aerial photographs and in his specific field.

There are several major elements that can be seen in air photographs that indicate ground conditions accurately. They are: landform, drainage and erosion, vegetation, soil tones, and man-made features. These features are discussed briefly hereafter; more thorough treatments appear in the papers of Belcher (1943, 1946) and Liang (1952). A bibliography on airphoto interpretation in general was compiled by Colwell (1952) and should be consulted.

Landform

The term landform as used by photointerpreters indicates a mappable unit

of the earth's surface that appears on the aerial photograph to be made up essentially of a single kind of geologic material, which together with similarity in overburden and in topographic expression give a recognizable homogeneity to the unit. Because the underlying geology tends to be the key factor in determining the appearance of a unit in aerial photographs, most of the landforms described in this chapter are given geologic terms.

Certain landforms are more susceptible to landsliding than are others, hence the identification of landform is highly important. By observing the topographic expression and the boundary of a unit area, and by comparing it with known sample photographs, a landform can often be identified on airphotos. For areas where geologic or soil maps are available, such identification can, of course, be checked against the facts shown on those maps.

The following major landforms (in the airphoto-interpretation sense) are classified according to differences in their physical composition: consolidated sedimentary rocks, intrusive and extrusive igneous rocks, metamorphic rocks, glacial deposits, unconsolidated sedimentary deposits, and windlaid materials. Each of these groups, together with the normal weathering products of each one, poses relatively distinct problems for the engineer, particularly from the standpoint of landslide susceptibility. Each one, moreover, can be more or less easily identified on aerial photographs. Numerous examples of each of the foregoing landforms, and of subtypes of each, are described and illustrated in the references previously cited.

Drainage and Erosion

The density and pattern of drainage channels in a given area reflect directly the nature of the underlying soil and rock. The drainage pattern is obvious in some cases, but more often it is necessary to trace the channels on a separate sheet of paper in order to study the pattern successfully.

Under otherwise comparable conditions, a closely spaced drainage system denotes relatively impervious underlying materials; widely spaced drainage, on the other hand, indicates that the underlying materials are pervious. Generally speaking, a treelike drainage pattern develops in flat-lying beds and relatively uniform material; a parallel stream pattern indicates the presence of a regional slope; rectangular and vinelike patterns, composed of many angular drainageways, are evidence of control by underlying bedrock, and a disordered pattern, interrupted by haphazard deposits, is characteristic of most glaciated areas. Indeed, disordered pattern of a much smaller scale is common in landslide deposits. There are other patterns developed in response to special circumstances. A radial pattern, for instance, is found in areas where there is a domal structure in the rocks, and a featherlike pattern is common in areas where there is severe erosion in rather uniform material, such as loess.

The shape of gullies appearing in airphotos gives valuable information regarding the characteristics of surface and near-surface materials. Thus, long, smoothly rounded gullies should indicate clays, U-shaped gullies indicate silts, and short, V-shaped gullies indicate sands and gravels.

Soil Tones

Soil tones are recognizable in photographs unless there is a very heavy vegetative cover. Black-and-white, rather than color, photography is commonly used in present-day engineering projects. Thus, the color tones examined are merely different shades of gray, ranging from black to white. Because gray tones are highly respondent to soil-moisture conditions on ground, they are an important airphoto element in landslide investigations.

A soil having high moisture content normally registers a dark tone and low moisture a light tone. The moisture con-

dition is a result of the physical properties of the soil or the topographic position of the ground, or both. The degree of sharpness of the tonal boundary between dark and light soils aids in the determination of soil properties. Well-drained coarse-textured soils show distinct tonal boundaries whereas poorly-drained fine-textured soils show irregular, fuzzy boundaries between tones.

VEGETATION

Vegetative patterns reflect both regional and local climatic conditions. The patterns in different temperature and rainfall regions can be recognized in airphotos. Locally, a small difference in soil moisture condition is often detected by a corresponding change of vegetation. A detailed study of such local changes is very helpful in landslide investigations. For instance, wet vegetation, represented by dark spots or "tails," is a clue to seepage in slopes. Cultivated fields, as well as natural growths, are good indicators of local soil conditions. Thus, an orchard is often found on well-drained soils; the sparseness of vegetation in nonproductive serpentine soils, where landslides are common, is very conspicuous and revealing.

MANMADE FEATURES

The identification of manmade features such as highway, railroad, and airport locations; dams, canals, and irrigation systems; sand and gravel pits, stone quarries, mining and other industrial operations, is obviously important in the investigation of landslides. With a little practice, an engineer who is familiar with these items on the ground should have no difficulty in recognizing them in airphotos. Some old, overgrown manmade features are actually easier to see in photos than on the ground.

Interpretation of Landslides in Airphotos

Having obtained a general understanding of a given area through airphoto examination of the major elements discussed in the preceding section, the engineer may proceed to a study of the specific features that are related to landslides.

LANDSLIDE INDICATIONS

An engineer already familiar with the appearance of landslides on the ground should orient himself to the airphoto view of landslides by examining photographs of some known examples. The difference between an air view and a ground view results chiefly from the fact that the former gives a three-dimensional perspective of the entire slide area, but at a rather small scale. Ground photos, on the other hand, show only two dimensions but on a larger scale. The indications of a landslide in airphotos are: the sharp line of break at the scarp; the hummocky topography of the sliding mass below it; the elongated, undrained depressions in the mass; and the abrupt differences in vegetative and tonal characteristics between the landslide and the adjoining stable slopes. Inclined position of trees in landslides is often observable in photographs.

Where a highway is built on unstable soil, the irregular outline and nonuniform tonal pattern of broken or patched pavement are often visible, even in relatively small-scale photography. Failures due to improper fill or inherently weak soil are also registered.

VULNERABLE LOCATIONS

Many slides are too small to be readily detected in small-scale photography. In addition, the highway engineer often must cover an extended territory. Consequently, it is very important for him to locate and to examine closely all of the areas where the visible signs of slides may not be apparent, but in which

there are special conditions that are conducive to slides. Typical vulnerable spots are as follows:

Cliffs or Banks Undercut by Streams. — Banks that are subject to attack by streams commonly fail by sliding. Where the banks are made up of soil or other unconsolidated material the weakest, hence most favorable slide position, is often located at the point of maximum curvature of the stream, where the bank receives the greatest impact from the water. In areas of rock outcrops, on the other hand, the section at and near the point of maximum stream curvature is often occupied by hard rock and the weak spots are to be found on both sides adjacent to that section.

Steep Slopes. — In stereo-examination of airphotos, it is reasonably easy to observe and compare the different hill slopes within a land unit. In a potentially dangerous area, large earth masses standing on the steepest slope are naturally the most vulnerable to landslides and should be examined closely. Comparison of slopes for this purpose should, of course, be confined to slopes of similar materials. Thus, a slope cut in earth or talus should not be compared with a rock cliff in an adjacent land unit.

Contributing Drainage. — Water contributes greatly to many slides. Careful examination of existing slide scars often indicates that a line connecting the scars points to some drainage channels on higher ground. Such drainage may appear on the surface or go underground and reappear as seepage water causing the damage. This drainage-slide relationship can frequently be detected in airphotos.

Seepage Zones. — Seepage is likely to occur in areas below ponded depressions, reservoirs, irrigation canals, and diverted surface channels. Such circumstances are sometimes overlooked on the ground because the water sources may be far above the landslide itself, but they become obvious in airphotos. The importance of recognizing the potential danger in areas below diverted surface drainage, especially in jointed and fractured rocks, needs particular emphasis. It has been proven repeatedly, through extensive field experience, that within an unstable area one of the most dangerous sections is the lower part of an interstream divide through which surface water seeps from the higher stream bed to the lower one. The recognition of seepage is sometimes aided by the identification of near-surface channels (appearing in airphotos as faint, dark lines), wet, tall vegetation on the slope (shown as dark dots or "tails"), and displaced or broken roads adjacent to the slope.

Old Landslides

An investigation of existing landslides in any area gives an excellent basis for evaluating the possibility of future landslides (see Fig. 47). The indications of an old slide are similar to those of new slides except that they are not as fresh or as striking. Thus, the scarp may not appear sharp; the hummocky ground surface, although still present, may be subdued topographically; drainage and vegetation may have become established on the mass; and the change of gray tones between the landslide mass and the adjacent areas may be gradational rather than abrupt. As a matter of fact, the degree to which the vegetation and drainage are established on the mass helps determine the relative age and stability of the moved land.

Once an old landslide is found on the photographs it serves as a warning that the general area has been unstable in the past and that new disturbances may start new slides. However, such a warning should not discourage construction unconditionally. The unstable condition of the past does not necessarily exist today. In some western states, for example, railroads built in extensive old landslide areas have been stable for a long time.

In addition to the registration of unstable slopes, the airphoto also furnishes an excellent reference for the engineer to judge the attitude of slopes that are

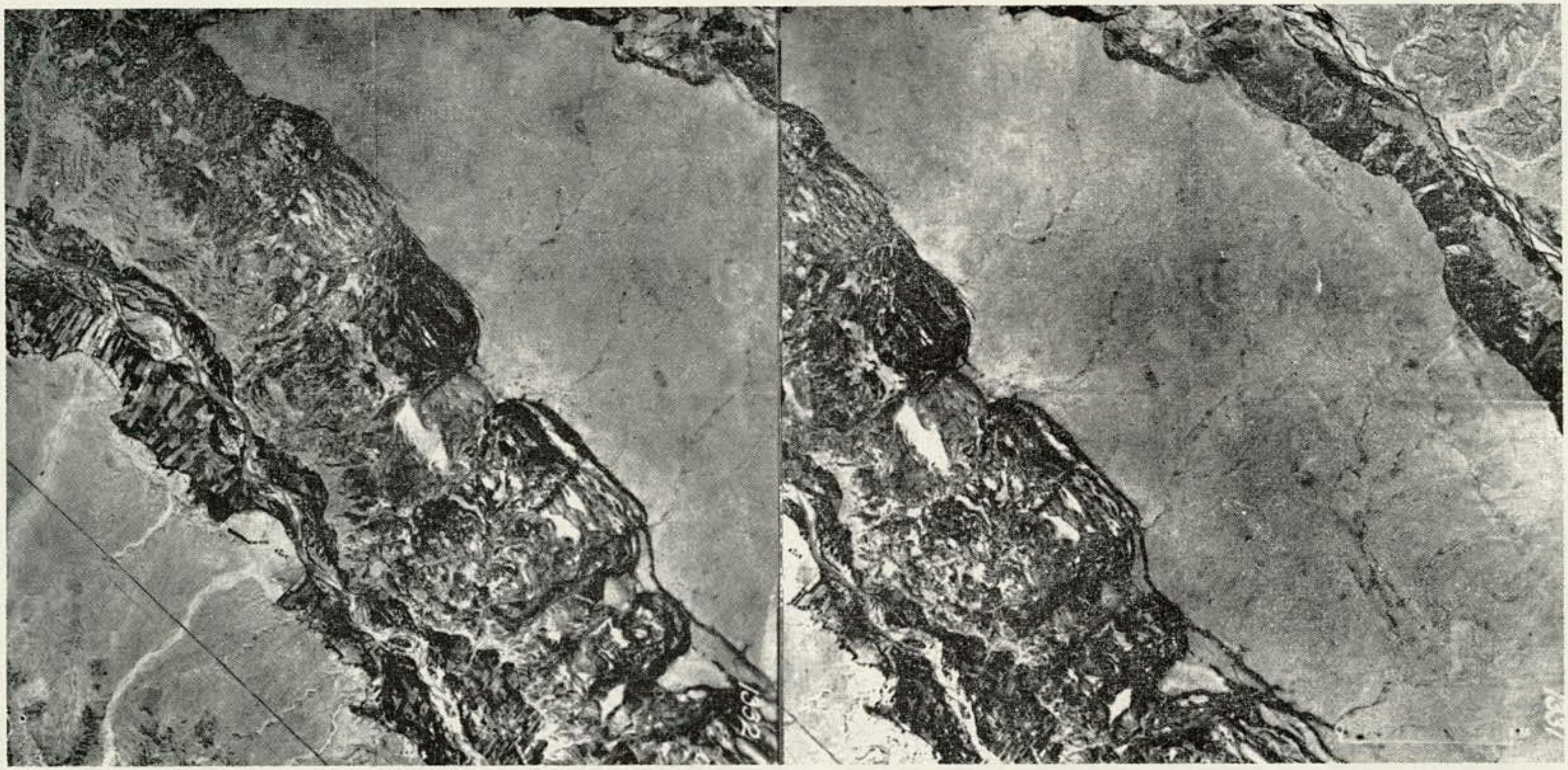

Figure 47. Old landslide, Rio Arriba County, N. Mex. This is one of the largest slide areas in the country. The slide is of such magnitude that it can be readily spotted even in the photo-index sheet. The characteristic sharp cliff at the scarp, hummocky surface and ponded depressions are well illustrated. Slides which the engineer ordinarily encounters are generally of much smaller magnitude, although they may assume similar forms.

The combination of basalt and the underlying sediments provided a favorable condition for the slide in this area; the once actively downcutting and laterally eroding river precipitated the movement. The well-established vegetation (shown in dark gray tones) and drainageways in the moved mass indicate that the general area is now stabilized. The currently critical spots are (a) where the river or artificial construction has cut into the toe of the lower slopes; (b) areas immediately below ponded depressions; and (c) areas along the cliff where imminent rockfall is indicated by breaking marks. The linear cliff above the slide indicates that the fracture pattern of the caprock is in coincidence with the horizontal axis of the slide. (Aerial photograph by U. S. Department of Agriculture)

generally stable. Within the photo coverage, there is always a wide choice of combinations of circumstances, such as drainage, topographic position, and association with a gully or stream. For guidance in the design of new slopes the engineer often can find some existing slopes having conditions similar to the ones he is to build.

Landforms Susceptible to Landslides

Landslides are rare in some landforms and common in others. Most of the forms susceptible to landslides are readily recognizable in airphotos. The identifying elements and significant facts about them are summarized and illustrated in the following sections.

It should be noted that the order of presentation hereinafter follows a sequence based on origin and character of the materials rather than on the order of their importance in landslide occurrence. In general, the forms most susceptible to landslides are basaltic lava flows, serpentine, clay shale, and tilted sedimentary rocks; other forms are susceptible occasionally, depending on local circumstances.

Consolidated Sedimentary Rocks and Their Residual Soils. — The discussion of rocks and their residual soils is combined in this and in the following two sections because the recognition of types of residual soils depends primarily on the recognition of the landform developed in the parent rocks. The determination of depth of residual soil requires considerable judgment. However, the engineer working constantly in his own region should have no difficulty in estimating the depth once he is familiar with local conditions.

Generally speaking, rounded topography, intricate drainage channels and heavy vegetation are indicators of probable deep soils, in contrast to the sharp, steep, resistant ridges and rock-controlled channels commonly found in areas of shallow soil. The local climatic and erosion pattern should be considered in the interpretation.

A very high percentage of all slides occurs in residual soils and weathered rocks. They are usually in the form of slumps or flows. Rockfalls and rockslides, by definition, occur only in bedrock terrain.

In horizontal positions, massive sandstone is little likely to slide. Clay shale, especially if interbedded with sandstone or limestone, is highly susceptible to landslides (Figs. 48, 49, 50, and 51). Landslides are uncommon in thickly bedded limestone unless it is interbedded with shale or other soft rocks. In steeply tilted positions, any sedimentary rock may fail by sliding (Fig. 52). Depending on the dip angle, joint system, and climate, slides may take one or a combination of the forms of rockfalls, rockslides, debris falls, debris slides, and earthflows. River undercutting and artificial excavation are important factors in initiating landslides in both horizontal and tilted rocks.

Methods of identification of sedimentary rocks in airphotos are well established. Hard sandstones are noted for their high relief, massive hills, angular drainage, and light tones; clay shales are noted for their low rounded hills and well-integrated treelike drainage system; and soluble limestones are characterized by their sinkhole development in temperate humid areas and by rugged karst topography in some tropical regions. Interbedded sedimentary rocks show a combination of the characteristics of their component beds. When horizontally bedded, they are recognized by their uniformly dissected topography, contour-like stratification lines, and treelike drainage; when tilted, the parallel ridge-and-valley topography, the inclined but parallel stratification lines, and the trellis drainage are evident.

The identification of landform as a means of detecting associated landslides is important in the flat-lying sedimentary group because the slides there are often small and, therefore, not very obvious in the photographs. This is particularly

Figure 48. Clay shale, Monongalia County, W. Va. This stereo pair shows an area where clay shales predominate and landslides are active. There are very few competent beds in the general area as evidenced by the rounded, soft slopes and dull, uniform, gray tones. Minor irregularities as signs of movement are seen in most of the steep slopes. Even without artificial disturbances, nature is actively reducing the relief of the area by creeps, flows, and slides. At area (A), both the railroad and highway have experienced continuous landslide troubles. The irregular outline of the bank along the river and the patchwork on the road pavement are clearly seen in the photos. The steep slope and active attack by the river provides a favorable condition for landslides. Furthermore, surface drainage in the back of the slope is blocked by a hill and water is seeping through the hill toward the river. Such a circumstance is conducive to slides. (Aerial photograph by U. S. Department of Agriculture)

Figure 49. Shale in same general area as shown in Figure 48, Monongalia County, W. Va. Area (B) shows one of the most unstable slopes in the area. The disordered, hummocky forms on the hillside indicate that flows and slides are active. The irregular outlines of the road is a sign of continuous refilling and repatching because of slides. Slide scars are also prominent on the opposite side of the valley, particularly on the steeper slopes. (Aerial photograph by U. S. Department of Agriculture)

Figure 59. Flat-lying sedimentary rocks, Mesa Verde National Park, Montezuma County, Colo. The interbedded competent sandstones and soft shales are nearly horizontal, as indicated by the contour-like stratification lines on hills. The numerous landslides and erosional scars, seen as white patches, are striking throughout the area. Serious slides are marked (A), (B), (C), (D), and (E). (C) indicates where caprock fails, (D) indicates slumps where shale is primarily involved. Drainage condition in back of (C) helped to promote the mass movement.

It is difficult to maintain the highway on the shale slopes because they are already oversteepened and do not provide a good foundation; further disturbance would hasten the slide. Because of the difficulty in maintaining the roads on the steep slopes, several routes (X) have been abandoned in the general area. A plan of relocating the scenic highway that passes the hazardous area (C) and (D) is now under consideration. The new route will follow the valleys and go through a 1,400-foot tunnel (F). (Aerial photograph by U. S. Department of Agriculture)

Figure 51. Ground view of rockslides and rockfalls in shale and sandstone, shown in Figure 50. (Photograph by National Park Service)

true for slides in colluvial deposits at the base of flat-lying beds. Furthermore, sedimentary rocks are the most widespread of all surface rocks and their conditions are to be met everywhere.

Intrusive and Extrusive Igneous Rocks and Their Residual Soils. — *Basaltic lava flows* are one of the most common representatives of the extrusive igneous rocks. They are readily identifiable in airphotos. Basalt is highly susceptible to different types of landslides (Fig. 53). Basalts often form the caprock in a plateau, with sharp, jagged cliff lines clearly visible in photographs. Surface irregularities or flow marks, sparseness of surface drainage, and dark tones are confirming airphoto characteristics.

If a basaltic flow is underlain by or interbedded with soft layers, particularly if it occupies the position of a bold escarpment, a very favorable condition for large slumps is present. The joints and the cracks in basalt give rise to springs and seepage zones and greatly facilitate movement. Rockfalls and rockslides along rim rock are usually favored by vertical jointing of basalt and by undercutting of basaltic cliffs. Talus accumulations of various magnitudes are found at the foot of cliffs. Disturbance of talus slope during road construction has caused some large slides of talus materials. Old slides and breaks indicating incipient slides often can be seen in photographs.

In areas of relatively deep weathering the landscape is somewhat modified. A more rounded topography and heavier vegetation develops, although dark tones still predominate. Slumps of both large and small size are common in basaltic soils.

Granite and related rocks are the most widely occurring intrusive igneous rock types. The landslide potential of granitic rocks varies widely, depending on

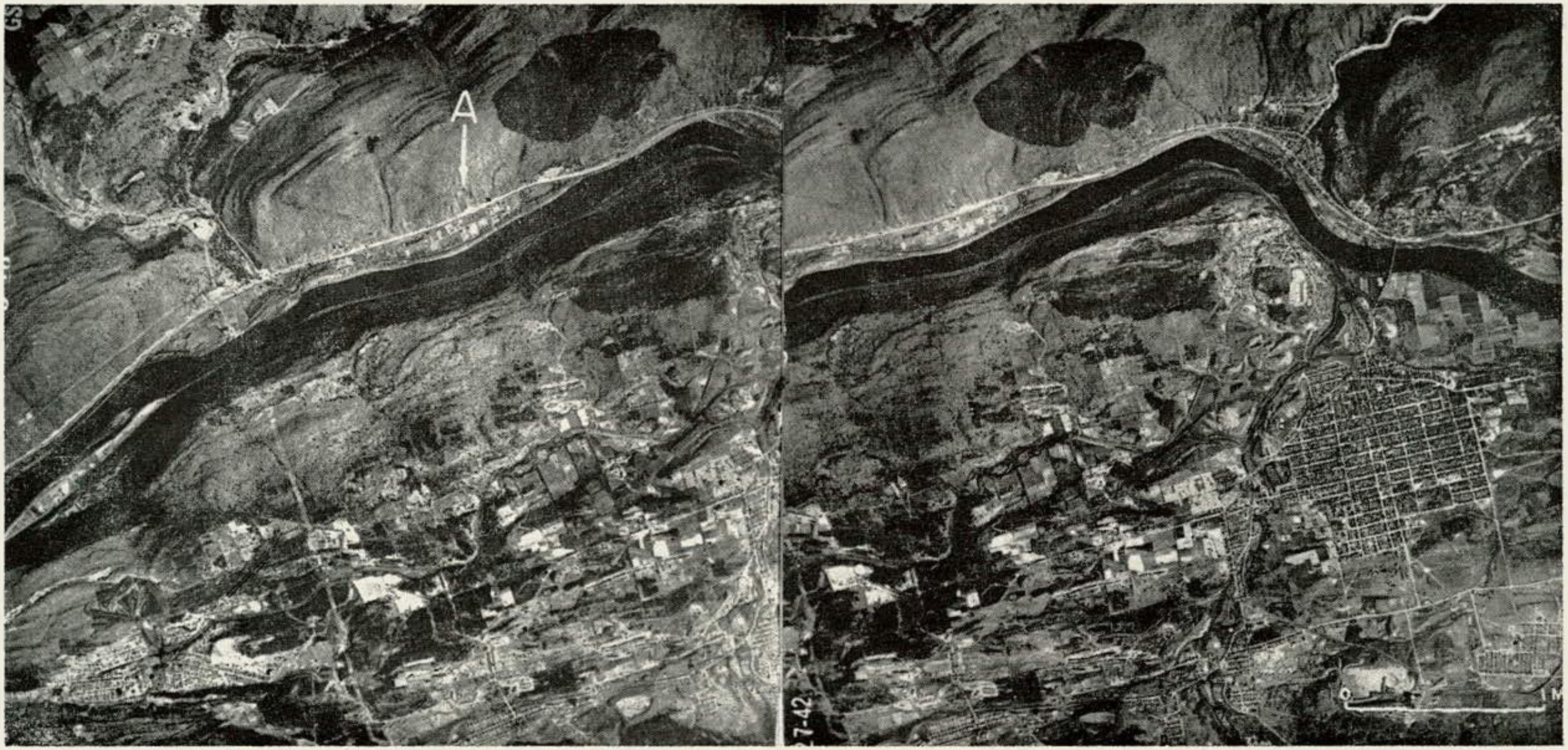

Figure 52. Tilted sedimentary rocks, Luzerne County, Pa. This stereo pair shows how an airphoto interpreter might predict the exact location and magnitude of a future slide. That this is an area of dangerously dipping sedimentary rocks is self-evident. Along the major highway, the most critical spot is at (A), where there is a clearly defined breaking line. Such an incipient break, although striking in the photo, is not obvious on the ground. Five years after this photograph was taken, when the highway below the break was being widened, the whole block of 400,000 cubic yards came down during an unusually heavy rain. (Aerial photograph by U. S. Geological Survey)

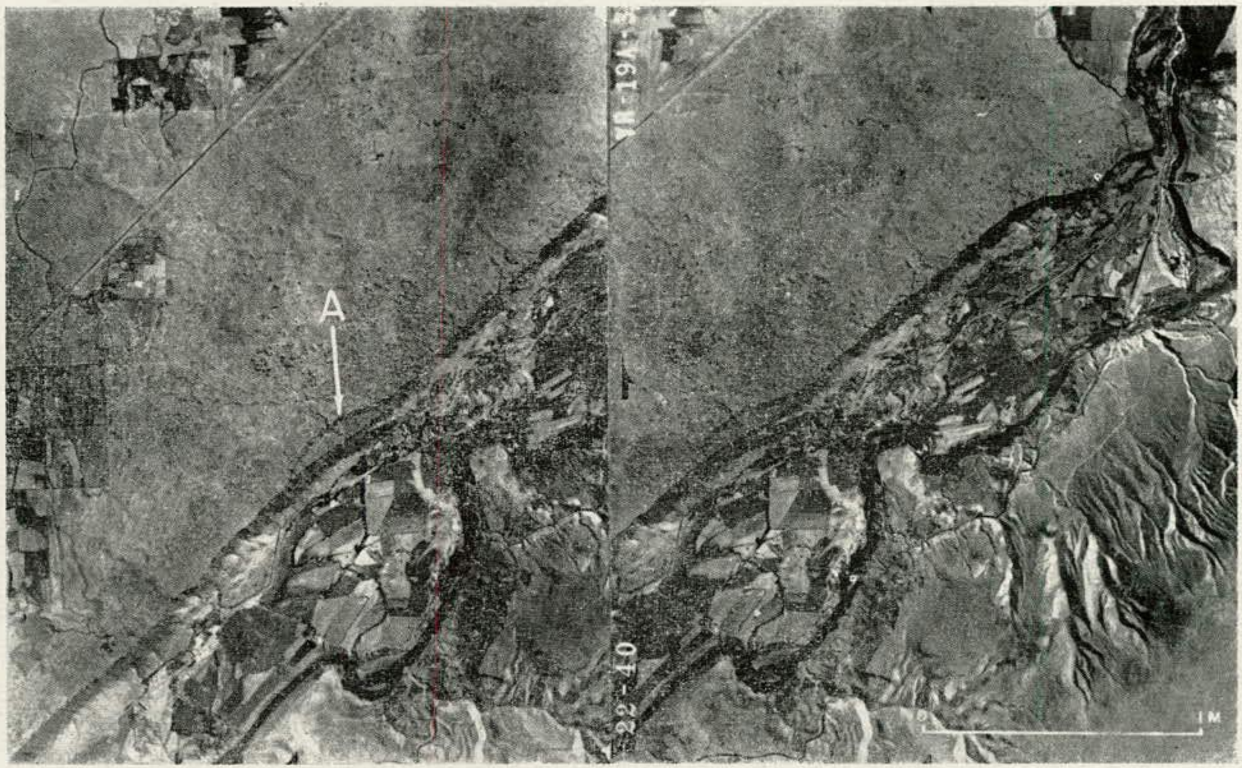

Figure 53. Basalt flow, Gooding County, Idaho. The basaltic plateau on the far side of the river is recognizable in the photo by its sharp cliff, minor surface marks, and dark tones. It is underlain by beds of tuff and clay, creating a favorable situation for landslides. There is a belt of talus accumulation and landslide deposits along almost the entire bottom of the cliff. Landslides are distinguished from talus slopes by the presence of a sharp break on the upland and the hummocky topography of the mass. An incipient slide is indicated at (A). Here, the partial breaking of a block of basalt from the mass is clearly shown; the slide can be precipitated by a slight disturbance. Smaller and less distinct breaks often appear in basalts along the cliff edge and can be detected by a careful inspection of airphotos. (Aerial photograph by U. S. Department of Agriculture)

the composition of the rock and its fracture pattern, the topography, and the moisture conditions. In granites that are highly resistant to weathering or of low relief, there is generally no slide problem. In hilly country where the granite is deeply weathered, slumps in cut slopes, as well as in natural slopes, are common. Fractures in the rock and high moisture condition undoubtedly are favorable factors in producing landslides.

Granitic masses are identified in airphotos by the rounded (old) to A-shaped (young), massive, uniform hills, and by the integrated treelike drainage pattern with characteristic curved branches. The presence of fractures and the absence of stratification and foliation aid to confirm the material.

Metamorphic Rocks and Their Residual Soils. — Landslides in metamorphic rocks vary greatly. The interpretation problem is rendered even more difficult because the criteria for identification of different metamorphic rocks in airphotos are not well established. Although the airphoto characteristics of major types of gneiss, schist, slate, and serpentine have been worked out, these rocks do not often have exposures of sufficient extent to be recognized by their topographic expression.

Within the metamorphic group, many slides are associated with *serpentine.* Serpentine areas are identified in airphotos by their sinuous ridge, smoothly rounded surface, short steep gullies, very poor vegetative cover, and dull gray tones.

There are, however, many serpentine areas where stable slopes prevail. Low relief and low rainfall are among the factors responsible for the stability of some of those serpentine slopes. A close examination of airphotos to detect existing scars is necessary before the instability of a serpentine area can be concluded. Within a general area, local conditions, such as vegetation, moisture, and slope, may create special, favorable circumstances for landslides.

Glacial Deposits. — Landslides are common in some glacial and glacio-fluvial deposits. Although most of the distinct glacial forms are easily identified in airphotos, there are complex areas which require a high degree of skill for their identification.

Moraines are found in nearly all glaciated areas. They are identified in airphotos by their jumbled, strongly rolling to hilly terrain. In moraines, particularly in the semiarid areas, there is a large proportion of waste, untilled land. Disordered drainage pattern, irregular fields, and winding roads are confirming clues.

Minor slumps, debris slides, and earthflows are common in cut slopes in moraines as the result of the presence of undrained depressions and seepage zones in the mass. Because morainic hills are usually small, these slides are not very extensive. They are, nevertheless, large enough to cause continuous trouble to many highway maintenance engineers (Figs. 54 and 55).

Slides in shallow *glacial mantle* overlying bedrock often take the form of slumps, debris slides, and debris falls, and often contribute to failures in artificial fill. They usually occur along valley walls that have been oversteepened by glaciation. The topography of such areas is basically that of the underlying bedrock with slight local modifications, depending on the thickness of the mantle. These cases are commonly found in the northern and northeastern United States where sedimentary beds predominate (Fig. 56). Slides seldom occur in other kinds of glacial deposits, such as kames, eskers, outwash plains, and till plains.

Unconsolidated Sedimentary Deposits. — Within this group, which includes such diverse forms as flood plains, alluvial fans, beach ridges, and swamps, most landslide problems are associated with dissected coastal plain deposits, river terraces, and lake beds.

Coastal plains are among the well-established forms that can be definitely recognized in airphotos. An undissected coastal plain is identified by its low, flat topography; its association with tidal

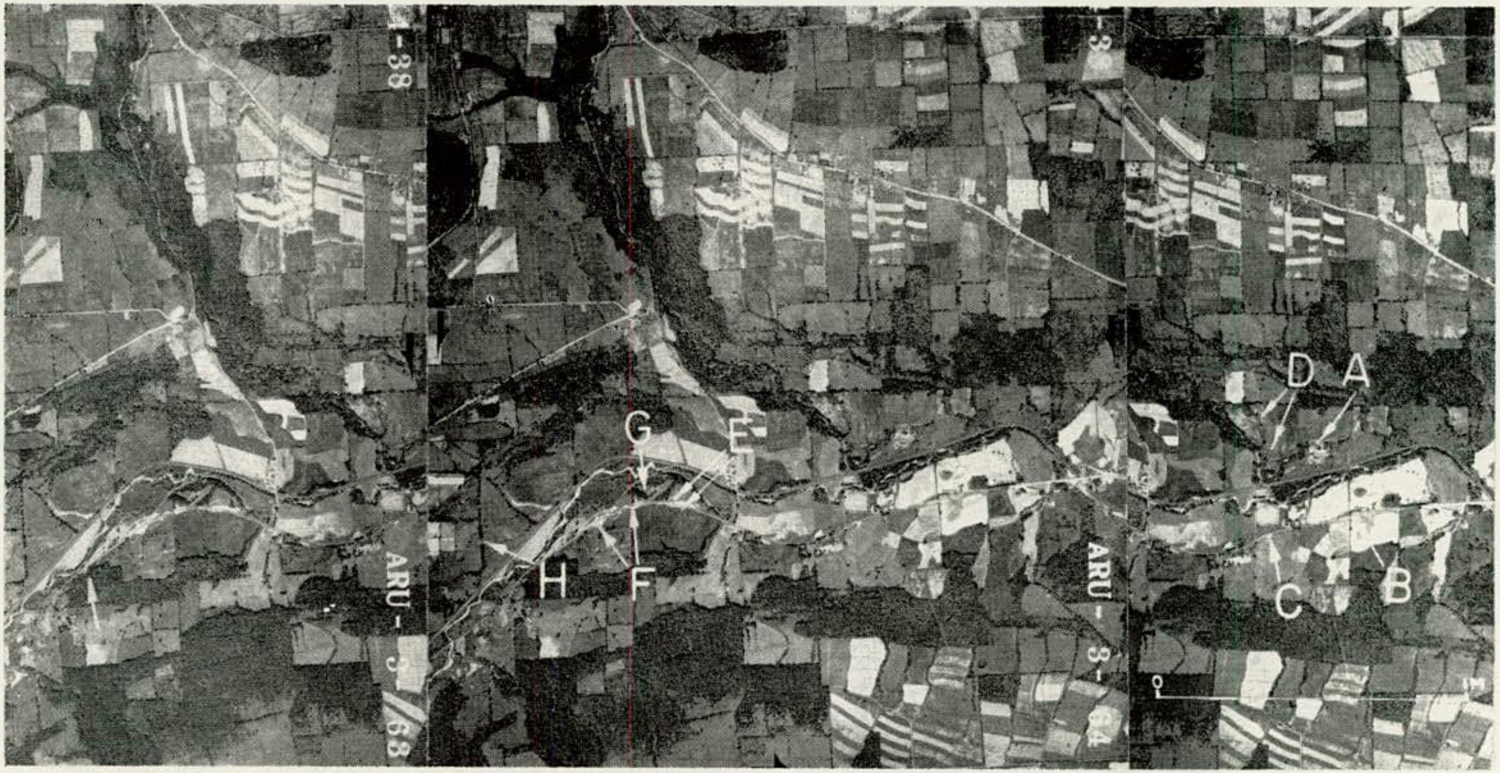

Figure 54. Moraine and lake bed, Tompkins County, N. Y. New slumps and debris slides, as well as old slide scars, are common occurrences in this glaciated valley where post-glacial erosion has dissected the moraines and the overlying lake deposits. Morainal areas are recognized by their hummocky topography. Lake deposits are usually distinguished by their flat, horizontal disposition. However, when lake clays are dissected, such a criterion no longer holds. Rather, the clues for clay identification, such as the characteristic smooth slopes, high degree of dissection, and gradual change of color tones, are more applicable.

A close inspection of the photo reveals that there are many old landslides, (A) being a prominent example. Other old slides, such as (D), (G), and (H), are common throughout the valley. All of them have been more or less stabilized, as indicated by the established vegetative pattern. Most highway cuts of moderate depth have experienced landslides, as in (B), (C), (E), and (F). Although deep-seated and large-scale slides are not likely to occur in such an area, continuous maintenance work in clearing the sliding material and in protecting slopes from erosion is necessary. (Aerial photograph by U. S. Department of Agriculture)

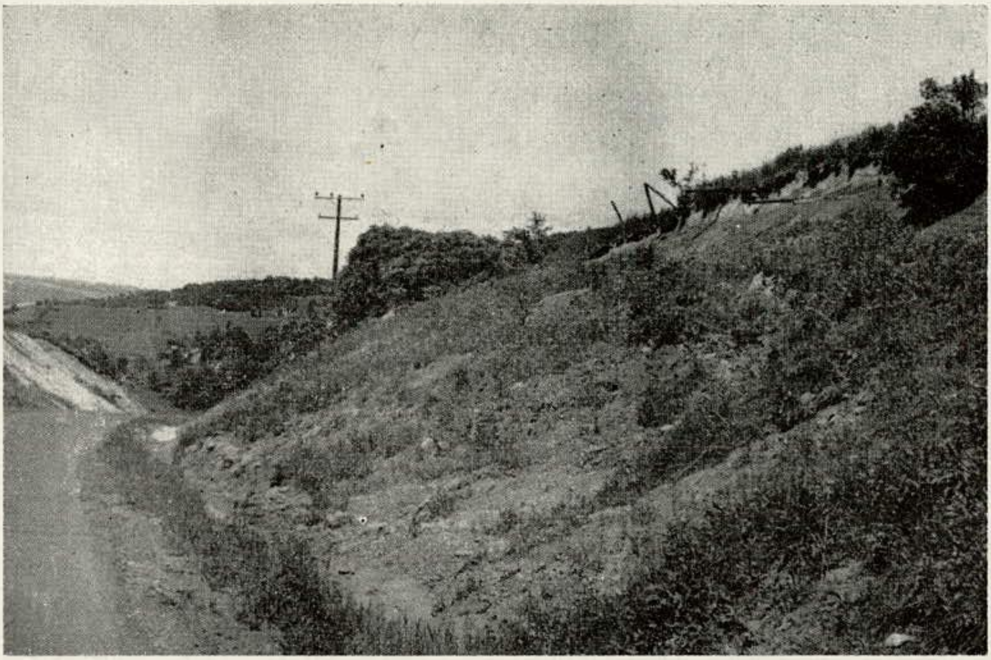

Figure 55. Ground view of a typical slide on a cut slope shown in Figure 54. (Photograph by Donald J. Belcher)

flats, marshes, and swamps; and the presence of broad, shallow, tidal stream channels. The dissected coastal plain is identified by its rolling to rugged topography and integrated drainage system. It is also associated with coastal features and appears on airphotos to be somewhat similar to areas underlain by consolidated sedimentary rocks.

In undissected plains, landslides offer a problem only in the construction of canals or similar structures that require deep excavation in flat lands. In dissected plains, however, slumps in natural hill slopes, as well as in road cuts, are common (Figs. 57 and 58). The stratified and unconsolidated nature of the sands, silts, and clays that characterize most coastal plains have provided a favorable situation for landslides.

Terraces are easily recognized in airphotos as elevated flat land along major or minor valleys. Terraces of gravel and sand are usually stable, maintaining a clean slope on the face. However, where terraces are composed of interbedded silts and clays, or where the natural equilibrium is disturbed by artificial installations, slumps will occur. Slumps in terraces naturally start on the unsupported slope facing the low land. The presence of slide scars along the terrace front is a reliable indicator of instability (Fig. 59).

Lake bed deposits generally display flat topography unless they are dissected. Although generally composed of clays, lake beds have little chance to slide except when exposed at valleys or at deep cuts. There have been slides of considerable magnitude in lake clays under each of the following circumstances: (a) where lake clays are interbedded with or, especially, are overlain by granular deposits, and (b) where lake clays overlie bedrock at shallow depth and the base level of erosion of the general area is greatly lowered. The former situation is common in some glaciated regions of New York. The latter combination has produced slides of extraordinary magnitude in western Canada.

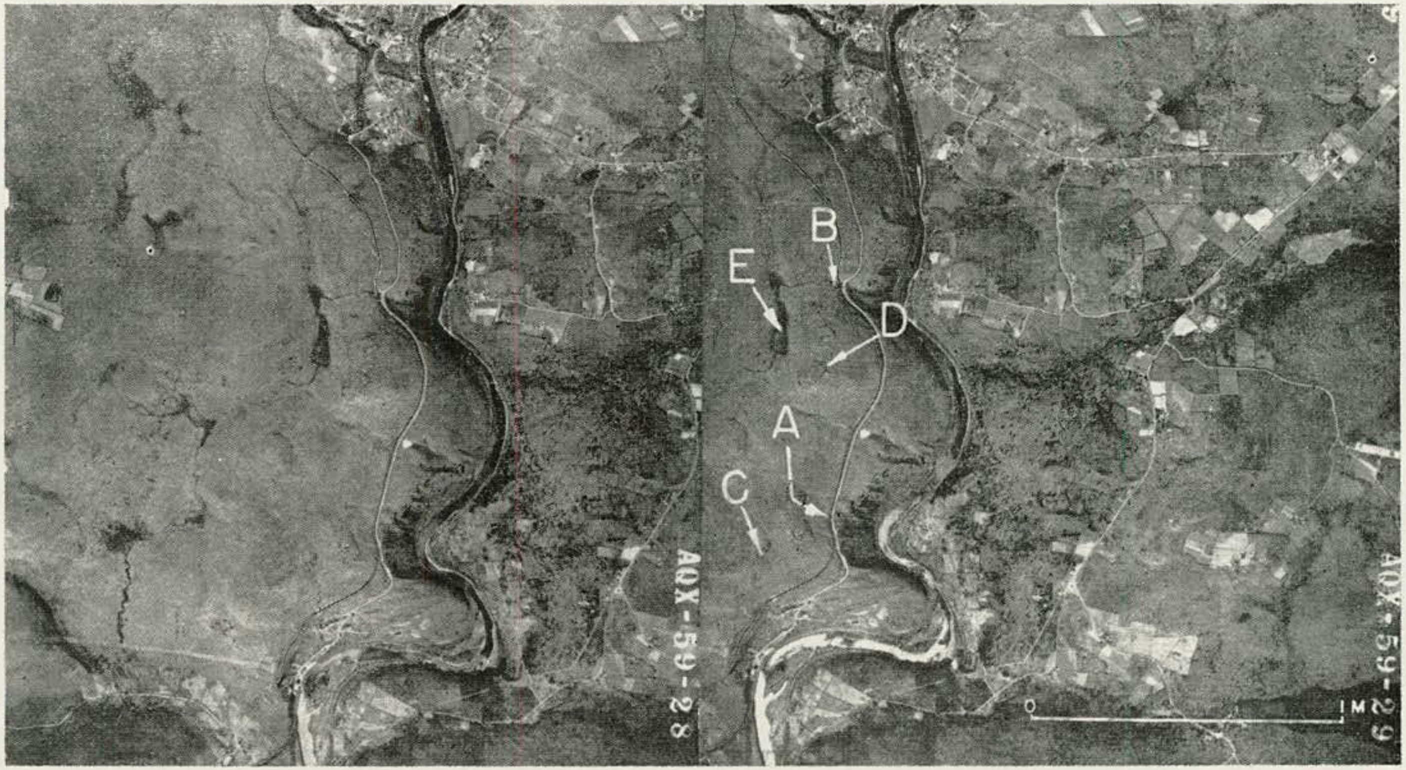

Figure 56. Glacial mantle over bedrock, Pike County, Pa. Thin deposits of unconsolidated materials on bedrock often develop landslides along stream valleys where undercutting is prevalent and the bank slopes are progressively steepened. Glacial deposits are usually unequally distributed over the bedrock — thinner on the hills and thicker over the valley. They tend to smooth the original bedrock topography. In the picture, at (A), the slide is shown to progress toward the road, threatening the road and the pipeline of a hydroelectric plant behind the road. A similar threat, though of lesser degree, exists at (B).

In examining the airphotos, it is clear that sandstone and shale outcrop at places like (C) and (D). On the basis of the general configuration of the sedimentary rock hills, the relative depths of unconsolidated deposits at various points can be estimated and a systematic, instead of haphazard, program for subsurface investigation can be planned.

Drainage conditions are clearly shown in the photographs. Ponded depressions, like (E), are obvious in the picture; but on the ground, it would take much time and effort to locate them in this tree-covered area. Drainage of such depressions would reduce the danger of impending slides below them. (Aerial photograph by U. S. Department of Agriculture)

Figure 57. Coastal plain, Prince Georges County, Md. The stereo pair shows a proposed road (white line on left photo). The dissected plain is identified by its low, soft hills and the associated tidal channels. Cut slopes steeper than the natural slopes are susceptible to slides unless adequate precautions are taken. In highway location in an area like this, it would be better to set the grade line below dangerous clay layers so that even if a slide occurs, it would not affect the foundations of the road. At (A), a road constructed after the photos were taken was located above the clay. The subsequent slide not only damaged the upper slope but took away part of the pavement as well. At (B) and (C), the road cut into the toe of the natural slopes. Since the road was located below the clay layer, slides in both places occurred on the cut slope only. The cut slope at (D) also failed, but the drainage and topographic situation was more favorable there and the slide was stabilized shortly. At (E) is an old slide that can be easily recognized in the photograph; it is hidden by vegetation when inspected on the ground. (Aerial photograph by U. S. Department of Agriculture)

Figure 58. Ground view of landslide at point (A) shown in Figure 57. Here, the gray clay layer lies underneath the pavement, which is damaged by the slide. (Photograph by Ta Liang)

Undissected lake clays are easily identified in airphotos by their characteristic broad, level tracts, dark gray tones, and artificial drainage practices. Dissected and complex lake bed areas are relatively difficult to identify, particularly for one that is not familiar with the local geologic conditions. Again, the presence of existing slides is the most reliable warning signal.

Windlaid Materials. — *Loess,* or wind-deposited silt, can be identified unmistakably in airphotos by its vertical-sided gullies, which are evenly spaced along wide, flat-bottomed tributaries to show a featherlike drainage pattern. Equal slopes on hills and valleys, an indication of uniform material, heavy vegetative cover, and soft gray tones serve to confirm the landform.

Loess is well known for its minor slumps, generally called catsteps. The catsteps are seen in airphotos as fine, roughly parallel, light tone contours (Figs. 60 and 61). On the ground, the individual steps of these small slumps are commonly 2 to 4 feet wide, and several inches to 2 or 3 feet high.

Complex Forms. — Most of the landforms previously described may be called simple forms because they consist predominantly of one type of material in each unit. In nature, however, complex or superimposed forms are numerous and of common occurrence. This is especially true in glaciated areas, as mentioned previously. They are further emphasized here because of their significance in landslide studies. Airphoto recognition of the basic simple forms is definitely helpful in the interpretation of complex forms.

A change of material vertically or horizontally in complex areas often affects the internal drainage characteristics and creates slope stability problems. The most common situation favorable to slides is when impervious formations

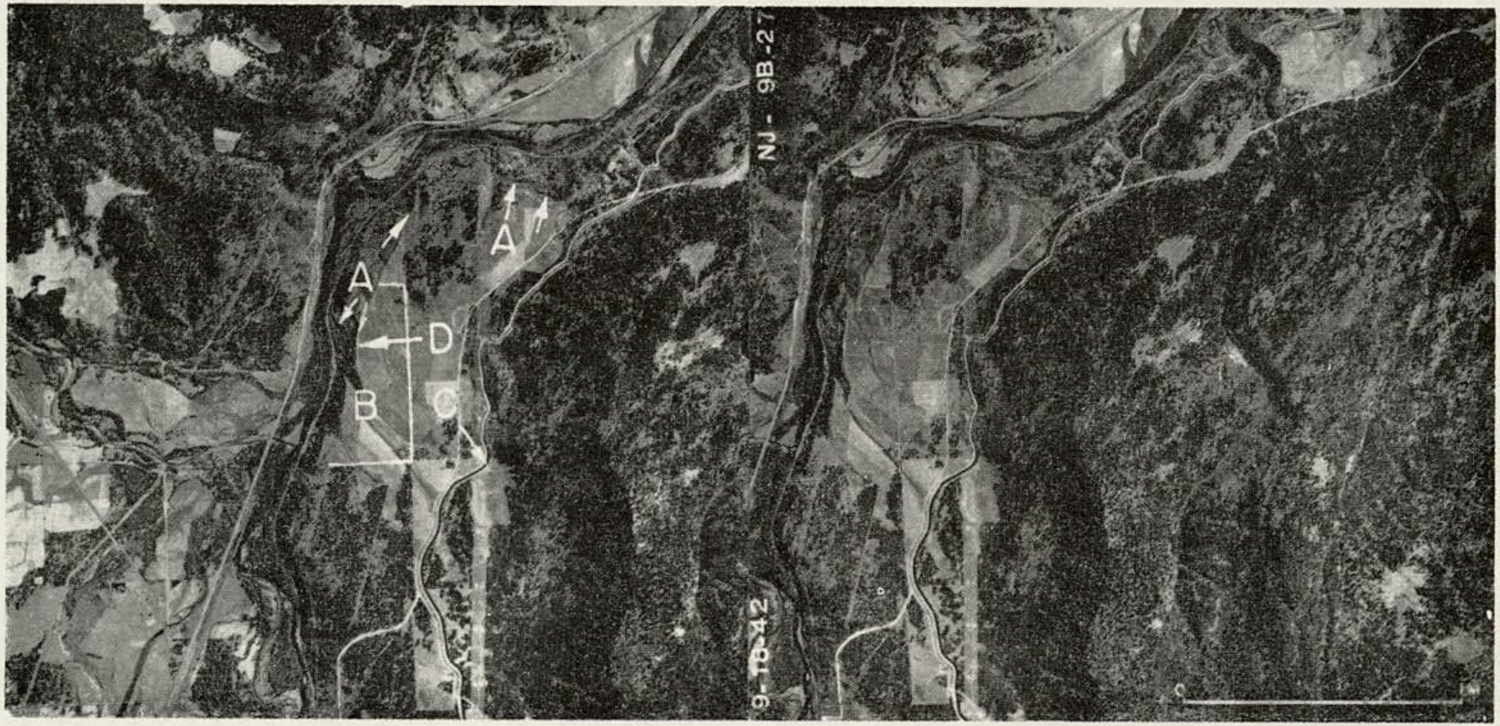

Figure 59. River Terrace, Kittitas County, Wash. The combination of pervious and impervious beds is a favorable condition for slides, often deep-seated ones. The instability of the land shown in this stereo pair is indicated by the numerous slide scars (A) along the terrace front. When the irrigation system of the farm (B) above the railroad was connected to the main canal (C) a new slide became imminent. The most probable next slide (D), which actually took place later, could be predicted in advance from airphotos as it is the steepest slope and is actively attacked by the river. (Aerial photograph by U. S. Department of Agriculture)

Figure 60. Loess, Lincoln County, Nebr. This stereo pair shows loess of great depth which is identified by steep-sided, flat-bottomed gullies, equal slopes in hills and valleys, and soft tones. The catsteps — small slumps — are seen as light fine contours all over the area. (Aerial photograph by U. S. Department of Agriculture)

Figure 61. A ground photo showing catsteps in loess, such as those shown in Figure 60. (Photograph by Ta Liang)

are underlain by relatively pervious beds.

Actual failures are commonly detectable in airphotos in the following situations:

1. Glacial outwash or delta deposit over old lake bed. Photo pattern changes from that of light-toned, well-drained outwash at high ground to poorly drained lake clays exposed on the slopes. Old landslide scars are present in the slopes.

2. Glacial drift over shale. The photo is likely to show numerous landslides along river banks composed of shallow drift.

3. Valley fill over bedrock. The photo may show the landform characteristic of bedrock, but this is modified locally by fill deposits. Slides of fill material along steep hill slopes may be observed.

4. Sand over clay. This combination is common both in glacial and coastal plain areas. Slope failures along natural or cut slopes can be seen in many photos.

Procedure for Detecting Evidence of Landslides in Airphotos

A step-by-step procedure for landslide investigation by airphotos is outlined in the following:

1. Lay out locations of road or other planned structure on photos.

2. Take a quick survey, on the photographs, of all cliffs or banks adjacent to river bends, and of all steep slopes in the photo area, to see if landslide movements are evident.

3. Outline areas along the right-of-way that show consistent characteristics of topography, drainage, and other natural elements within the same unit.

4. Evaluate the general landslide potential of the areas with the help of Table 2.

5. Make a detailed study of all cliffs or banks adjacent to river bends and all steep slopes above and below the center line of the road. It is important to com-

TABLE 2

AIRPHOTO IDENTIFICATION AND LANDSLIDE EVALUATION OF LANDFORMS

Elimination Procedure	Supporting Characteristics	Probable Landform[1]	Landslide Potential[2]
I. Level terrain			
A. Not elevated:		Flood plain, etc.	(c)
B. Elevated:			
	Uniform tones	Terrace, lake bed	(b)
	Surface irregularities, sharp cliff	Basaltic plateau	(a)
II. Hilly terrain			
A. Surface drainage not well integrated:		Limestones, etc.	(c)
B. Surface drainage well integrated:			
1. Parallel ridges			
a. Parallel drainage	Dark tones	Basaltic hills	(a)
b. Trellis drainage	Ridge-and-valley topography, banded hills	Tilted or folded sedimentary rocks	(a)
c. Featherlike drainage	Vertical-sided gullies	Loess	(b)
2. Branching ridges			
a. Featherlike drainage	Vertical-sided gullies	Loess	(b)
b. Treelike drainage			
(1) Banding on slope		Flat-lying sedimentary rocks	(b)
(2) No banding on slope			
	Moderately to highly dissected ridges, uniform slopes	Clay shale	(a)
	Low ridges, associated with coastal features	Dissected coastal plain	(a)
	Winding ridges connecting conical hills, sparse vegetation	Serpentine	(a)
3. Random ridges or hills			
a. Treelike drainage			
	Low, rounded hills, meandering stream	Clay shale	(a)
	Massive, uniform, rounded to A-shaped hills	Granitic rocks	(b)
	Bumpy topography[3]	Moraine	(b)
b. Disordered drainage			
	Disordered, overlapping hills, associated with lakes and swamps[3]	Moraine	(b)

[1] The landforms listed are the most likely ones to represent the condition listed. It must be remembered, however, that other kinds of geology and terrain can give photographic representation similar to some of those listed. Only a high degree of skill in photo interpretation or knowledge of the local geology can be regarded as certain to avoid errors.

[2] (a) susceptible to landslides; (b) susceptible to landslides under certain conditions; (c) not susceptible except in dangerous locations discussed above.

[3] Glaciated areas only.

pare slopes within the same unit area rather than of different areas. For instance, slopes in bedrock would be more stable, even though steeper, than slopes in adjacent soil areas. Realize that slides usually appear small in photos, and so look carefully, inspecting slopes in minute detail. Look especially for:

a. Existing slides. Relatively new slides appear in white tones; vegetation and drainage are not well established on them. The reverse conditions are true for old slides.
   (1) Hillside scars and hummocky topography.
   (2) Parallel moon-shaped dark patches on hillside, likely to reflect vegetation in minor depressions. Draw a line through the axis of scars or crescents in the slides. This line often points to drainageways on higher ground that contribute to the landslide movement.
   (3) Irregular outline of highways and random cracks or patches on existing pavement.

b. Potential slides
   (1) Ponded depressions and diverted drainageways.
   (2) Seepage areas suggested by faintly dark lines, which may mean near-surface channels and fanshaped dark patches, probably reflecting wet vegetation.

6. Ground check some of the landslides that are recognized in airphotos.

7. Ground check all suspected spots, using methods and criteria described in Chapter Four.

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