state occur in most tropical countries. Figures 13 and 14 illustrate these in Puerto Rico. Each landform has its strength and weaknesses, and by identifying the landform and knowing its traits, a better job of engineering can be done. In this way, the risk can be calculated with some reasonable assurance of safety.

On the good side of the record, it is certain that most limestones furnish one of the best and most extensively used aggregates. With the exception of the very cherty limestones, it forms a dependable and high quality material.

ENGINEERING SIGNIFICANCE OF SAND AREAS INTERPRETED FROM AIRPHOTOS

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The investigation summarized here was established as a doctoral thesis in the interpretation of soils by the use of aerial photographs, the interpretation to include both engineering mapping and analysis of highway problems associated with the types of soils classified. It was attempted to interpret the complex patterns of the airphotos of northwest Indiana--patterns which have been made complex by the large variety of glacial and post-glacial deposits which have provided the parent material for the developments of the soils of the region. All or portions of twelve counties were mapped, using airphotos, in the belief that a good knowledge of the soil types of an area is the basis of good highway design in that area. Consequently, the area was studied both from the standpoint of developing techniques of mapping engineering soils from aerial photographs and from the standpoint of determining applications of the knowledge of the mapped soils to problems of highway design and construction. Studies of pavement performance were made during the spring breakup and during the summer season to correlate soil types with the performance of both rigid and flexible pavements.

Before the variable of soil texture can be applied to the performance of a highway, it is necessary to know what the soils involved are--their origin, profile development, drainage characteristics, texture, plasticity, and topography. In the interests of economy it is necessary to develop rapid means of identification of soil types and of characteristics. Until the recent advent of the techniques of airphoto soils interpretation, no rapid method of soils mapping had been developed. To the skilled interpreter, the aerial photograph, combined with a knowledge of the general development of the area being studied and of some of the basic concepts of pedology, as well as a familiarity with methods of soils engineering, is a rapid method of obtaining knowledge of the engineering characteristics of the soils of an area.

The basic techniques of airphoto interpretation of soils have been described in the past (1,2). They include acquaintance with geological developments and processes in the area being studied and with pedological information as to profile development, erosion, and vegetative cover. Study of broad areas is combined with stereoscopic examination of matching prints to determine the details of the surface features. The elements of the airphoto pattern (color tones, drainage, erosion, vegetation, topography, and land use) are used to bound soil areas on the basis of origin, development, texture, topographic position, climate, drainage and plasticity. An important factor used in airphoto mapping is the concept that any given pattern will be changed if other deposits are accumulated on top of the soil of that pattern. The amount of modification depends upon the amount and nature of the overburden. The complex patterns of northwest Indiana proved to be modifications of the more standard patterns and could be worked out by a process of reasoning following careful observation of the elements of the patterns.

Many states have realized that in their highway system they have an extensive field research laboratory, and large-scale performance surveys have been undertaken in many areas. Many of these have been reported in part and some have established strong correlation between soil types and pavement performance (3,4,5). There are many factors which may affect the performance of a particular section of concrete pavement; coarse aggregate, fine aggregate, mix design, construction procedures, joint design, subgrade, base, drainage, and others. A similar list of factors can be developed in regard to flexible pavements. Consequently, isolating one of these factors and successfully correlating it with pavement performance is not a simple task, but it has been handled with apparent success in at least some areas.

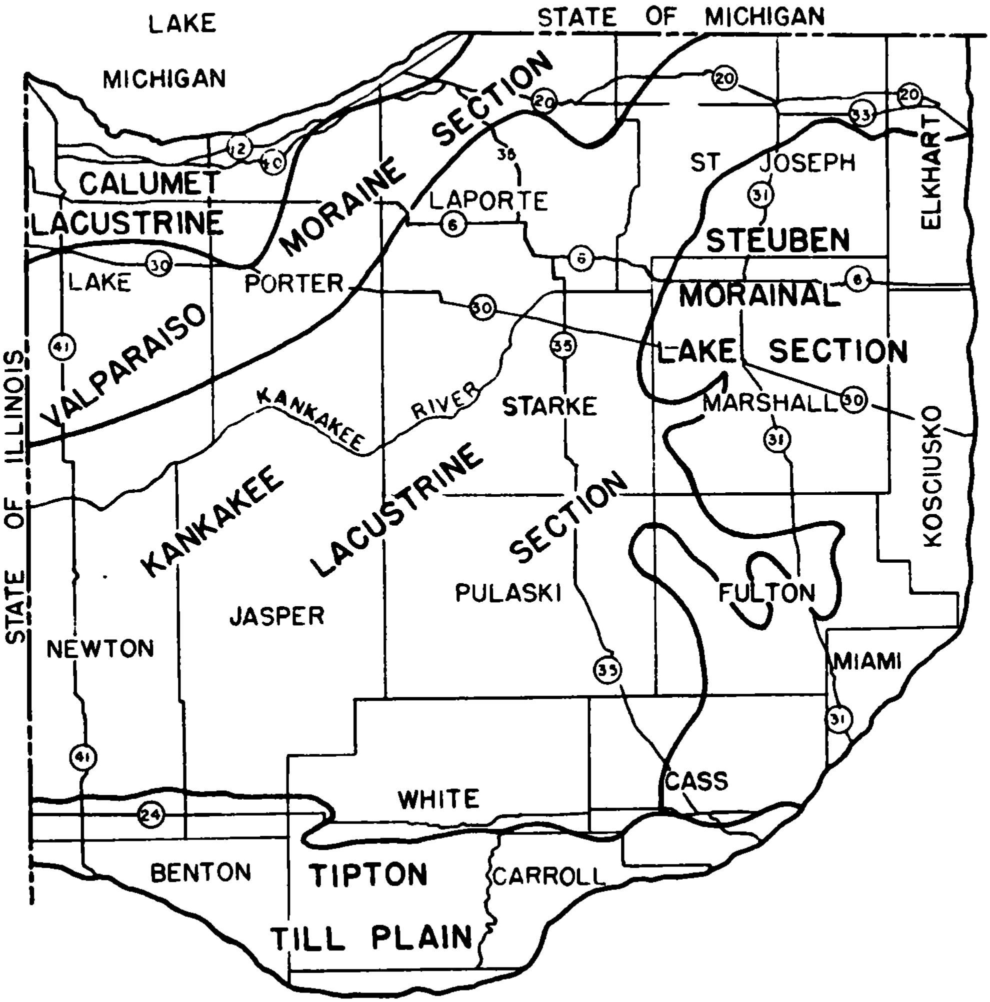

Figure 1. Physiographic Divisions and Federal Highways in Northwest Indiana

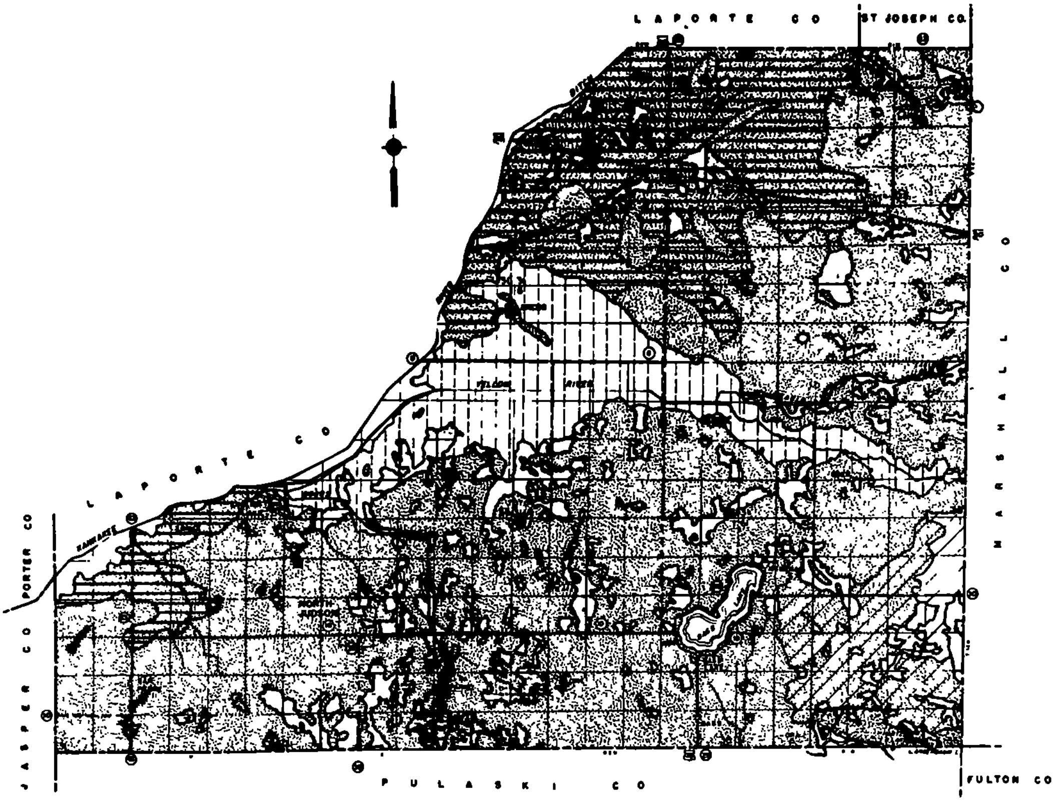

Figure 2. Typical County Engineering Soils Map. This soils map is of Starke County in Indiana in the Kankakee basin. It is typical of the several counties which have the Kankakee River for their northern boundary. The soils are largely of lakebed development except for a small area of outwash gravels in the northeast corner and an area of semi-plastic drift in the southeast portion of the county. Eight soils were mapped in this county and the detail is representative of that which can be obtained from airphotos.

AREA AND METHODS

Seventeen counties in northwest Indiana were surveyed in order to map the sand areas described in this report. They fall within the region known physiographically as the Northern Moraine and Lake Section, a region bounded on the south by the Tipton Till Plain. Three of the divisions of the section are involved in the area studied, illustrated in Figure 1. These are the Calumet Lacustrine section, the Valparaiso Moraine section, and the Kankakee Lacustrine section. The Steuben Morainal Lake section borders the area studied on the east. The major portion of Indiana has been covered once or more by the glaciers and their heterogeneous deposits of drift. The northern part of the state lies within the bounds of the last great advance of the glaciers--Late Wisconsin--so that the soils and topography of that part of the state are almost wholly controlled by the glacial deposits and some subsequent development. In the Valparaiso Moraine section and the Steuben Morainal Lake section the surface deposits are those of the glaciers--the Valparaiso Moraine being the most prominent terminal moraine of the Michigan lobe of the glacier and the deposits in the Steuben area being those of the Erie and Saginaw lobes. The rolling hills of the terminal moraine are the predominant features of the topography in these areas. Actual till plains are rather rare in this section of Indiana. In the Lacustrine sections, the deposits are those which were laid down by running or impounded waters during and following the time of the glaciers.

The entire region is so comparatively young that with the possible exception of sand dune formation there have been no great natural changes in topography since the respective deposits were laid down. Drainage developments and erosion have been relatively scant. Other surface changes have been wrought by the efforts of man in the past hundred years. These are vegetation, construction of highways and railroads, and artificial drainage of many of the swampy areas. The Calumet Lacustrine section is the former lakebed of glacial Lake Chicago--an extension of Lake Michigan --and is marked by several prominent beach ridges, plastic and sandy lacustrine deposits, swamps, and the more recently developed prominent dunes bordering Lake Michigan. The Kankakee Lacustrine section embraces a large area lying south of the Valparaiso Moraine. It centers about the Kankakee River which at one time carried vast quantities of glacial waters and when dammed up to the west in Illinois, impounded water over a large area, giving rise to the deep sand deposits which cover much of the basin. Extensive areas of outwash materials occur about the borders of the basin and to the north and east. Artificial drainage has lowered the water table in most of the sandy basin reclaiming a vast swamp for productive pursuits and drying the surface sands to the extent that many active dunes have been and are being formed.

Many prominent federal highways from the Chicago area fall within the area studied and other important east-west and north-south highways were available for performance studies as well as many state highways and surfaced roads of lesser importance. The US highways crossing the area are also shown in Figure 1 and include US 6, 12, 20, 24, 30, 31, 33, 35, and 41. These heavily traveled roads, traversing many different soil areas, made this area

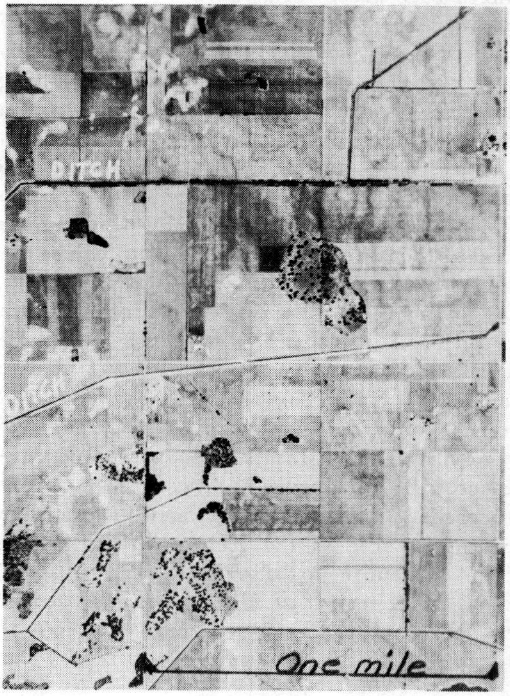

Figure 3. Airphoto of Large Flat Areas of Sands. This pattern of flat-lying sands in Jasper County, Indiana, has been modified by wind-swept sands, both active and stabilized. The white spots are currently shifting sands whereas the patches of trees mark dunes which have become stable. The main area shows the very flat topography and uniform light-gray color tones of the flat sand areas. There is almost complete lack of natural surface drainage but the area has been ditched to lower the water table.

a particularly fruitful one for performance studies.

Mapping was conveniently done in units of counties. A mosaic of the prints of the county was assembled on a board and studied. After a preliminary understanding of the area and its soils had been developed and after preliminary approximate boundaries had been lightly marked on the prints where it seemed possible to make an early prediction, the prints were examined stereoscopically in considerable detail. When it had been ascertained what boundaries could be marked with strong assurance and which boundaries were somewhat questionable, a field trip was planned. Field checks of soil types were made and samples taken to check textural composition and Atterburg limits. After the additional information of the field work was available, the marking of the boundaries was completed on the airphotos and the markings transferred to a base map of the county by means of a transfer table. Figure 2 is an illustration of a typical county soils map.

Soils areas as marked were combined into broad groupings, such as are described later in this report, on the basis of features and characteristics identifiable from the airphotos. On the basis of previous experience in correlation of pavement performance with soil types, it was then possible to predict the type of highway problems to be encountered in the areas mapped. Spring breakup studies of flexible pavements and condition surveys of rigid pavements served to substantiate these predictions.

SOIL AREAS AND THEIR INTERPRETATION

Large Flat Areas of Sand - These were laid down as lakebed deposits at the time when the Kankakee River was dammed and perhaps have been reworked during lower stages of of the lake. Topographically, they are monotonously flat. During the time of Kankakee Lake, numerous beaches and islands were formed and modified so that many long-standing mounds and ridges are scattered throughout the area. Later wind action has further modified these hills so that they have the appearance of and are commonly referred to as dunes. These may occur at random in the flat sand areas or in close groupings over large areas, in which latter case they were mapped separately on the strength of topography, position, and drainage. The surface deposits in the flat areas are fairly uniform in size and tend toward one-size sands, although silt may occur in the topsoil. In many cases they

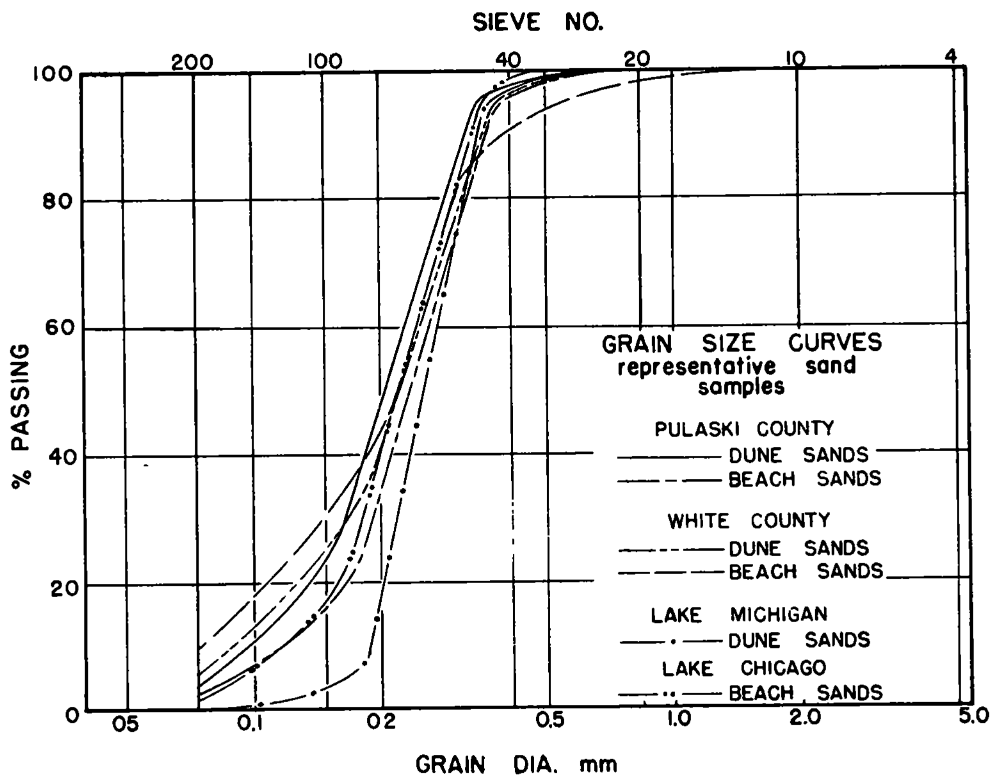

Figure 4. Grain Size Curves of Dune and Beach Sands

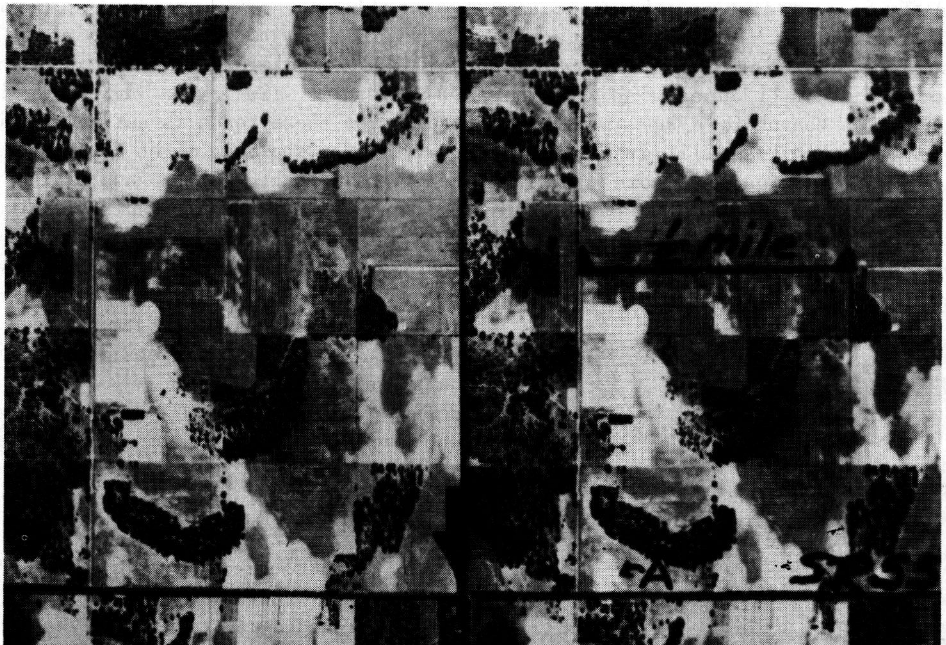

Figure 5. Airphoto of Sand Dune and Ridge Area. This stereogram is very representative of the sand dune areas in the Kankakee basin. It covers a portion of a band of dunes two or three miles wide extending across the flats. In the lower left corner of the picture may be seen the change to the flat areas of sands.

are underlain by coarser sands and gravels. They drain well when the water table is low enough and artificial drainage has accomplished this in most of the area.

These areas are marked by rather uniform light-gray color tones (Fig. 3). The topography is very flat and the field pattern is rectangular. Wind whipping across the surface has picked up sand and deposited it in small dunes, indicated by white spots on the photo. Dunes which have reached a state of equilibrium and have retained their shape for some time are marked by native trees, usually oaks. There is an almost complete absence of natural surface drainage and at least one ditch may be found in every square mile of the area.

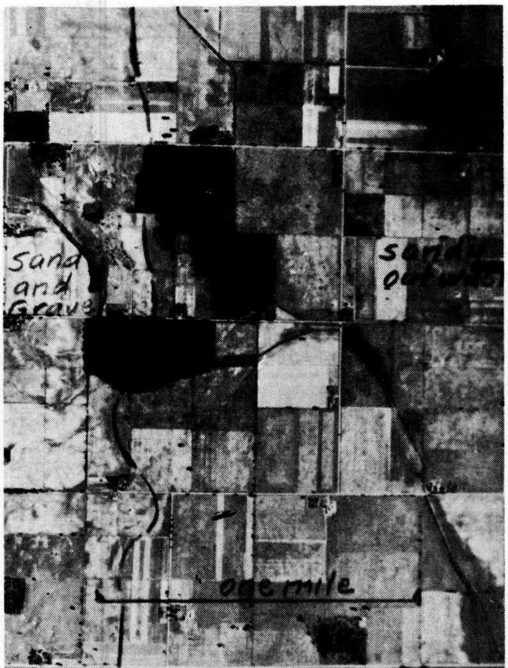

Figure 6. Airphoto of Sandy Outwash. The major portion of this photo is of the sandy outwash area in northwestern St. Joseph County in Indiana. It shows gently rolling to flat topography and light-gray color tones. Infiltration basins are faint and there are no gullies. The left portion of the picture bounded by the dashed line, shows the contrast of the more granular pattern. Figure 7 is illustrative of the topographic change at this boundary.

There are some faint indications of slow-flowing water to be seen in the area but these are probably due to a former condition at the time of draining.

In regions where artificial drainage has lowered the water table, these soils generally provide excellent subgrades. There are many miles of excellently performing flexible and some rigid pavements on sands of this type. In general the traffic on these roads is not heavy. Under heavy loads, faulting might be appreciable. Location is no problem because of the flatness of the area and no cuts, with their changes in profile, need be considered. The area contains many small regions where the top soil is very highly organic and this soil presents a problem in location. If these small regions, easily identified on the airphotos, cannot be avoided, it is desirable to excavate the organic material and back-fill with clean sand. No other granular materials are likely to be available in the immediate vicinity.

Sand Dunes and Ridges - There are extensive areas of this soil type lying south of the Kankakee River and another broad belt of dunes surrounding the south and west shores of Lake Michigan. Their most characteristic feature is the topographic expression of sands in the dunes and ridges. The dunes appear in modifications of the crescent shape, as long ridges, and occasionally as mounds. An effort was made to determine whether the ridges might not be of water-laid origin rather than wind-blown. Many comparative samples were taken from wind-blown tops of ridges and from deeper down where it was expected the sands may have been water-laid. The plot of the grain-size distribution curves (Fig. 4) showed no significant difference in the grain sizes at the two locations. To determine whether a difference in grain size of wind-blown and water-laid sands might be expected, similar samples were taken from the large dunes along Lake Michigan and from deep in the beach ridges of Lake Chicago. The data were compared and it was concluded that the beach sands and the dune sands were of essentially the same size. This conclusion is reasonable because all the sands are from the same source,

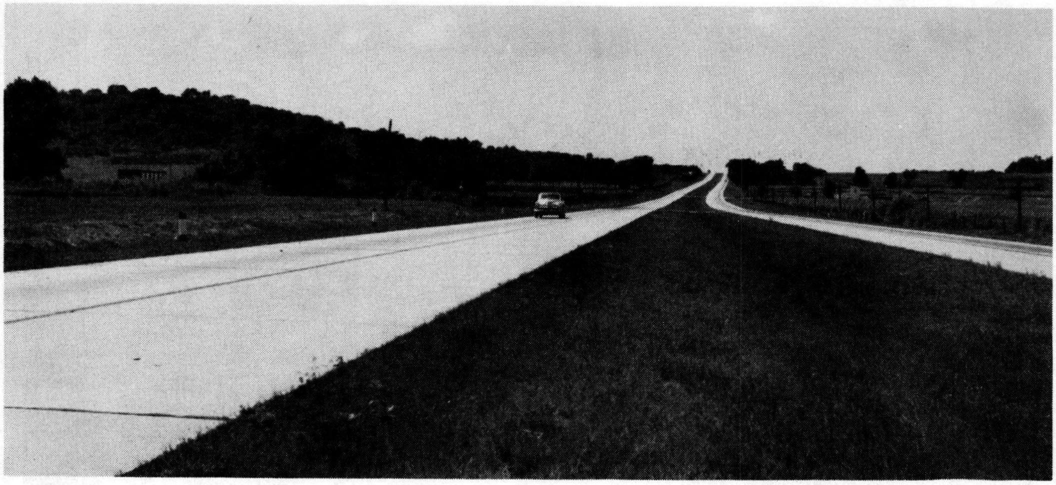

Figure 7. Ground Photo of transition From Sandy Outwash to Gravel Outwash. This photo, taken along SR No. 2 in Eastern St. Joseph County, shows the sharp change in topography at the border between the sandy outwash area and the gravelly outwash marked in Figure 6. The hill to the left rises over 100 ft. above the level of the adjacent plain--an extreme local change in elevation for these types of materials.

although it might be expected that water action could wash up larger particles and that wind deposition would be more selective. It was also noted that there was a striking uniformity in size between the sands surrounding Lake Michigan and those in the Kankakee basin.

This soil type is one of the easiest to recognize on the airphotos as the shape and topography of the dunes, the light color tones, the blowouts, the absence of gullying and surface run-off, and the patches of trees can hardly be mistaken (Fig. 5). Another strong feature of the area marked in the airphoto pattern is the large number of muck pockets found in some portions of the area. The field pattern is likely to be irregular and ditches are frequently used to lower the water table in the muck-filled depressions.

Location of highways in this area is largely a problem of avoiding the muck pockets. Cuts are required through the dunes and ridges but the sands are deep and no change in texture is involved. A definite problem with these sands is the matter of stabilization. The sands are subject to wind erosion in the natural state, which will also cause some modification of cut and fill slopes. This process is slow, however, and the slopes are usually left bare on secondary roads. Rounding the slopes, bringing in top soil, and developing a sod cover or planting special grasses are practiced on some primary roads. The sands are stable when confined but are likely to rut in a natural surface because of lack of binder. The same is true of these sands under very thin surface treatments. To be entirely satisfactory, the subgrade should be stabilized or the pavement should have some structural strength. It has been shown that bituminous materials and other additives may aid in such stabilization. Sands also present a problem in compaction because of their uniform size. They are subject to vibratory compaction and consequently are prone to compact under the action of traffic and cause settling and faulting of the pavement. It is this type of action that has led to faulting on many rigid pavements placed on a 4 or 6-in. insulating blanket of sand. In some instances the sands may be mechanically stabilized by bringing in fine material. The excellent drainage characteristics of

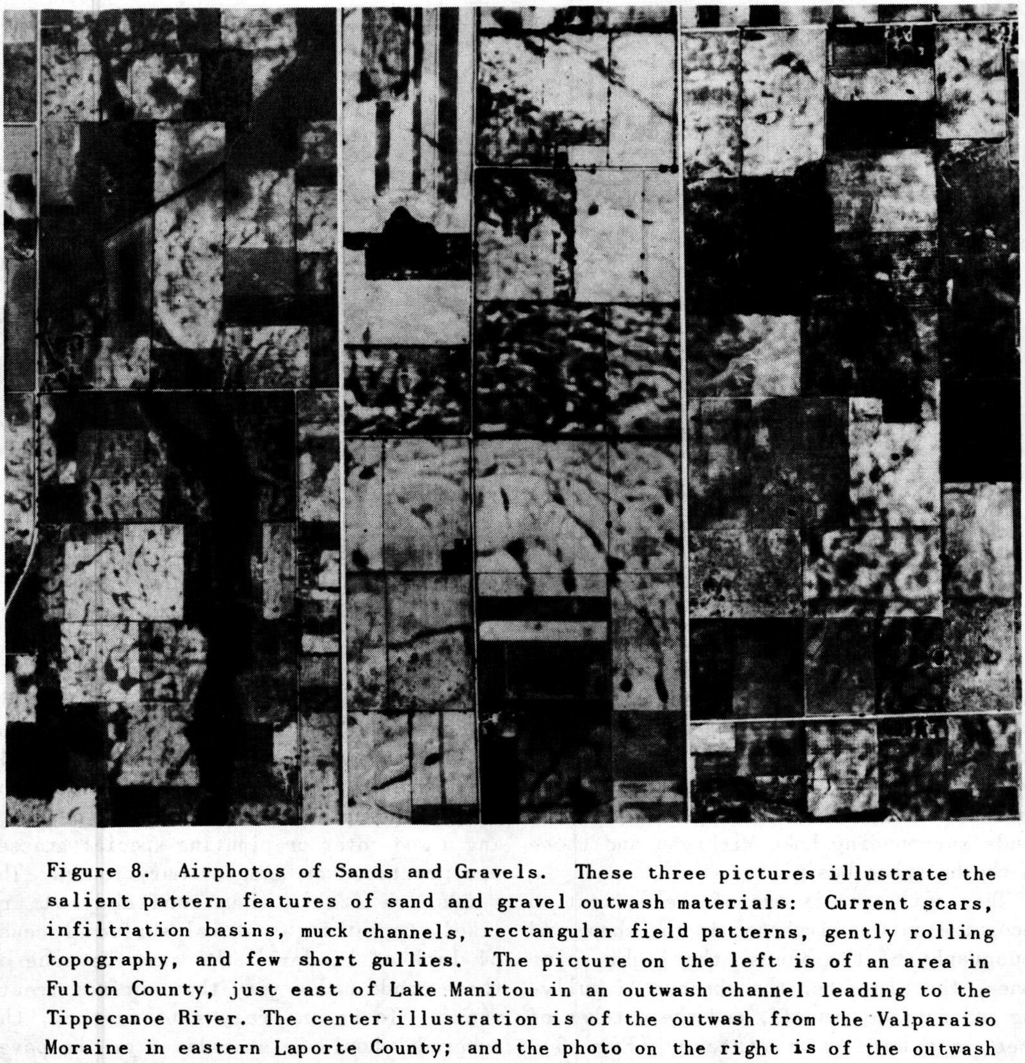

Figure 8. Airphotos of Sands and Gravels. These three pictures illustrate the salient pattern features of sand and gravel outwash materials: Current scars, infiltration basins, muck channels, rectangular field patterns, gently rolling topography, and few short gullies. The picture on the left is of an area in Fulton County, just east of Lake Manitou in an outwash channel leading to the Tippecanoe River. The center illustration is of the outwash from the Valparaiso Moraine in eastern Laporte County; and the photo on the right is of the outwash pattern in northern St. Joseph County. All three photos are to the same scale.

the sand may require that water-proof paper be laid on the subgrade before concrete is poured to halt the draining of the water from the mix into the subgrade.

Sandy Outwash - Northern Indiana has many areas of sandy outwash formed during the time of the Late Wisconsin glacier by break-throughs or over-flows of the moraines by waters impounded by rapid melting of the glacial front. The surface and topography is quite similar to the area mapped as large flat areas of deep sands except that sand dunes are much less in evidence. The texture of the surface sands does not fall within such narrow bands as that of the sands previously described and the underlying material, frequently gravel, may occur at shallow or considerable depths. The topography may be gently rolling and there is little surface drainage. The granular nature of the soil and the underlying gravel is such as to give excellent internal drainage, but artificial drainage has been practiced to lower the usually high water table.

There is often marked contrast in the airphoto pattern between soils of this group and the adjacent sand and gravel areas, as seen in Figure 6. The topographic contrast is also well-marked (Fig. 7). The color tones of the airphoto of sandy outwash are quite uniform gray. There are no gullies in evidence although faint infiltration basins and current scars may be seen. The field pattern is rectangular. The highway problem of major consequence in this area is that of drainage, for unless the area has been ditched the free-water surface may be too near the surface to allow stable subgrade conditions. Faulting also may occur.

Sands and Gravels - Large areas in northern Indiana were mapped as sands and gravels consisting largely of outwash deposits along glacial streams and from water impounded behind moraines. Soil profiles in this area usually show 6 to 18 in. of sand, including some topsoil, over a foot or two of gravel containing varying amounts of sand, silt, and clay. Since the materials were water-laid they are stratified, and layers of sands and gravels may be encountered to an appreciable depth. The topography varies from undulating to strongly rolling. Surface drainage is not strongly developed as the drainage is largely internal. Muck channels may be fairly numerous.

The feature of the airphoto pattern is the mottled and pitted appearance typical of coarse, granular materials. Although the surface drainage is slight there are short V-shaped gullies and many current scars and infiltration basins. Color tones are predominantly light to light gray but many dark muck pockets and channels are likely to develop. The field pattern is usually rectangular, and orchards are frequently visible on the photos. The similarities among the patterns from widely scattered locations may be observed in the photos in Figure 8.

These materials are among the best of the subgrade soils. They are well drained and stable. In some areas the topography is sufficiently rugged to cause fairly steep grades and rather deep cuts. Excellent performance may be expected in general in these soils although some faulting may occur at slab joints under heavy traffic. Muck pockets should be avoided but an abundance of granular materials is available for fills and other construction. Slight evidences of pumping have been observed in cuts in this area, but samples of the subgrade soil from the locations involved showed no measurable plastic or liquid limits and had but 3 to 15 percent of the total sample finer than the No. 200 sieve.

Plastic and Semiplastic Drift - Although the terminal and ground moraines of the Wisconsin drift sheet are not included in

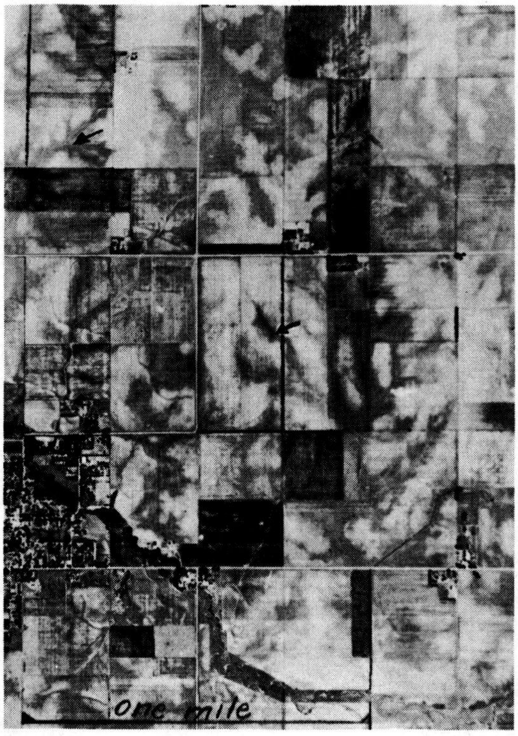

Figure 9. Airphoto of Plastic Drift. This airphoto, covering an area just south of US 24 in southern Jasper County, Indiana, is representative of the pattern of large areas of Wisconsin drift till plains. It shows absence of intense erosion, abundance of phantom drainage as indicated by the arrows, gently blended light and dark color tones, and rectangufield which are features usually found in airphotos of this soil type.

the "sands" discussed here, it is necessary to describe them in order for them to be used as background for the airphoto interpretation of shallow sands on drift as well as for description of the engineering characteristics of the shallow sands. Mapped as plastic drift are the ground moraines, occurring in the area, many of the terminal and marginal moraines, and areas of waterworked drift. The B horizon of these soils may be a combination of plastic clays and silts with sands while the parent material is a somewhat heterogeneous mass of clays, silts, and pebbles. The soil is relatively impermeable and has flat to gently rolling topography except in the morainic areas where it is somewhat rougher. The semiplastic moraines exhibit topography somewhat less regular than the plastic till. Its profile development is similar to that of the plastic drift although the B and C horizons are somewhat more granular. The parent material contains sufficient sand and gravel to provide some permeability.

The airphoto pattern of plastic drift as seen in Figure 9 exhibits an absence of intense erosion, and in the non-morainic areas ditching has been necessary to provide some drainage. The patchy light and dark areas, gently merging, are a development of the drainage conditions, the dark areas being the depressions and the lighter areas the relative rises. There is an abundance of phantom drainage because of the impervious nature of the subsoil. Rec-

Figure 10. Airphoto of Semiplastic Drift. This photo is of an area in southern Fulton County mapped as semiplastic drift. By contrast with the pattern of plastic drift, illustrated in Figure 9, it shows more irregular slopes, some eroded slopes, a more definite transition from light to dark color tones, and a somewhat more developed drainage but with some infiltration basins as indicated by the arrows.

Figure 11. Airphoto of Granular Drift. Representative of the granular drift of the Maxinkuckee Moraine in northern Fulton County, this photo is of an area along US 31. It exhibits the typical features of the pattern of this type of area: Abundance of steep slopes and freshly eroded slopes with V-shaped striated gullies (a). There are muck pockets and an abundance of infiltration basins (b) and light color tones predominate.

tangular field patterns are characteristic of a plastic soil. The pattern of the semigranular areas (Fig. 10) is intermediate between the plastic drift as described and granular drift. The slopes are more irregular than in plastic drift; there are some evidences of phantom drainage and also some fresh gullies; the color transition from light to dark is more pronounced; and there may be some infiltration basins.

The major problem in the plastic drift area is that of cuts into the plastic B horizon and parent material. Due to the gently rolling nature of the topography, there is a tendancy in design to cut in the rises and fill in the depressions. The fill in the depressions is advantageous for it provides an elevated grade line in an area where drainage is poor. However, further elevation of the grade line is desirable to avoid cuts. Performance of pavements in cuts, particularly where the grade crosses changes in profile, is generally rather poor. The impervious nature of the soil makes drainage a problem in these areas. Rigid pavements will frequently develop pumping in these cuts. Frost heaves are also frequent occurrences in cut sections and spring breakups of flexible pavements are prevalent in the cut sections during the season. If the grade line cannot be sufficiently elevated and cuts prove to be necessary, a blanket layer of granular material is recommended. Problems in the semiplastic areas are not unlike those just described; although the texture of the soils is less plastic, it is still sufficiently poor to cause poor pavement performance in cuts. The rougher nature of the topography makes elimination of cuts unlikely so that the blanket course in cuts is desired in construction. Drainage measures need also be taken.

Granular Drift - These deposits are more likely to have been left as terminal or edge moraines than as ground moraines. They exhibit a rougher topography than the more plastic forms of drift. The parent material is granular and contains large percentages of sand and gravel, as well as some silt and clay. It is often characterized as "dirty gravel." The comparative steepness of the slopes has retarded the development of the B horizon so that this horizon is more shallow than in the more plastic drift soils and it tends to be predominantly silty.

The steepness of the slopes is accompanied by relatively greater depressions and the development of muck areas is more prevalent in this type of drift. Except in the muck areas, light color tones predominate, but they are interspersed with many infiltration basins, indicating the granular nature of the parent material. The slopes are more freshly eroded and gullies are more numerous than in plastic or semiplastic drifts. The gullies frequently have a striated appearance and have

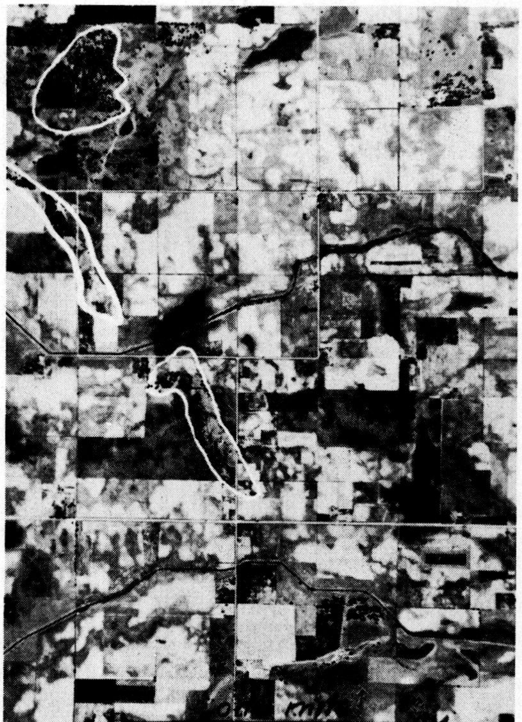

Figure 12. Airphoto of Sand (3 to 5 feet deep) Area. This area in central Jasper County occurs on the northern slopes of the Marseilles Moraine where the sands of the Kankakee basin have been carried up over the drift. It is marked by smooth slopes with some dunes which are usually covered by native trees. Three of these dunes are outlined on the photo. There is little evidence of surface runoff and the light and gray color tones take the pattern of the underlying drift.

fairly steep sides. Many of these features will be noted in Figure 11. Ditching is not necessary to secure drainage for these soils.

The major problem of this area is probably that of location. The topography is relatively rough and the slopes are sufficiently steep to introduce the need for moderately deep cuts and correspondingly high fills. Another factor in the location problem is the occurrence of muck pockets in the area. However, the problem of cuts and fills is not a difficult one because of the granular nature of the soils. They provide excellent embankment material and drain well, even in cuts. Gutters of moderate depth in deep cuts should keep the subgrade reasonably well drained. The materials are sufficiently graded to provide excellent borrow material and can be used as surfacing for county roads. Poor performance is not to be expected except under adverse conditions of traffic and climate. The problem of surface erosion is one which should be considered, and protection is needed for cut and embankment slopes to retard eroding.

Figure 13. Airphoto of Shallow Sands on Plastic Drift. This area occurs in central Newton County in Indiana on the northern slopes of the Marseilles Moraine, but unlike the similar location in Jasper County (Fig. 12) these sands average less than 3 ft. in depth. This photo exhibits most of the features of the airphoto pattern of plastic drift, including phantom drainage. Color tones are very light on the elevated areas and gray in the depressions.

Sands on Drift - These sands were included as an intermediate group between the shallow sands, which were mapped as 3 ft. or less in depth, and the deep sands, which included those 5 ft. deep and more. In sands of this intermediate depth the character of the underlying drift has some influence on the airphoto pattern as well as on the highway problems involved, but it did not appear feasible to attempt to diffentiate between the different types of underlying drift on the basis of the airphoto pattern. Field sampling showed sands of this depth lying on plastic, semiplastic and granular drift. The superficial features of this area are those of the deep sands as discussed earlier. The sands are either water-laid or wind-blown and generally are one-sized in texture although the water-deposited sands may include larger grains.

Figure 12 shows that the color tones of this soil pattern are light and gray, occurring in a pattern similar to that of the underlying drift. However, the characteristic mottling shows through in a modified form and the surface is further modified by sand dunes and ridges. The slopes are generally smooth and there is a certain amount of phantom drainage. Surface runoff is generally lacking. As is characteristic of sand dunes, they may be covered with oak trees when they are sufficiently rough and have so little topsoil development that they are not tillable. Depth of sand in the dunes may, of course, be over 5 ft. but on a small scale map it was not reasonable to map such isolated spots.

The highway problems of this soil area are not dissimilar to those of the areas of more shallow sands, except that the problems can be expected to occur with less frequency. The sands are of sufficient depth that they provide a good subgrade in spite of the character of the underlying drift, unless cuts penetrate too deeply. Consequently, only in the deeper cuts need we be concerned with poor subgrade conditions. The topography will be affected by that of the underlying drift. If the drift is granular there is the problem of location to avoid deep cuts and fills and to avoid muck pockets. In the more shallow areas of sand and where the cuts are deeper, the problems involved are those of the underlying material. In deep cuts into plastic drift it is particularly necessary to provide intercepting drainage for ground-water flow from the sand-drift boundary. The grain size of these sands makes them subject to wind erosion, as well as erosion by running water. The lack of binder material leads to problems in embankment construction as discussed earlier.

Shallow Sands on Plastic Drift - This classification includes sands of depths to about 3 ft. This type may occur in areas where deep, water-laid sand deposits are bordered by pre-existing areas of drift and also includes areas of shallow wind-blown sand which may or may not be isolated from their source of supply. The surface is well-drained but the drift below necessarily has the characteristics of sands-on-drift as described above. The topography will take the form of the underlying drift with some modifying by the sands, particularly where scattered dunes have formed.

Salient features of this soil pattern may be seen in Figure 13. Slopes are generally rather smoothly rounded except at the random dunes. There is little erosion, and phantom drainage may be seen in many places. The field pattern is regular and some ditching is evident. The smoothly blended light and dark areas of the plastic drift pattern are in evidence through the overlying sand but the overall pattern has been lightened in color so that the higher portions of the terrain show up very light in color tone and the depressed areas are not black but gray.

The undulating nature of the topography in this soil area indicates that cuts through the shallow sand and into the underlying drift may be expected frequently. The zone of intersection of the sand and drift boundary is likely to show evidences of poor performance. The combination of sharp change in soil texture combined with the plastic and impervious nature of the drift makes this soil area one of the worst mapped from the standpoint of highway problems. The usual problems of silty clays will be encountered in the regions of cut where the pavement is laid on the drift. Where pavements are laid on 1 to 2 ft. of sand, a good subgrade condition may prevail although faulting at joints is possible under heavy axle loads. Drainage is a

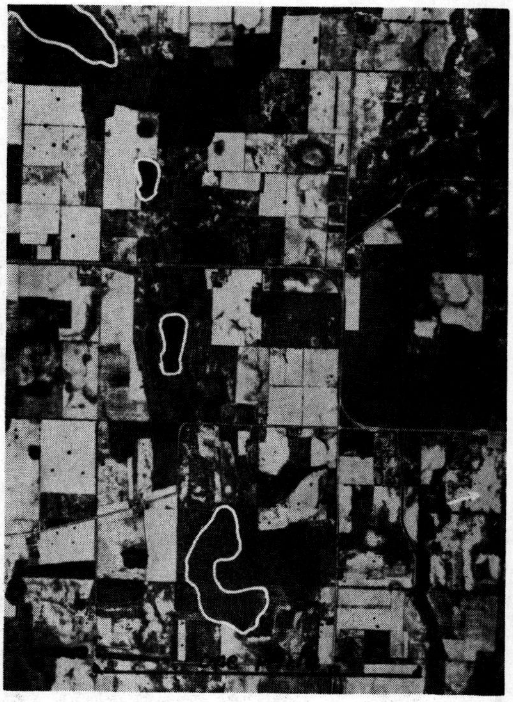

Figure 14. Airphoto of Shallow Sands on Granular Drift. This airphoto exhibits a combination of the features of sands superimposed on those of granular drift. Infiltration basins are evident and many muck pockets are seen, some of which are outlined on the photo. An area of deeper sands and dunes may be observed in the lower right side of the print as indicated by the arrow. This photo is of an area along Indiana SR No. 17 in western Marshall County.

problem in the moderate and deep cuts and it will be necessary to intercept the ground-water flow. Frost heaves may be encountered, not only in the cuts but possibly in other areas where the sand is shallow. The solution for the problems is essentially that of maintaining a high grade line or of providing a blanket layer in the deep cuts and maintaining proper drainage.

Shallow Sands on Granular Drift - Again, as was the case with granular drift, the topography of this soil area tends to be irregular and is influenced almost entirely by that of the underlying drift. The sands tend to modulate the slopes, but there are occasional dunes providing accents to the topography. The surface is well drained, largely internally, except in the depressions where muck pockets have formed. The depth of the sands varies from ½ to 3 ft.

Figure 15. Airphoto of Scattered Areas of Sands on Plastic Drift. This pattern is predominantly that of plastic drift, but superimposed on it are light sand patches as outlined. It represents an area in southeast Newton County.

and they are underlain by a partially developed granular drift B-type horizon with the gravelly parent material below.

Comparison of Figure 14 with Figure 11 will show how the surface layer of sand has modified the airphoto pattern of the granular drift. There is still an abundance of steep slopes, slightly modified by the sand. The gullies are fairly sharp and inflitration basins are noted. The greatest difference in the patterns is perhaps the contrast in color tones. On the shallow-sand print, the higher areas are much whiter than on the granular drift but there are much blacker tones on the shallow-sand prints for muck pockets are more prone to develop. Scattered areas of wind-blown action may be seen, some of it still active, and native trees cover most of the dunes.

The problems of this soil area, other than that of location because of the rough topography and muck pockets, are not expected to be great. The change in texture is less sharp than for shallow sands on plastic drift with the result that performance, even in deep cuts, will not ordinarily be bad. The soil provides good subgrade support, except possibly in regions of high ground water where there may be appreciable softening of flexible pavements. Sufficient granular material is available for fill as needed. Problems of compaction and erosion, as discussed for sand dunes and ridges, have some application in the shallow sand areas too.

Scattered Areas of Sands on Drift - These soil areas were separated and mapped not because of their importance but because of the danger of including them as sand areas if they were not pointed out. The characteristics vary from those of the underlying drift, whether it is plastic or granular, to those of deep sands. The drift predominates, but it may be covered with sand in scattered areas. These sands will vary from thin smears of wind-blown sand only a few inches deep to wind-blown deposits in dune form, the latter sometimes being many feet deep. There may also be areas of water-laid sands which were deposited along shores of small former lakes. As with most sand surfaces, the topsoil development is limited, particularly on the slopes. The topography is basically that of the drift, undulating for plastic drift and comparatively rough for granular drift, with occasional modifications where the sand has caused rounding of the slopes or where wind-formed dunes have punctuated the high points of the topography.

Airphoto patterns of this type are illustrated by Figures 15 and 16. In the plastic drift areas, the features of the plastic drift pattern predominate. The slopes are smoothly rounded, sometimes accentuated by dune formation. The patchy light and dark color tones are occasionally punctuated by a lighter area indicating a sand deposit. Phantom drainage and ditching are prominent. Color tones of the pattern in the granular drift area will not be greatly changed by the scattered areas of sand since the drift pattern was fairly light due to the well drained nature of the soil. However, the scattered areas of sand may introduce occasional lighter spots. The amount of modification of the pattern is an indication of the depth of the overlying sand; if the pattern is but little modified, there is very little cover; if the pattern is greatly modified, the influence of the sand is evidently stronger. Slopes will be steep and freshly eroded with V-shaped gullies with occasionally a wind-swept appearance to the modifications.

Soils in these regions should receive essentially the same consideration as those in the surrounding drift areas. It is important that they not be treated generally as sand areas, particularly in the plastic drift region for the soil type is little better than that of the underlying drift and has the further disadvantage of an additional change in texture.

Associated Muck, Peat, and Flood Plains - Alluvial areas have been subjected to flooding during comparatively recent times and may currently be liable to flood. They are made up of a series of waterlaid deposits which may vary appreciably in texture. They form an area of possible shifting stream channel as evidenced by oxbows, old current marking, meanders, and other like markings (Fig. 17). The soils are predominantly granular but may be found with plastic layers. The characteristic markings make airphoto identification easy. Color tones are usually dark gray, even when not covered by heavy vegetation, because of the depth of the organic matter in the upper horizons. There will frequently be a sharp drop from the upland to the alluvium, and short gullies may occasionally be found cutting down through the wall.

Muck and peat deposits are particularly numerous in the areas of sand dunes and ridges and in the other predominantly granular soil areas and consequently it is appropriate to discuss them in connection with the sand with which they so often occur in conjunction. The deposits may vary from shallow to great depths and may be underlain by sands, gravels, marl, silts, clays, or combinations. The nature of oc-

Figure 16. Airphoto of Scattered Areas of Sands on Granular Drift. This photo is representative of a large portion of western Fulton County. It has many of the characteristics of the granular drift pattern but is modified with many smoothly rounded slopes of windswept appearance. Color tones are light and gray except for the muck pockets.

Figure 17. Airphoto of Alluvial Soil Area. This photo shows the alluvial area along the Tippecanoe River in northwest Fulton County. Current scars may be seen as slight variations in the color tone.

curence of the areas is such that their drainage will be very poor unless they have been thoroughly ditched. The heavy black areas are so evident on the airphoto as hardly to require pointing out, the interpretation may rather be one of degree of development. Figures 18 and 19 are illustrative of these areas.

The highway problem is usually one of carrying the highway across the area because it cannot be avoided. Alluvial areas are generally found parallel to streams, so it is as necessary to cross them as it is to cross streams. A high, level grade is usually indicated in both cases; across alluvium because of projecting the grade line from the level in the upland to the level of the bridge crossing (and to stay above flood level) and in muck and peat areas because fill is usually required for foundation support. The matter of foundation support is not likely to be serious in alluvial areas because of their frequently granular texture. The totally inadequate supporting power of muck and peat soils acting as a subgrade under a pavement is so well known as not to require any consideration. Rather, in construction across these beds it is a problem of designing and constructing a fill which will carry the pavement without settlement. The problem resolves into either removing the questionable material and backfilling with a granular material or speeding the consolidation of the muck and peat so that detrimental settlement will not occur after the pavement has been laid. The failure to accomplish this end is attested to by obvious settlements across muck and peat areas. These problems are currently being studied by a committee of the Highway Research Board.

SUMMARY AND CONCLUSIONS

The basic techniques of interpretation of aerial photographs for engineering soil characteristics have been applied to an extensive and glacially complex areaof northwest Indiana. Working from techniques of interpretation of airphoto patterns previously established, using field trips to aid in classifying areas in which the airphoto pattern was complex, and applying

TABLE I

SUMMARY OF AIRPHOTO AND HIGHWAY ENGINEERING CHARACTERISTICS OF SOIL AREAS

SOIL AREA	CHARACTERISTICS	AIRPHOTO PATTERNS	HIGHWAY PROBLEMS	CORRECTION
Large Flat Areas of Sands	Very Flat over large areas Occasional dunes Granular Textures Artificial drainage Uniform grain size in surface sands	Very flat Uniform light gray color tones No natural surface drainage Ditching Oak trees on dunes	Faulting Depressions	Fill across depressions Elevated grade Ditching
Sand dunes and Ridges	Topographically irregular Dunes and ridges Uniform grain size Muck Pockets	Dunes and ridges Blowouts No surface run-off Ditching Irregular field pattern	Muck Pockets Slope erosion Faulting	Grass or sod for slope protection Fill across muck
Sandy Outwash	Flat to rolling Little surface drainage Sandy materials	Gently rolling to flat More uniform light gray color tones No gullies Some ditches Faint infiltration basins	High water table Faulting	Ditching Elevated grade
Sands and Gravels	Sand topsoil Layers of gravels and sands Rolling topography Well-drained internally Muck channels	Rolling Few gullies Pitted appearance Current scars Infiltration basins Muck channels Short gullies	Muck channels Faulting	Good construction practices
Plastic Drift	Flat to gently rolling Impermeable Plastic to semi-plastic	Smoothly-rounded slopes Intense erosion absent Patchy light and dark merging areas Phantom drainage Rectangular field pattern	Very poor subgrade in cuts Drainage Pumping Frost heaves	Blanket layers Elevated grade Granular bases Deep gutters or subdrainage in cuts
Semi-Plastic Drift	Less regular topography More granular soil	More irregular slopes Some eroded slopes Sharper color tone changes Phantom drainage More infiltration basins	Poor subgrade in cuts Drainage Frost action	Elevated grade Blanket layers Deep gutters or subdrainage in cuts
Granular Drift	Often morainic Granular parent soil Steep slopes Muck areas	Steep slopes Freshly-eroded slopes V-shaped gullies Light color tones Muck pockets	Location Erosion of cut and embankment slopes Fill across muck areas	Slope protection Gutters in cuts Good muck construction
Sands (3 to 5 feet deep) on Drift	Variety of underlying material Sands are one-sized Some features of underlying material Dunes	Smooth slopes Some dunes, covered with trees Light and gray color tones in drift-like pattern Phantom drainage	Poor subgrade in deepest cuts Drainage at soil boundaries Faulting	Blanket layers Intercepting drainage
Shallow Sands on Plastic Drifts	Drained surface Impervious below Occasional dunes	Plastic drift pattern underlying Light color on rises Gray color in depressions Phantom drainage	Poor subgrade in cuts Drainage Frost heaves	Blanket layers Elevated grade Intercepting drainage
Shallow Sands on Granular Drift	Irregular topography Muck pockets Occasional dunes Well-drained	Sand pattern over granular drift pattern Infiltration basins Muck pockets	Location for cut and fill and to avoid muck pockets Fill across muck Slope erosion	Slope protection Good embankment procedures Special muck construction
Scattered Areas of Sand on Plastic Drift	Like plastic drift with some dunes and thin smears of sand	Plastic drift patterns with light-colored patches	Same as plastic drift	Same as plastic drift
Scattered Areas of Sand on Granular Drift	Like granular drift with scattered dunes and thin surface smears of sand	Granular drift patterns with light-colored patches	Same as granular drift	Same as granular drift
Muck and Peat	Heterogeneous subsurface materials Low lying Low density	Unconformities Sharp boundaries Black to dark gray color tones	Support Drainage Settlement	Elevated grade Special methods of construction
Recent Flood Plains	Water-laid deposits Meanders Marsh	Low areas Adjacent to stream Dark gray color tones Much vegetation Current scars, Oxbows	Flooding Settlement	Elevated grade Improved embankment design and compaction methods

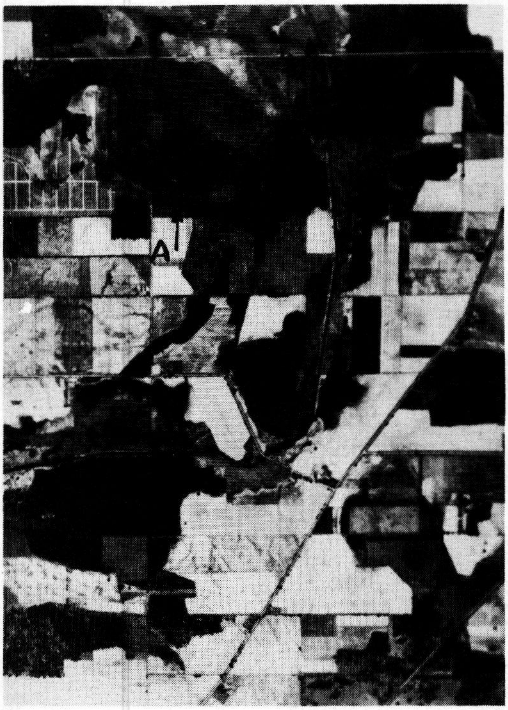

Figure 18. Airphoto Showing Stages of Muck Development. This picture was taken near the outwash-sand border in southeast Laporte County. The black spot in the upper left corner of the picture is a portion of a lake which at one time spread over a much larger area. The black spot at "A" is a marsh which has developed in the bed of the former lake. The area surrounding the marsh is enough higher that mucky soils are developing there.

Figure 19. Airphoto of Muck Channel Along Kankakee River. This is the narrowest constriction of the Kankakee basin and the walls, particularly on the right, are quite distinct. The outwash to the right furnishes some of the best gravel in Indiana. That to the left of the channel is more sandy. Muck and peat deposits here are many feet deep, causing the uniform flat gray color tone.

knowledge of soils engineering and of geological and pedological developments in the area, all or portions of 12 counties were mapped.

It was found that the comparatively complex airphoto patterns of soils in glaciated regions can be interpreted, with confidence, to predict the salient characteristics of the soils photographed. The method is essentially one of adding to knowledge already gained about some patterns and, by a reasoning process, determining how those patterns would be changed if the ground they represented were covered by some other soil material. For instance, the pattern of shallow sands on plastic drift shows evidences of the airphoto patterns of both materials, but the combination is a new one.

Results from extensive pavement performance surveys make it possible, after the soils of a given area have been identified from the airphotos, to predict the type of highway performance to be expected in that area or to outline the general features to be considered in the design of new construction. Table 1 is submitted as a summary of the characteristics of the various soil areas discussed in this report.

It may be concluded from the study that:

(1) Mapping of glacial deposits and reworked glacial materials of Wisconsin glacial origin can be done in considerable detail where accompanying field investigations can be made.

(2) Complex patterns, or patterns of combinations of surface soil conditions can usually be identified as combinations of the components of the constituent prints. This lends support to the belief that similar methods can be applied to many other types of areas.

(3) From a knowledge of highway problems in different types of soil areas and from the ability to identify these soil areas on the airphotos, it is possible to predict the type of highway problems to be encountered in a given area by studying the aerial photographs.

(4) On the basis of observations made, plastic drift, shallow sands on plastic drift, and scattered areas of sand on plastic drift along with muck and peat may be grouped as the soils studied on which the poorest performance is to be expected. Grouped as soils contributing most to good pavement performance are sands and gravels, sandy outwash, large flat areas of sands (if well drained), and areas of sand dunes and ridges (excluding muck pockets).

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BIBLIOGRAPHY

1. Belcher, Donald J, The Engineering Significance of Soil Patterns; *Proceedings*, Twenty-third Annual Meeting Highway Research Board.

2. Frost, R. E. and Mollard, J. D.; New Glacial Features Identified by Airphotos in Soil Mapping Program; *Proceedings*, Twenty-sixth Annual Meeting Highway Research Board.

3. Woods, K. B. and Gregg, Lowell E,; Pavement Performance Related to Soil Texture and Compaction; *Proceedings*, Twenty-fourth Annual Meeting Highway Research Board.

4. Sweet, Harold S. and Woods, K. B.; Map Cracking in Concrete Pavements as Influenced by Soil Texture; *Proceedings*, Twenty-sixth Annual Meeting Highway Research Board.

5. Stevens, J. C., Maner, A. W., and Shelburne, T. E.; Pavement Performance Correlated with Soil Areas; *Proceedings* Twenty-ninth Annual Meeting Highway Research Board.