Application of Color Aerial Photography to Geologic and Engineering Soil Mapping

J. P. MINARD and J. P. OWENS, Geologists, U. S. Geological Survey, Washington, D. C.

Color aerial photographs are helpful to the geologist and soils engineer in mapping a part of the Atlantic Coastal Plain in New Jersey. Color differences can be seen between exposures consisting almost entirely of light-gray to yellow-brown quartz sand and exposures consisting largely of quartz sand but containing 5 to 15 percent of green glauconite. Color differences also are apparent among formations containing different amounts or kinds of clay, and between weathered and unweathered parts of the same formation or soil. The ability to distinguish on color aerial photographs among soils of different composition, texture, and degree of weathering is a significant advantage to the soils engineer.

● VERTICAL aerial color transparencies were used to aid in the geologic mapping of the Pemberton 7½-min quadrangle. This quadrangle, an area of about 57 sq mi, is in the Atlantic Coastal Plain physiographic province about 15 mi south of Trenton, New Jersey (Fig. 1).

Rocks similar in texture, composition, and age to the consolidated sedimentary rocks of Late Cretaceous and Tertiary age in the coastal plain of New Jersey underlie the Atlantic Coastal Plain from Long Island to Virginia. Therefore, although this paper concerns a small area, the recognition criteria, interpretation techniques, and mapping methods can be applied to much of the Atlantic Coastal Plain from Long Island to Virginia.

During the geologic mapping of the Pemberton quadrangle, it was evident that information useful to the soils engineer could be interpreted from the color transparencies. It is this application, largely a broad interpretation of the rocks as they affect the soils engineer, that is discussed here. Holman and others (1) describe an engineering soil survey of the entire State and discuss applications of the resultant engineering soil maps. That survey was made by interpretation of black-and-white aerial photographs in conjunction with field studies and laboratory procedures. Holman and Nikola (2) discuss interpretation methods and criteria applied to black-and-white photographs in a coastal plain area.

As used in this report, the term "soils engineer" means a civil engineer having a background in highway and foundation studies and construction and having a particular knowledge of soil mechanics. Soil, as used by the soils engineer, is the unconsolidated material lying above consolidated bedrock. It thus includes the soils of the pedologist's definition, as well as the unconsolidated material below the soil profile. By this definition, large parts of the formations in the Pemberton quadrangle and in the rest of the Coastal Plain are soils.

The color transparencies used in this study were taken by Aero Service Corp., in late spring 1958 and were made available to the U. S. Geological Survey. Complete coverage of the quadrangle was provided at a scale of 1:17,000, as well as several other flight strips at scales of 1:12,000 and 1:24,000. All film was exposed through a pleogon lens of 6-in. focal length.

GEOLOGY

The Pemberton quadrangle is a sandy coastal plain area of low relief. Several low hills rise 30 to 80 ft above the surrounding land surface. The formations that crop out in the quadrangle are mostly unconsolidated sedimentary rocks of Late Cretaceous and Tertiary age. They are the Mount Laurel sand and Navesink formation, of Late Cretaceous age, and the Hornerstown sand, Vincentown formation, Manasquan formation, Kirkwood formation, and Cohansey sand of Tertiary age. Limestone and iron-oxide-cemented layers locally form resistant beds in parts of some formations. The formations trend northeast, dip 10 to 50 ft per mi southeast, and range in thickness from 20 to 60 ft. Quaternary alluvial deposits as much as 30 ft thick mask much of the outcrop area of the older formations (Fig. 2). These deposits are mostly Pleistocene sands and gravels that were derived largely from the underlying and nearby Cretaceous and Tertiary formations. The sedimentary rocks range in color from dark yellowish-orange (10YR 6/6) to light gray (N 7) and white (N 9), dusky green (5G 3/2) to greenish-black (5GY 2/1), dark greenish-gray (5G 4/1) to light greenish-gray (5GY 8/1), and dusky brown (5YR 2/2) to light brown (5YR 5/6). All color names are from the Rock Color Chart (3). This variety of colors enhances the value of color aerial photographs in the interpretation of the formations and soils.

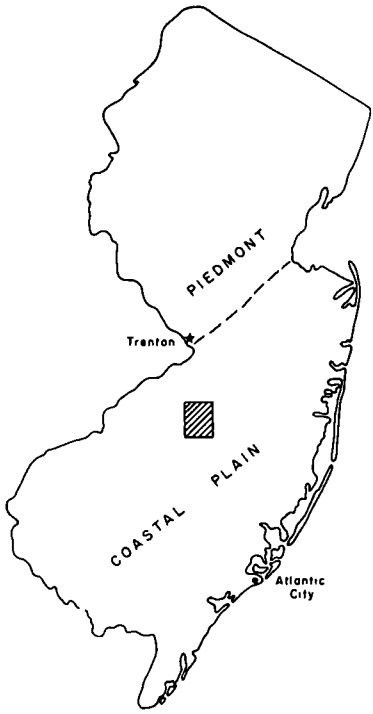

Figure 1. Map of New Jersey showing location of Pemberton $7\frac{1}{2}$-min quadrangle.

MAPPING TECHNIQUES OF THE GEOLOGIST AND SOILS ENGINEER

Geologic and engineering soil mapping in the coastal plain have a common objective, namely, to determine the areal distribution of the different rocks exposed. The use of black-and-white aerial photographs in mapping is well known, but the use of color aerial photographs is still in the initial stages.

The geologist and the soils engineer may approach the mapping differently because of their different requirements. The soil engineer's primary interest is in the surface and near-surface materials, whereas the geologist is interested equally in the surface rocks and their extension underground, and in the subsurface rocks not cropping out. The geologist may group or split his rock units on the basis of composition, texture, or fossil content for the location of ore bodies or aquifers, or for descriptive purposes. The soils engineer, however, may group rocks of several formations into a single classification because of their similar composition, texture, and suitability for a particular purpose. The Mount Laurel sand, the basal part of the Vincentown, and certain Quaternary deposits illustrate this. These rocks, where exposed, are essentially similar quartz sands containing considerable glauconite grains and are almost equally suitable for use as fill or in asphalt mixes. The geologist maps these units individually because they are uniform lithologic units having definite areal distribution, both in outcrop and in places where overlain by other formations and because they are separated by other units of different lithologies and ages. The Quaternary deposits are more variable in their thickness and distribution and are not overlain by other formations; they are present only as surface deposits.

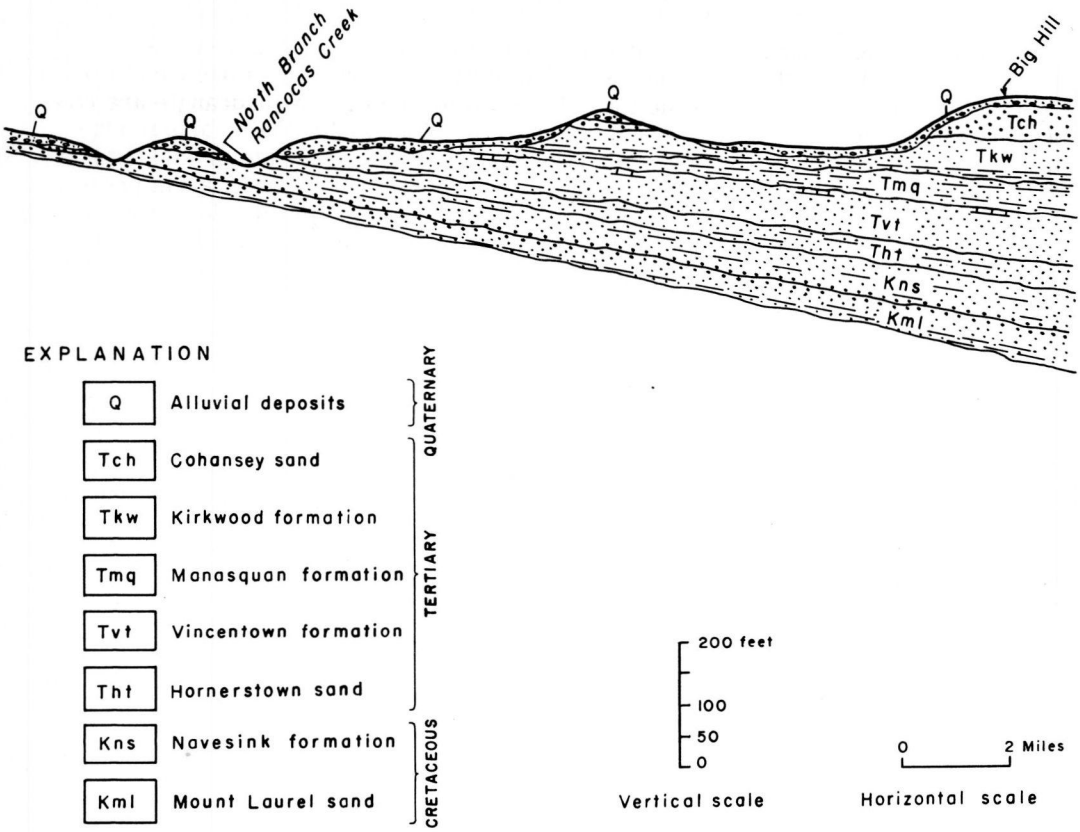

Figure 2. Northwest to southeast cross-section of the Pemberton $7\frac{1}{2}$-min quadrangle. The vertical scale greatly exaggerated (about 30 times the horizontal) to show lithologies, surface configuration, and downdip thickening.

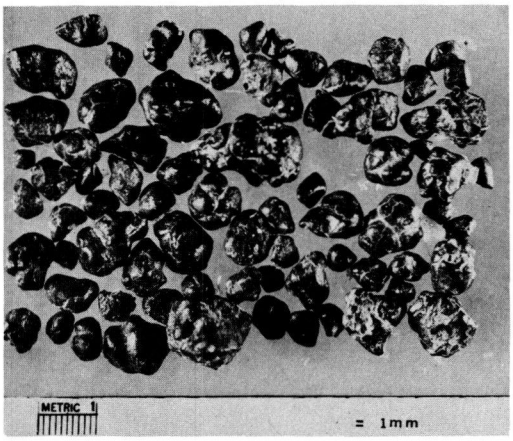

Figure 3. Photomicrograph of rounded glauconite grains showing zones of weakness where smaller grains or fragments are weakly jointed to form larger grains.

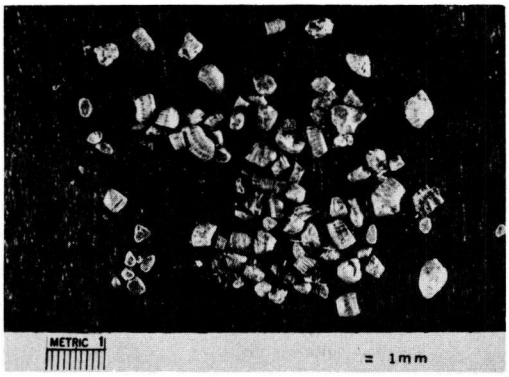

Figure 4. Photomicrograph of elongated grains of glauconite showing cleavage-plane zones of weakness.

USE OF COLOR AERIAL TRANSPARENCIES IN MAPPING

The appearance of any unit on aerial photographs, either black-and-white or color, is largely a function of the constituents of that unit; and if more than one consitutent is present, the ratio of them. All the formations in the Pemberton quadrangle are composed chiefly of either quartz or glauconite sand or both, and contain various clay minerals. Three general types of soil, consisting of these minerals in varying proportions, are present in the quadrangle. Type 1 is mostly quartz sand and is present on the Cohansey sand and the Kirkwood formation and on the Quaternary deposits derived from them. Type 2 consists largely of quartz sand but contains as much as 20 percent glauconite sand. This soil type is present on the Mount Laurel sand and basal part of the Vincentown formation and on the Quaternary deposits derived from older glauconite-bearing formations. Type 3 consists largely of glauconite sand and some clay minerals. This type is present on the Navesink formation, the Hornerstown sand, and the Manasquan formation. These three types and their pertinent physical properties and uses are listed in Table 1.

Large quantities of good quality quartz mortar sand is available in the Cohansey sand, and in Quaternary deposits largely derived from the Cohansey sand (Type 1 soils). It is somewhat difficult to distinguish between the Cohansey and Cohansey-derived sediments in many places. It is important, however, that the geologist do this, largely because of the erratic distribution and thickness of the Quaternary deposits as compared with the Cohansey and because of the "ilmenite" ore bodies in some Quaternary deposits (4). The soils engineer interested in mortar sand or good quality "borrow," however, need not distinguish between the two equally suitable materials.

Some of the Quaternary deposits, most of which are quartz sands, contain as much as 20 percent glauconite (Type 2 soils). Because glauconite contains exchangeable potassium and sodium ions and is soft and structurally weak (Figs 3 and 4), it is not desirable in quantity in mortar or concrete mixes. Soils containing it are used satisfactorily in asphalt mixes.

Quartz sands of the Cohansey sand and Quaternary deposits, and glauconite-bearing quartz sands of the Mount Laurel, Vincentown, and other Quaternary deposits can be identified tentatively on black-and-white aerial photographs by several characteristics: landform (i.e., hills, ridges, slopes, terraces), drainage (i.e., density, gully or bank slope, pattern), and to some extent vegetation. These characteristics, together with differences in tone on black-and-white photographs and color on color transparen-

TABLE 1

ENGINEERING SOIL TYPES, ASSOCIATIONS, AND USES IN THE PEMBERTON QUADRANGLE

Soil Type	Parent Material	Composition and Texture	Agronomic Soil	Present Use	Engineering Use
1	Kirkwood formation, Cohansey sand, Quaternary deposits—largely derived from the Kirkwood and Cohansey formations.	Mostly quartz sand, containing some quartz silt, small pebbles of quartz, sandstone, quartzite, a little chert, clay (kaolinite), and some heavy minerals (mostly an "ilmenite" suite)	Sassafras, Lakewood, St. Johns, Freneau	Wooded, cranberry bogs, huckleberry fields	Mortar sand, concrete aggregate, subgrade, asphalt mix, molding sand
2	Mount Laurel sand, basal part of Vincentown formation, Quaternary deposits—largely derived from older glauconite-bearing formations.	Mostly quartz sand, containing as much as 20 percent glauconite sand and some small pebbles (quartz, quartzite)	Collington, Keansburg, Shrewsbury, Freneau	Good farmland	Asphalt mix, subgrade fill
3	Navesink formation, Hornerstown sand, Manasquan formation	Mostly glauconite sand, containing some quartz sand and considerable clay (kaolinite, glauconite, montmorillonite)	Collington, Keansburg, Shrewsbury, Freneau	Excellent crop land, soil conditioner, base exchange material	Fill

cies are given in Table 2. If the material is to be used as ordinary fill or in asphalt mix, no further division is necessary. If good quality fill or mortar sand is desired, however, a means must be found to differentiate between quartz sand and glauconite-bearing quartz sand. These both appear essentially the same light gray (N 7) to white (N 9) tone on black-and-white aerial photographs, but on color transparencies a distinct color difference between the two is apparent. This is clearly seen on color aerial transparencies of two pits in Pleistocene alluvial sand along the south side of the North Branch Rancocas Creek. The sand in one pit, 1 mi southeast of South Pemberton, appears very light gray (N 8) to white (N 9) on the color transparencies (Figs. 5 and 6). The sand in this pit, derived from the Cohansey and Kirkwood formations, is nearly all quartz. The sand in a second pit, 1 mi west of South Pem-

TABLE 2

CHARACTERISTIC APPEARANCE OF THE DIFFERENT FORMATIONS ON AERIAL PHOTOGRAPHS

Soil Type	Unit	Landform	Drainage	Vegetation	Tone (Black-and-White Photographs)	Color (Color Photographs)
1	Quaternary deposits	Stream terraces, flood plains, hilltop remnants	Good internal, few gullies, wide spaced, random pattern	Mostly wooded sparse deciduous trees and scattered pines, some sparse grasses	Circular and oval mottled pattern, white (N 9) where exposed	Light brownish-gray (5YR 6/1), very light gray (N 8) to white (N 9) where exposed
1	Cohansey sand	Hills and ridges	Good internal, few gullies, wide spaced, somewhat rectangular	Mostly wooded sparse deciduous trees, some pines and brush	Uniform medium light gray (N 6) to light gray (N 7), very light gray (N 8) to white (N 9) where exposed	Yellowish-gray (5Y 7/2 to light brownish-gray (5YR 6/1), grayish-yellow (5Y 8/4) to moderate yellow (5Y 7/6) where exposed
1	Kirkwood formation	Low broad hills, basal hill slopes, lowlands, and swamps	Much swampland, dentritic to somewhat parallel	Mostly wooded sparse deciduous trees, cranberry bogs, blueberry fields, swamp vegetation	Extremely mottled due to high ground water table, very light gray (N 8) to white (N 9) where exposed	Yellowish-gray (5Y 7/2) to light gray (N 7) and brownish-gray (5YR 4/1), very light gray (N 8) to white (N 9) where exposed
2	Quaternary deposits	Stream terraces, flood plains, surficial cover on broad level areas	Good internal, few gullies, wide spaced	Crops, woods	Circular and oval mottled pattern, very light gray (N 8) to white (N 9) where exposed	Pale greenish-yellow (10Y 8/2) to grayish-yellow green (GY 7/2) Moderate greenish-yellow (10Y 7/4) to yellowish-gray (5Y 8/1) where exposed
2	Vincentown formation	Steep stream banks (mostly covered by Alluvium)	Fair internal, moderately spaced, somewhat rectangular	Crops, woods	Fairly uniform, medium gray (N 5) to medium light gray (N 6), basal part very light gray (N 8) where weathered	Yellowish-gray (5Y 8/1) to dusky yellow-green (5GY 5/2) and very light gray (N 8), Light olive gray (5Y 5/2) to grayish-yellow green (5GY 7/2) where exposed
2	Mount Laurel sand	Steep stream banks and slopes	Moderately spaced, dendritic	Crops	Fairly uniform medium gray (N 5)	Light olive gray (5Y 5/2)
3	Manasquan formation	Broad level areas, low slopes along streams	Moderately spaced, dendritic	Crops	Medium light gray (N 6) to medium dark gray (N 4)	Light olive gray (5Y 5/2)
3	Hornerstown sand	Broad level areas, steep stream banks, low hills	Moderately spaced, dendritic	Crops	Fairly uniform medium gray (N 5) to medium light gray (N 6)	Dusky yellow green (5GY 5/2)
3	Navesink formation	Low hills and slopes	Moderately spaced, dendritic	Crops	Medium gray (N 5) to medium light gray (N 6)	Dusky yellow green (5GY 5/2) to grayish-green (5G 5/2)

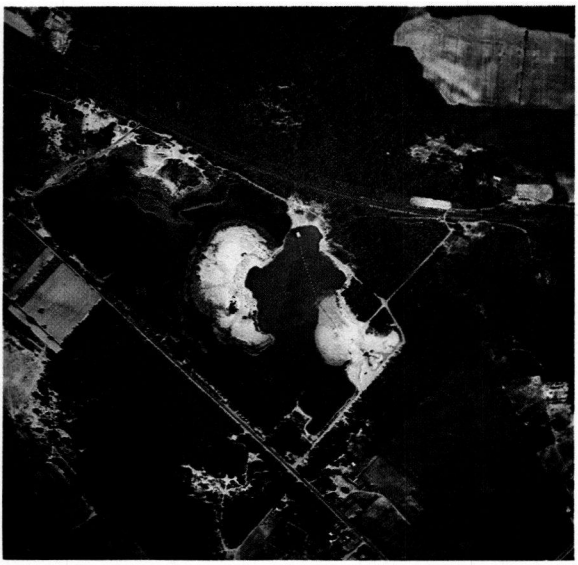

Figure 5. Pit in quartz sand of Quaternary age along south bank of North Branch Rancocas Creek. (From aerial photograph, scale 1:17,000.)

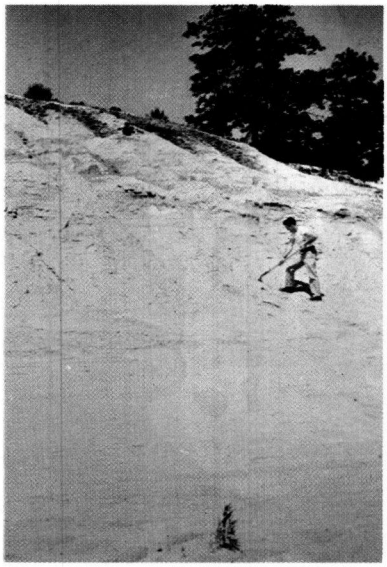

Figure 6. Ground photograph of pit shown in Figure 5 containing quartz sand derived from Kirkwood and Cohansey formations.

Figure 7. Pit in glauconitic quartz sand of Quaternary age derived from Vincentown and Manasquan formations outcropping downstream from pit of Figure 5. (From aerial photograph, scale 1:17,000.)

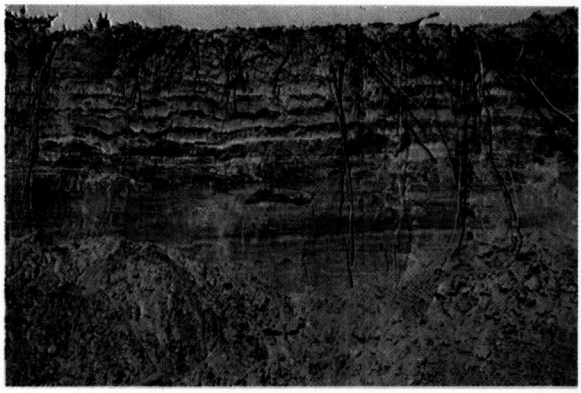

Figure 8. Ground photograph of glauconitic quartz sand pit shown in Figure 7 along south bank of North Branch Rancocas Creek. Note marked stratification, suggesting fluvial nature of this Quaternary deposit.

Figure 9. Area several miles northeast of town of Pemberton containing many pits and construction site excavations in the Cohansey, Kirkwood, and Quaternary materials. Note that in the black and white photograph all of these materials appear to have essentially the same tone; that is, very light gray (N8) to white (N9).

Figure 10. Same area as in Figure 9. In this more recent photograph several more excavations are evident and more detail can be seen. Note brown oxidized sand at bottom center, black organic material in sand at bottom right, white quartz sand at bottom center, and greenish glauconitic quartz sand at left center.

Figure 11. Cohansey sand deposit showing podzol soil profile. The upper 18 to 20 inches consist of a white quartz sand of the eluviated A horizon over a yellow-brown zone of oxidation and accumulation.

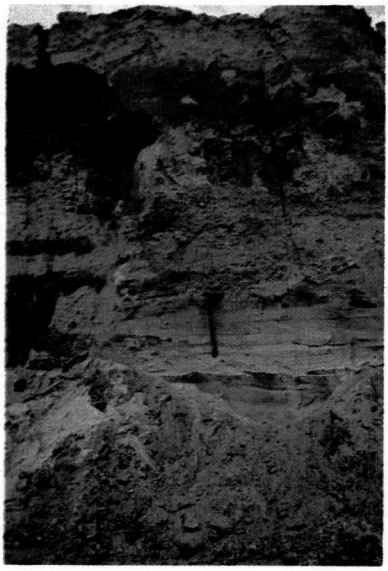

Figure 12. Light-colored Cohansey sand (below shovel blade) overlain by Quaternary alluvial gravelly sand, overlain by greenish-gray Quaternary glauconitic quartz sand. Color of upper exposed material represents only a few feet of material.

Figure 13. Exposure of Hornerstown glauconite sand. Essentially unwetted material at base is dusky green, overlain by progressively browner more silty weathered material, showing profile development.

Figure 14. Exposure of Quaternary alluvial silty gravel and sand such as that on the higher hilltops. Reddish-brown color, the result of oxidation, shows up well on color aerial photography.

berton, or 2 mi downstream from the first pit, appears moderate greenish-yellow (10Y 7/4) to yellowish-gray (5Y 7/2) on the color transparencies (Figs. 7 and 8). The sand in this pit is mostly quartz but contains as much as 20 percent green glauconite that is derived from the Vincentown and Manasquan formations where they crop out upstream from this pit but downstream from the first pit.

Other color differences also are apparent on color aerial transparencies (Figs. 9 and 10). Exposures of eluviated quartz sands in the Vincentown and Kirkwood formations, Cohansey sand, and Quaternary deposits appear very light gray (N 8) to white (N 9) on both black-and-white and color aerial transparencies, whereas exposures of less weathered or only partly oxidized sands of these units appear as different colors on color transparencies. The sands of the Cohansey, for example, appear grayish-yellow (5Y 8/4) to moderate yellow (5Y 7/6); those of the Kirkwood appear yellowish-gray (5Y 7/2) to brownish-gray (5YR 4/1).

In the Pemberton quandrangle the contact between the Manasquan and Kirkwood formations and the contact between the Kirkwood formation and Cohansey sand locally can be distinguished on color aerial photographs. This is important to the soils engineer because (a) the upper part of the Manasquan contains considerable montmorillonite; (b) the basal part of the Kirkwood is largely silt and contains less clay and a different kind (kaolinite) than the Manasquan; and (c) the basal Kirkwood is a zone of ground-water accumulation and movement. The Manasquan may have a lower bearing capacity than the Kirkwood, particularly under dynamic load, because of its high content of glauconite grains and their tendency to crumble under a dynamic load. The presence of montmorillonite in the Manasquan necessitates consideration of its great capacity for absorbing moisture and the resultant possibility of large volume changes. The ability to distinguish between the Kirkwood formation and Cohansey sand, on color photographs, is important also because the latter is, as previously mentioned, a source of good quality mortar sand and concrete aggregate, whereas the Kirkwood is mostly too fine grained for these uses.

Many erratically distributed Quaternary deposits are more easily identified on aerial photographs because their surfaces are indented by numerous nearly circular or ellipsoidal basins or depressions. These basins are postulated to be of periglacial origin (5). Many are more readily apparent on color aerial transparencies than they are on black-and-white photographs. The difference in moisture content and vegetation between the permeable, well-drained sandy rims and the low, often poorly drained, silty and organic-rich centers is more clearly seen as color differences on color aerial transparencies than as tonal differences on black-and-white aerial photographs. Wolfe (5, p. 135) states that these geomorphic features are present in formations of Cretaceous, Tertiary, and Quaternary age in the coastal plain of New Jersey. In the Pemberton area, however, they are present only in Quaternary deposits.

COST, DISADVANTAGES, AND INFLUENCING FACTORS

Although color aerial transparencies are presently more expensive than black-and-white photographs, this fact may not appreciably inhibit their use. Ray (6, p. 35) cites the cost of a linear mile of land surface recorded on color aerial photography at $15 to $40 as compared with $4 to $20 for black and white. Results of present studies show that good quality black-and-white diapositives made from color positives are suitable for use in topographic mapping. The color positives would be available for use in geologic, soil, or agricultural mapping or studies, thereby utilizing one flight for two or more programs or purposes.

To obtain maximum information from the interpretation of color aerial transparencies in areas similar to the Pemberton quadrangle, the photographs should be taken when field planting and cultivating are at a maximum and foliage and grasses at a minimum, either late fall or early spring. Summer foliage obscures stream banks and artificial cuts, and grasses mask the colors of the soils in many cultivated fields. This latter fact is of particular significance in the Pemberton quadrangle, where much of the aerial-photographic interpretation of the formations and the soils is based on the slight green color imparted by the glauconite. Even under optimum photographic conditions, interpretation may be difficult because the soil profile masks the color of

the parent material (Figs. 11-14). Fortunately the persistence of some of the color, the shallowness of some of the profiles, and the numerous cuts help counteract this factor.

Color transparencies appear to be the best medium because the colors are most faithfully reproduced on them. However, it may be that by using different film and filter combinations, colors may be selectively emphasized, thereby making possible quicker identification of specific soils or formations. A disadvantage of color transparencies is that they must be used in transparent envelopes on an illuminated or light-reflecting surface and cannot be annotated directly. It would be helpful if an easy method were developed for accurately transferring annotations from the envelopes to a base map.

Flying height of the aircraft from which the photographs are taken is another factor to consider. Color photographs of the Pemberton quadrangle, taken from a height of 6,000 and 8,500 ft, recorded the colors nearly as they would appear to the eye, whereas those taken from 12,000 ft have a bluish-gray haze (7, p. 115).

REFERENCES

1. Holman, W.W., MacCormack, R.K., Minard, J.P., and Jumikis, A.R., "Practical Applications of Engineering Soil Maps." Engineering Soil Survey of New Jersey Report 22, Rutgers Univer. Press (1957).
2. Homan, W.W., and Nikola, H.C., "Airphoto Interpretation of Coastal Plain Areas." HRB Bull. 83, p. 40-57 (1953).
3. Goddard, E.N., and others, "Rock Color Chart." Geol. Soc. America (1951).
4. Owens, J.P., Minard, J.P., Wiesnet, D.R., and Markewicz, F.J., "Concentrations of Ilmenite in the Miocene and Post-Miocene Formations near Trenton, New Jersey." U.S. Geol. Survey Prof. Paper 400 B., p. B57-B59 (1960).
5. Wolfe, P.E., "Periglacial Frost-Thaw Basins in New Jersey." Jour. Geology, 61: 133-141 (1953).
6. Ray, R.G., "Color Aerial Photography." Western Miner and Oil Review, 31: 35-37 (1958).
7. Minard, J.P., "Color Aerial Photographs Facilitate Geologic Mapping on the Atlantic Coastal Plain of New Jersey." Photogrammetric Engineering, 26: 112-116 (1960).