Identifying Landforms and Soils by Aerial Photographs*

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In the process of analyzing aerial photographs to obtain information on the engineering characteristics of soils, the first and perhaps the most important step is to identify the landform. The landform may consist of hills, valleys, plains, terraces, beaches, dunes, and other topographic features largely created by the forces of erosion. The importance of the landform lies in its relation to the soil that has been produced by the weathering action that has played a part in shaping the features of the terrain.

Within a given area there usually will be found two types of landform: destructional and constructional. The hills of high ground are being worn down by erosion, while the flood plains of streams are built up by deposition of the material eroded from the upland. For the best results from photo-interpretation, particularly in areas where the interpreter's experience is limited, sufficient photo-coverage should be available to include both constructional and destructional features. This is especially true where the survey is expected to include the location of gravel and sand deposits, since they are most often found within areas of constructional landforms.

The landform is the key to the type of parent material, and the parent is the key to the general physical properties of the soil. Therefore, it is important first to identify correctly the landform. In doing this, the angle of repose of weathering slopes is highly significant. Without going into details, most observers will credit the more resistant materials with an ability to maintain steep slopes, while the less weather-resistant materials assume "soft" slopes. Consequently, when an area of very gentle slopes is examined, we can tentatively assume an easily

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* This paper contains most of the material in a thesis entitled "The Determination of Engineering Soil Characteristics by the Use of Aerial Photographs," by Donald J. Belcher, which was submitted to the faculty of Purdue University in fulfillment of the requirements for the degree of Civil Engineer, March, 1943.

weathered material. The form or shape of hills may also be a valuable index. The differential weathering of tilted sandstones, limestones, and shales produces a series of parallel hills with each material assuming a characteristic slope but differing from the others. Sand dunes, loess hills, morainic hills, hills of igneous rock, and other parent materials owe their form and slope to their mode of origin and their relative resistance to weathering.

If the landform owes its shape to the mode of origin, then the slopes will also be a function of the types of weathering as well as the texture and weather resistance of the material. Since these landforms exist in many climates, some consideration of climatic influence is in order.

By an identification of the type of parent material from the landform, the climate from vegetation and related features, the process of applying pedologic principles will outline the physical properties to be expected. These are then to be checked by observations of the other elements of the soil pattern outlined in the section under analysis.

Climate and parent material are considered as two of the principal factors in soil formation. For pedological classification they provide an established basis; for engineering soil classification based on the same principles of formation a careful examination of these two factors is necessary to evaluate their significance. Since the information available is mainly of a pedologic nature its significance to engineers is worth appraisal.

In considering the information that is available, it is necessary to examine and evaluate the various sources and to use them in their proper place. Since the work of the pedologists has formed the basis of the methods used heretofore, it is only natural to investigate the pedological field for general and specific information on soils.

Climate

Examining the more general of the two: First, the existing pedological (Russian) method of classifying the great soil groups does not meet the over-all requirements of engineering soil identification. The Russian system of classification is based upon the influence of climate upon the development of soils. We have the word of the masters that climate is of primary importance in soil formation and that all other influences are minimized in mature profiles. That is to say that within a climatic zone, mature soils are sufficiently similar to be classed as a group. Pedologically, this may be satisfactory, although it appears to lean toward the agronomic field of interest. Evidence shows that the adequacy of the classification remains in doubt even within the pedological group.

Extremes of climate have a profound influence on the development of soil. Through the means of temperature changes and precipitation, physical and chemical weathering occur. These actions break down the parent material and form the soil profile, and it is these actions that contribute to the transient and final properties found in the profile that create the soil (engineering) problems. The condition of under- or over-emphasis of either of these agencies of weathering is reflected in the profile in direct proportion to its intensity or absence.

A hypothetical case for examination may be offered in which an absence of either precipitation or temperature change would result in insignificant products of weathering. In contrast, the maximum of rainfall with high temperature produces excessive weathering (including biological). Under these conditions, leaching of soluble material and mechanical displacement of colloids progress rapidly with resulting laterization. The condition of minimum rainfall and extreme temperature range produces a preponderant physical weathering resulting in a more or less mechanical breakdown of the parent material.

In dealing with pedological association, the term "mature profile" is often used. This is a soil profile developed under the same climatic conditions for a long period of time, possessing well-developed characteristics (horizons, etc.), and being in equilibrium with the local environment. Many soils within a climatic zone are not mature, and therefore fall outside the generalizations made concerning the soils identified with certain climatic conditions.

In the category of soils without normal profiles it has been found that the general climatic classification does not apply. Locally we find that at least one-half of Indiana's and two-thirds of Ohio's soils do not have normally developed profiles and therefore fall outside even the very general classifications. A rough estimate indicates that approximately one-half of the United States has soil profiles that are not considered normal.

Since this is the situation, it is necessary to examine and to accept or discard the usable features of the Great Soil Group method of classification proposed by the Russians. To this end it now appears that the Lateritic Group may be used satisfactorily. In hot tropical climates with high rainfall, mature soils are completely laterized and therefore bear little relation to the parent rock. In arid climates the soils (residual) have textures directly related to the parent. In between these there are gradations depending upon the climate, but at present it appears that for engineering purposes residual soils can be considered in three climatic zones: arid, humid, and wet; the humid including the sub-humid and the arid including the semi-arid.

Parent Material

I quote from Robinson's[1] summary the following specific examples of conflicting evidence in relation to climatic classification:

> It is obvious, therefore, that a classification of climates without reference to geology can only give a partial classification, even of the major soil groups.
>
> In the more detailed classification of soils of a limited region, geology is frequently the main guide . . . In Southeastern England, typical podzols are developed on light sands and gravels . . . Under the same climate, other parent materials yield brown earths and even soils which may have affinities with terra rossa.

Bryan and Hines report that within a comparatively small area of Queensland having approximately a uniform climate, "soils comparable with chernosems, podzols, red earths, yellow earths, and laterites of other countries are to be found. This diversity can be satisfactorily explained by considerations of parent material and topographical relief."

The parent materials from which soils occur may become numerous according to the degree of refinement used in classification. This, of course, is a reflection of the use to which the identification is put. In engineering soil work the separations can be made quite general. Actually, in some climates the distinctions can be very broad and inclusive. For instance, in some areas of wet tropical climates, soils may all be highly weathered with laterization resulting to a more or less advanced degree. In such an area, serpentine and limestone might be classed as one, since the resultant soils from these two parent materials (and other rocks of divergent nature) have like engineering properties. In other less severe climates a distinction must be made.

In general, the major parent materials may be classed as:

Residual

- Igneous
- Metamorphic
- Sedimentary

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[1] Robinson, G. W.—*Soils—Their Origin, Constitution, and Classification,* Thos. Murby & Co., London, 1936, p. 358.

Transported

Glacial Drift
Loess (Windblown Silt)
Water-laid Silts, Clays, and Sands (Marine and Glacial)
Alluvial Materials (River)
Sand (Aeolian)
Accumulations (Alluvial Fans, etc.)

In detail these include:

Igneous: Granite, syenite, felsite, gabbro, diorite, diabase, basalt, and porphyries.

Sedimentary: Sandstone, conglomerates, shales, limestone, dolomites, marl, and chalk.

Metamorphic: Gneiss, schists, slates, and quartzite.

For the purposes of soil studies[2] these rocks may be regrouped into five groups: acidic or granitic; basic or ferromagnesian; siliceous; clay; and calcareous rocks.

Acidic rocks are igneous or metamorphic and include: granite, a light-colored, coarse-grained rock composed of quartz, feldspar, and mica with some apatite and hornblend; syenite, similar to granite but lacking quartz; felsites, fine-textured granite or syenite. Granitic porphyry, also acidic, is fine-grained granite mottled with coarse grains of quartz or feldspar and gneiss, a metamorphosed granite containing mica.

The rate of weathering of these rocks depends upon the climate and the texture of the rock. In general, the soils produced by the weathering of granite, gneiss, and syenite are of a sandy texture and are formed rather rapidly. These rocks are more resistant to weathering in humid than in arid climates. Daily extremes of temperatures common to arid regions are reported to be more severe than the action of water in the humid and wet regions. The finer-textured felsitic granite and porphyry weather at a slower rate and produce a soil having a correspondingly fine texture. Gneiss soils are sandy in texture and, because of the mica fraction, present a special problem of subgrade support where compaction is involved.

Basic rocks are also of igneous and metamorphic origin but have a high content of hornblend and pyroxene (iron and magnesium). They include diorite, a dark-colored rock of fine texture containing hornblends, plagioclase, quartz, and other minor minerals; gabbro, a very

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2 Wilde, S. A.—"Forest Soils", Mimeog. by the Kramer Business Service, Inc., Madison, Wis.

dark, coarse-grained rock similar to diorite; diabase, a greenish rock similar to diorite; basalt, a fine-grained gabbro; and schists.

These basic rocks weather relatively fast and result in deep soils of fine texture. Diorite weathers more slowly and is characterized by coarse-grained (gravel), shallow soils. Schists produce sandy soils with a high mica content.

Siliceous rocks are both metamorphic and sedimentary and contain large proportions of quartz. As the name implies, sandstone is principally quartz cemented with silica, lime, iron, kaolin, or clay. The properties and cementing power of these materials have a marked effect on the rate at which the rock weathers as well as the resulting functional texture.* Conglomerates are cemented gravels yielding gravelly soils at a rate that depends upon the cementing medium. Quartzite is very weather resistant and yields shallow sandy soils.

Clay rocks include shales (sedimentary) and slates (metamorphic). The principal constituent of these rocks is kaolin. Shales high in quartz yield sandy soils, and those low in quartz, deep, fine-textured clays. Slate soils are usually shallow and are coarse-grained.

Calcareous rocks include the limestones and related rock. These are the pure limestone, magnesium limestone, cherty limestone, chalk, and marl. In humid and wet climates pure limestone weathers rapidly to form deep silty clay or clay soils. In arid climates it is most resistant. Cherty limestone produces a somewhat sandier soil, depending largely upon the proportion of impurities. Chalk in most climates weathers rapidly to produce porous soils.

Since glacial drift varies with the source from which it was transported, nothing can be said, except in general terms, regarding the soils of glaciated regions. Within Indiana alone there occurs a range in drift texture from silty clay to sand. And in addition, the age of the drift produces soil characteristics that are at variance with drift soils of another age. Large areas of North America, England, Europe, and Asia have glacial drift as parent material and possess the various formations typical of drift areas.

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* The term *functional texture* has been coined for this work inasmuch as texture in a broad sense does not always control the engineering properties of the soil; i.e., the highly permeable, non-plastic laterized clays of the tropics contain approximately 80 percent of colloidal particles. In contrast, sandy clays are often quite plastic and rather impermeable. Likewise, limestone (residual) soils, although high in clay content, have developed a soil structure that renders them permeable in an undisturbed state. This net effect of the soil profile contributes to the surface drainage pattern apparent in airphotos.

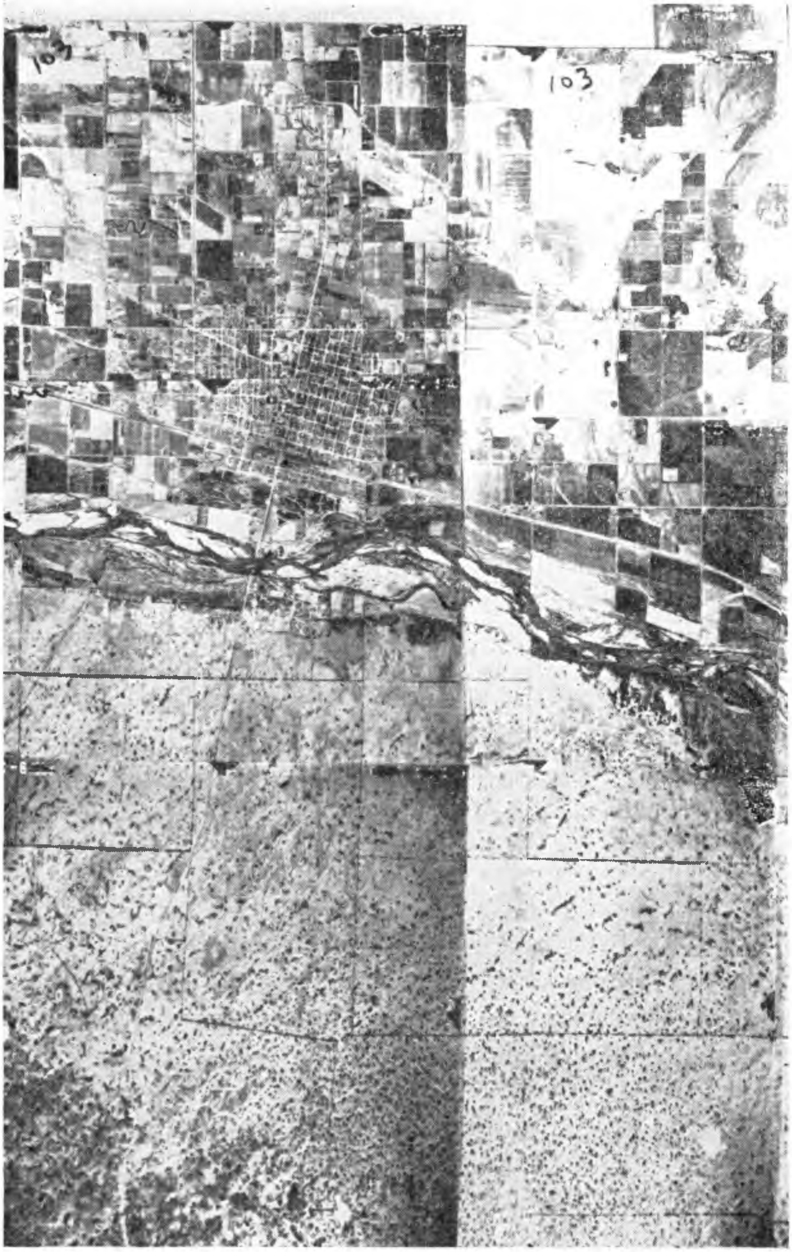

Fig. 1. An uncorrected mosaic showing an area of sand dunes (left) bordering a stream and an area of alluvial soils. Note the barrenness of the sand hills compared with the cultivated and irrigated terrace area. Black spots in sand area are inter-dune depressions.

Loess as a parent material has distinct properties that make it unusual in soil engineering work. Its occurrence in many countries and its characteristic forms create regional soil problems as much as any other single parent material. In the United States the main loess areas are found in association with the Mississippi River and its main tributaries, and also in the Palouse area of Washington. Well-drained in its natural state, loess presents problems in compaction, erosion, and stability when used in highway or runway construction. Its uniform contour and susceptibility to erosion make it easily identified in aerial photographs.

Coastal plains materials, lacustrine, and similar deposits occupy appreciable areas of all regions. Because of their method of deposition, they are often of fine texture. Drainage is usually unfavorable, and when associated with silty clay or clay texture these soil areas are often expensive sites for airport location. Fortunately in most areas beach lines or similar sand and gravel formations are found in association.

Alluvial materials include the more or less recent deposits of existing drainage systems. They, too, bear a direct relation to the materials of the area from which they have been washed. Within each drainage system the process of selective deposition produces clay textures as well as more granular texture in soils. The separation of these often can be made on photographs on the basis of color and drainage pattern.

Windblown sand is perhaps the most distinct type of deposit. According to the local conditions, dunes of different shapes will form. However, in each instance the lack of surface drainage, uniformity of relief, and the streamlined shape of the dunes make them outstanding. (See Fig. 1.)

Accumulations of the desert and Great Plains areas are somewhat similar to the Coastal Plains. They consist of eroded materials from mountainous areas and therefore are influenced by the texture of the original rock. As a product of erosion they, too, are assorted and stratified into a wide range of textural variations. These deposits are usually associated with an arid or semi-arid climate.

To show the tendency of weathering on soils in various climates, a tabular record of numerous soil reports has been prepared. This also forms the nucleus of proof that climatic classification is not satisfactory for engineering purposes.

An examination of Table I strongly indicates the tendency of level and depression soils to be of a poorly drained, plastic, clay nature regardless of the parent material and climatic influences. Exceptions are noted in sand areas where the texture remains sandy, although some appreciable degree of plasticity may be found because of the presence of organic material in the surface horizons. In humid and wet climates the position and ground-water condition appear to contribute to the development of this texture and consistency, while in arid climates much of the soil in this topographic class is transported by erosion from the high ground. And because of its texture, the clay is transported the greater distance to the level or slightly depressed positions. In areas where the climatic conditions prevent the formation of organic material, the coarse soils in depressions are usually identified by changes in the type of cover.

The following series of photographs illustrates the pattern of some of the parent materials, as they exist in various regions and under various climatic conditions.

The Analysis of Aerial Photographs

On the basis of the foregoing discussion, it can be seen that pedology can be applied to the problems of location, design, and construction of highways and runways, and that aerial photographs can be used directly as a means of interpreting soil conditions. Where airphotos are used as a basis for mapping soils, the resulting detail will be somewhat dependent upon the other information available to the engineer.

In the examination of aerial photographs of areas, the background of knowledge concerning the area under study is of great importance in evaluating the factors observed in the photograph. As has been stated previously, the more that is known concerning the soils of an area the greater the detail that can be incorporated in the conclusons drawn from an examination of the photographs.

Since the greater part of this work has been concerned with the soil problems of familiar areas, some attention should be given to the situation in which little is known concerning the soil. For that purpose a method of procedure is offered. Based on a minimum of external material, it attempts to organize and evaluate the various observable factors that are present in aerial photographs. Obviously a full treatment of each cannot be attempted in this work, but a sufficient amount can be presented to illustrate the method. Table II shows the form of an analysis sheet.

TABLE I

SUMMARY OF PARENT MATERIALS, CLIMATE, AND RESULTING SOIL PROPERTIES

Geological Material	Mode of Formation	Type of Relief	Drainage	Color	Texture	Consistency	Series	Country	Climate	Reference No.
Sandstone and Shale	—	L-D	P	GB	H	Compact	Crotin	New Jersey	Humid	
	—	L-D	G-EX	R	H	Compact	Crotin	New Jersey	Humid	9
Sandstone (Triassic)	R	L-R	G	—	S	Non pl.		Palestine	Arid	3
						Friable	Granville	No. Car.	45-60°	
					Sc			Va.		
Limestone (Karst)	—	R	—	R	mH	Plastic	—	Tanganyika		4
Limestone (Karst)	—	R	—	R	mH	Plastic	—	Zanzibar		4
Limestone (Hard)	R	st.-D G(Sur.) (perm.)		R-Y	C	—	Tanama	Puer. Rico		5
Limestone (Soft)	R	R G(Sur.)		dG-Br	C	Friable	Colinas	Puer. Rico		5
Limestone (Soft)	R	sl F		G-Br	C	Plastic	Santa Clara	Puer. Rico	Humid	5
Limestone (Soft)	R	L-gSl F(Dit.)		Bl	Sic	Waxy-plastic	Camaguey	Cuba Haiti	65-100"	6
Limestone	R C	L-gR G Perm.		G-Br	C	Sl. Pl.	Matanzas	Cuba Haiti		6
Limestone	R C	L-gR G Perm.		G-Br	C	Sl. Pl.	Bayamon	Cuba Haiti	180 cm.	5
Limestone	R	L-gR	G Perm.	G-Br	C	Sl. Pl.	Coto	Cuba Haiti	45-60"	5
Limestone	R C	L	vG	R (T.R.)	C	Non-pl.	Ensenada	Cuba Haiti	29"77°F	5
Limestone (Hard)	R C	—	—	R	C	Plastic	—	Palestine		7

TABLE 1—Continued

Geological Material	Mode of Forma-tion	Type of Relief	Drainage	Color	Texture	Consistency	Series	Country	Climate	Reference No.
Limestone	R	L-R	G	R	C	Plastic	Decatur	Ala. & Tenn.		8
Limestone (Cherty)	R	L-R	G	R	C	Medium	Dewey	Ala., Tenn., Georgia		8
Limestone	—	D	v. Sl.	Bl.	C	V. Plas.	Hollywood	Va., N&S Car., Ga., Alabama		8
Igneous	R	L-D	P	B	H	Plastic	Vlei Mbuga	Africa		4
Granite (Gneiss)	R	L-D	G	R	Sy	Friable	VasmGishu	Africa (Narobi)		4
Granite (Gneiss)	R	D	P	Bl.	H	Plastic	Bl. & Gr.	Africa (Narobi)		4
Granite (Gneiss)	R	R-St.	G	G	C	Friable	Ashe	US—No. Car.	45-60	8
Gneiss	R	L-D	P	Bl.	H	Plastic	—	(Ukamba)		4
Gneiss	R	L-D	G	R	Sy	Friable	—	(Ukamba)		4
Gneiss (Schists)	R	v. St.	G	Br	C	Friable	Porters	US-No. Car.	45-60	8
Loess	W	gR-R	—	Bl.	H	Friable	Tshenosen	Hungary		10
Loess	W	L	—	Bl.	H	Medium	Bl. medow	Hungary		10
Loess	W	D	—	Bl.	vH	Plastic	Szik	Hungary		10
Tuffs (Tuffaceous)	R	—								
	R	St.	G-Ex	bR	L	Friable	Kihuyii	Africa Puer. Rico	65″	5
Tuffaceous Rock	—	St.	G(Sur.)	Br	Sic	Med.-Pl.	Mucora	(Narobi) Puer. Rico	65″	4
Tuffaceous Rock	R	Sl	Sl(Sur.)	dGBr	C	V. Plas.	Junus			
Trap Rock	R	L-St.	G	R-B	H	Open	Montalto	N. Jersey		9

TABLE I—Continued

Geological Material	Mode of Formation	Type of Relief	Drainage	Color	Texture	Consistency	Series	Country	Climate	Reference No.
Trap Rock	R	D	P	1B-G	H	Compact	Watchung	N. Jersey		9
Trap (Basaltic)	R	L	—	Bl.	H	Plastic	Regur	India	1200 mm. r.f. Seas	1
Schists (Mica)	R	v. St.	G-Ex	Br	Si	Friable	Talladega	Va.	45-60	1
Schists (Talcose)	R		G-Ex	Br	Si	Friable	Talladega	Va.	45-60	
Diorites, Gabbros & Hornblends	R	L-gR	v. Sl.	Br	C	V. Plas.	Iredell	Va., N&S Car., Ga., Ala.		8
Basalt	R	gR-R	P	dR	C	Plastic (shrink)	—	Palestine		7
Chalk	R	Sl-St	Ex	G-Br	H	Mellow	Downland	England		9
Chalk	C	L	G	G-Br	H	Mellow	Sidelands	England		9
Chalk (Soft Limestone)	R	L(Bad-land)	P G(por.)	G	si	—	—	Palestine		7
Marl (Mudstone) (Soft Limestone)	R	R	P	dBr	H	—	—	Tanganyika		4
Marl (Calcareous)	R	L-D-R	F(Sur.)	Bl.	C	Plastic	Soller	Puer. Rico	200 cm.	5
Clay	R	L-gSl	P	Y-G	vH	V. Plas.	Thorne	England		9
Clay (Wadhurst)	R	L-R	F	Y-B	H	V. Plas.	Hildenborough	England		9
Clay (Atherfield)	R	L-R	F-P	G-B	H	V. Stiff	Lamberhurst	England		9
Clay (Tertiary)	R C	gR-R	F	Br.	C	V. Plas	Moca	Puer. Rico	200 cm.	5
Clay		L(Bad-land)	P	—	C	Plastic	—	Palestine		7
Sand (Folkstone)	W	R-L	Ex	B-YBr	S	Loose	Potters	England		9

TABLE I—Continued

Geological Material	Mode of Formation	Type of Relief	Drainage	Color	Texture	Consistency	Series	Country	Climate	Reference No.
Sand (Fine)	M	D	P	B	Sy	Compact	St. John	N. Jersey		9
Sand (Fine)	M	L-R	F	GBr-Br	vH	Plastic	KeyPort	N. Jersey		9
Sand (Fine)	M	L-D	P	G-W	Sy	Compact	Leon	Florida		8
Gravel	A	—	—	gBr	S	Loose	Pakihi	New Zealand		1
Dolerite	R	D	P	Bl	C	—	Vlei	S. Rhodesia		1
Dolerite	R	gR	G	R	C	Friable	—	S. Rhodesia		1
Norite	R	Level	—	Bl	C	Waxy	Bl. Turf	S. Rhodesia		1
Diabase	R	Level	G	R	—	Friable	—	S. Rhodesia		1
Serpentine (Soft)	R	—	—	R	C	Dense	Limones	Cuba		4
Igneous (Acid)	R	—	—	Br	Sy C	Loose	Ilepa	S. Nigeria	70-90°F	1
Shale and Sandstone	R	—	P	R	C	—	—	So. China	50-60"RF	1
Chalk	M	—	G	G	SySi	Loose	—	England		9
Limestone	R	—	F-P	R	HC	Plastic	Terra Rosa	Medit. Countries		1

Mode of Formation:
- R=Residual
- C=Colluvial
- W=Windblown
- M=Marine
- A=Alluvial

Type of Relief:
- L=Level
- D=Depressions
- R=Rolling
- St=Steep
- Sl=Sloping
- g=Gently (modifier)
- v=Very (modifier)

Drainage:
- P=Poor
- G=Good
- Ex=Excessive
- F=Fair
- Sl=Slow
- v=Very (modifier)

Color:
- W=White
- G=Gray
- Y=Yellow
- Bl=Black
- Br=Brown
- R=Red
- d=dark (mod.)
- b=bright (mod.)
- l=light (mod.)

Texture:
- H=Heavy (clay-like)
- C=Clay
- Pl=Plastic
- Sy=Sandy
- S=Sand
- Sc=Sandy clay
- Sic=Silty clay
- Si=Silt
- m=Medium (mod.)
- sl=slightly
- v=Very (mod.)

TABLE II

PHOTOGRAPHIC ANALYSIS SHEET FOR SOIL CONDITIONS

1. General Climatic Conditions:	
Rainfall	________
Temperature	________
Climatic Classification	________
2. Parent Materials	________
Observable Factors:	
3. Relief:	
General Land Form	________
Microrelief	________
4. Drainage Pattern:	
Alluvial	________
Upland	________
5. Erosion	________
6. Color Pattern	________
7. Vegetative Cover:	
Cultivated	________
Uncultivated	________
8. Land Use	________
9. Other: ________	
10. Conclusions: ________	

INTERPRETATION OF RELIEF

The significance of the relief apparent in the photograph is of high order. Often the relief accurately reflects the climate and the nature of the parent material. The scope of this particular phase is large and the subject interesting. Only the briefest treatment can be given within the limitations of this paper.

Relief is a product of geological adjustment, time, and the action of weathering. The resistance of various types of rock to weathering has been treated in the section on parent materials. Geomorphology and physiography provide an index to interpretation of the regional relief. Geomorphology, a study of landforms, is a branch of geology that furnishes an excellent source of information relating landforms to material and structure.

By abridging this vast field into a few sentences, it can be said that the texture of relief is influenced by the action of climate in carving characteristic forms. Fig. 4 shows the type of relief common to arid regions—the vertical or rugged structures, talus slopes, and filled valleys forming playas. In the arid regions the low rainfall reduces the protective cover and the rainfall usually occurs in concentrated periods resulting in violent water erosion. Sinkholes, pepinos, and mogotes characterize limestone at various stages of weathering; granites and gneiss generally form rounded hills; eruptive rocks form cones and flows; while horizontal limestones, sandstones, and shales form plateaus with escarpments. Sand dunes and silts deposited by wind action possess a distinctive type of relief that is characterized by smoothly flowing outlines. Glacial drift, unless modified by bedrock at a shallow depth, has topography unlike other formations. The components of glacial topography, such as moraines, outwash plains, kames, eskers, terraces, and drumlins, are likewise recognizable in aerial photographs.

Since the action of weathering is a continuous process of degradation, the relief of a general area will vary from the high ground through a well-defined gradient to the bottom (alluvial) land. In the photographic interpretation of soils it is well to have sufficient coverage to establish the relationship of the specific area in question to the general relief of the region. Quoting de Sigmond,[3] "We are therefore very often able to guess the nature of the parent rocks and of the soils formed therefrom from the shape of the hills."

The Drainage Pattern

The drainage pattern visible in an aerial photograph is of major importance in evaluating the porosity of the soil profile. It is essential to identify the drainage system of the area under examination. Its evaluation as an indication of the drainage characteristics of the soil is a matter of experience and judgment modified by other related factors entering into the development of the pattern.

A wide selection of photographs shows that a sand plain produces the same pattern under conditions of arid and humid climate. In areas of resistant bedrock material, the drainage system is usually coarse in texture; a medium texture is found in a moderately resistant material; while fine-textured or highly integrated surface drainage is usually associated with clays and weak shales.

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[3] de Sigmond, A. A. J.—*The Principles of Soil Science*, trans. by Yalland, A. B., Thos. Murby & Co., London, 1938.

Fig. 2. An air view of the Canterbury Plains of New Zealand showing the porous nature of the gravel parent material. The free-draining quality of the gravel terrace is illustrated by the absence of channels dissecting the plain, although the surface run-off from the mountains is fed directly into the plain through the numerous valleys. (New Zealand Aerial Mapping, Ltd.)

Fig. 3. An illustration of severe erosion of the fine-textured Lisian marl terrace in the Jordan Valley in Palestine. Compare this pattern with the lack of surface drainage in Fig. 2. (The Orient Press Photo Co.) (Tel-Aviv)

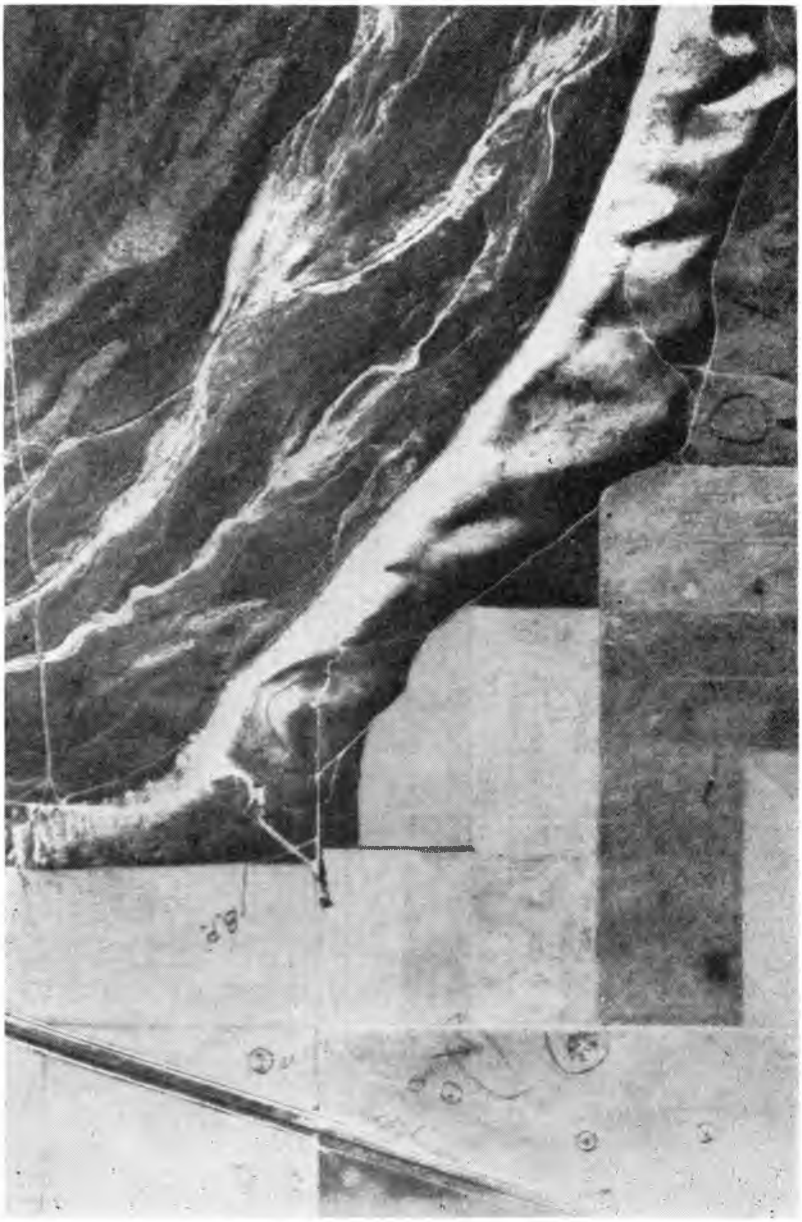

Fig. 4. Sample photograph for analysis. (By Fairchild Aerial Surveys, Inc.)

TABLE III

PHOTOGRAPHIC ANALYSIS SHEET FOR SOIL CONDITIONS SHOWN IN AIRPHOTO OF FIG. NO. 4

1. General Climatic Conditions:	
Annual Rainfall	5 in.
Mean Annual Temperature	
Climatic Classification	Arid
2. Parent Materials	Unknown
Observable Factors:	
3. Relief:	
General Landform	Plain
Microrelief	Pebble-grain and dune
4. Drainage Pattern:	
Alluvial	Dry bed—flashflood type
Upland	None to minor, ditch
5. Erosion	Minor erosion, north bank, small fans, at foot of gully
6. Color Pattern	Principally vegetative (grass)
7. Vegetative Cover:	
Cultivated	—
Uncultivated	Shrubs
8. Land Use	Farming, dry
9. Other (include Parent Material if known)	Sierra Nevada Mountains east of location

10. Conclusions: Flat relief, pebbled microrelief, absence of surface drainage, source-bordering lee dunes, and fan-terminated erosion indicate sand plain. Parent material, sandy outwash from mountains. Sand profile, excellent subdrainage, favorable topography, uniform wind direction (from east). Dunes, 20-30 feet in height. Coarse aggregate available in dry stream bed.

EROSION AND ITS SIGNIFICANCE

By definition there are several types of erosion:

Sheet Erosion—Even or uniform removal of topsoil.

Hill Erosion—Concentration of water in streamlets. Trenching is usually in straight lines. Soils high in silt or loose soils over dense subsoils are especially vulnerable.

Gully Erosion—Often starts from depressions, trails, roadways, or wherever water naturally concentrates.

After gullies start, their shape and length are controlled by the soil profile and parent material. Where the soil (surface) and subsoil are friable, they are easily cut by flowing water. Under such conditions the gullies are U-shaped, since they tend to develop vertical walls which result from undermining and collapse of the banks. They progress in a headward direction and tend to branch. Where the subsoil is resistant to rapid cutting because of clay texture or toughness, and where the parent material or substratum is more resistant than that material above, a broad, shallow V-shaped gully forms. In the humid regions and in soils having very plastic clay, B horizons (Susquehanna, Lowell, White Store, etc.), broad, shallow gullies, form with gently sloping sides. In the Black Belts of Texas, Alabama, and Mississippi (Houston and Bell soils) the eroded gullies are even more shallow and broad.

A combination occurs when V gullies develop, in a downstream direction, into a U-shape because of the friable nature of the substratum or parent. Gullies of this type develop in soils derived from granite, especially when the B horizon is a tough clay (Iredell and related series).

In shallow loessial soils when underlain by clay (Grenada series), as in Mississippi and in some claypan soils of the West, gullies progress laterally as well as in the headward direction. Sand texture over clay does not lead to as severe an erosion as in a reverse condition.

In the Puerto Rico Report[4] we find:

> In most granite areas the drainage-ways are U-shaped rather than V-shaped, as is characteristic in other areas of the island. In the humid uplands most soils occur on steep hills, and numerous V-shaped drainage-ways dissect their entire area.

The Color Pattern

The color pattern of surface soils is often an indicator of soil properties that can be distinguished in airphotos. Black, white, and red are the common colors found in surface soils, and in each instance the color reflects some property of the soil profile.

Black soil color usually characterizes low ground, often alluvial in formation. In some areas of the United States the soil color is rather uniformly black. These occur in the chernozem belts and in some areas of Alabama, Texas, and in the Palouse area of Washington. These areas are calcareous and include a variety of soil materials with a common black surface color. In other areas (humid) the black surface

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[4] *Soil Survey of Puerto Rico,* Supt. of Documents, Washington, D. C.

color is often related to soils existing in low, poorly drained situations. The mucks of the world present this color, the depression soils of the till (Wisconsin and Iowan) plains, the organic sands of the eastern United States, the "mbuga" of Tanganyika, and the "vlei" of South Africa, have this characteristic in common. In the Uganda Protectorate the swamp soils "consist typically of an intensely black topsoil overlying a gray or bluish-gray waterlogged clay".[5] Within a wide range of climate there seems to be marked tendency for black soils occurring on poorly drained depressions to be of silty-clay or clay mixture with high liquid limits.

Red color in soils is almost universally an indication of a well-drained profile. In ordinary aerial photography the red soils appear to have the same color value as the brown soils. However, in the red soil areas of the humid regions the color pattern is two-tone (red and black), and the differences are readily detected.

Limestone soils, although often of clay-like texture, possess an open structure and under the proper conditions of rainfall have a characteristic red color. Saint reports in detail on the occurrence of red soils at 700 or more feet above sea level in the Barbados. At between 400 and 700 or more feet of elevation they assume an intermediate red color; are intermediate black from 200 to 400 feet; and from sea level to 200 feet the soil from this limestone is black in color. Milne[6] describes "discontinuous patches of red-brown clay loam developed on raised benches of coral limestone" on the island of Tobago (B. W. I.) and on the coast and adjacent islands of East Africa. Shantz and Marbut also mention the "red-black" soil pattern in their report on soils in Tanganyika and Somaliland. In Ukamba (Africa), "the soil types become catenary, calcareous black clays occupying the more level country, and red earths the more elevated ground, both soils being derived from gneiss".[6]

Many of the soils of the tropics are a red color due in some degree to the process of laterization. Lateritic soils apparently have this color in common. The Nipe series of the West Indies has a reddish-purple color.

White or light gray colors in soils of the humid regions are usually an indication of poor drainage for prolonged periods. Locally, examples of this color are found in the Crosby, Fincastle, and Clermont soils of the Late and Early Wisconsin and Illinoian drift sheets. Light-colored

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[5] Stamp, L. Dudley—"Land Utilization and Soil Erosion in Nigeria", *Geog. Rev.*, 1938, Vol. 28, p. 32.

[6] Milne, G.—"A Provisional Soil Map of East Africa".

soils predominate in arid regions and do not indicate the same drainage condition. Extremely white color in local areas within valleys of arid regions indicates the presence of alkali. When these are accompanied by black rings or spots, carbonate of soda is present.

Vegetative Cover and Land Use

Without exception, the character of the vegetative cover is an indication of the soil-climate relationship. There are several recent instances of this interpretation being used in areas of dense growth. One of the most recent has been on the Alcan Highway. "For example, poplar growths indicate good dry ground, well-drained; jack pine indicates sand and gravel formations, also well-drained; dense growths of small-size spruce and tamarak usually indicate muskeg; large spruce indicates fair ground conditions; and alder, willow, and buck brush may be interpreted as indicating wet ground". In giving essentially the same relationship, Wilde[2] also warns that "numerous species occur on soils varying greatly in texture, drainage, and other properties. For instance, white pine and aspen occur in sandy as well as clay soils, on well- and on poorly-drained soils. In general, however, sandy soils support pines, scrub oaks, white birch, aspen, etc. Loams support spruce, fir, hard maple, basswood, elm, and white ash."

Hence, it can be seen that vegetative cover can be used in connection with other factors to evaluate soils. In maturely dissected plateaus or in other instances where layers of rock outcrop, belts of vegetation develop in harmony with the soil variations and these often appear as contour lines around hillsides.

Land use is also distinctly related to the soil and is actually a subdivision of vegetative cover. Certain crops find favorable growth on specific soils. Fruit orchards are always found on well-drained soils such as gravels and sands. In North Africa, as in other Mediterranean climates, grain crops are raised on the wettest of the alluvial areas, and the olive groves occur on very plastic clays. In arid climates the presence of alkali is indicated by local absence of plant growth.

Many of the tasks of the farmers or inhabitants are indicated in photographs. Plow lines, paths, shapes of fields, uncut timber, and other factors too numerous to mention are influenced by the soil.

Bibliography

1. Robinson, G. W.—*Soils—Their Origin, Constitution, and Classification*, Thos. Murby & Co., London, 1936.
2. Wilde, S. A.—"Forest Soils", Mimeog. by the Kramer Business Service, Inc., Madison, Wis.
3. de Sigmond, A. A. J.—*The Principles of Soil Science*, trans. by Yalland, A. B., Thos. Murby & Co., London, 1938.
4. *Soil Survey of Puerto Rico*, Supt. of Documents, Washington, D. C.
5. Stamp, L. Dudley—"Land Utilization and Soil Erosion in Nigeria", *Geogr. Rev.*, 1938, Vol. 28, p. 32.
6. Milne, G.—"A Provisional Soil Map of East Africa".
7. Kallner, D. H. and Rosenau, E.—"The Geographical Regions of Palestine", *Geogr. Rev.*, 1939, Vol. 29, p. 61.
8. Bennett, H. H. and Allison, R. V.—"The Soils of Cuba", *Trop. Plant Res. Found.*, Washington, D. C.
9. Strahorn, A. T.—"Agriculture and Soils of Palestine", *Geogr. Rev.*, 1929, Vol. 19, p. 581.
10. *Soils Manual*, F. C. A., Washington, D. C.
11. Lee, L. L.—"The Possibilities of an International System for the Classification of Soil", *Bull. of the Dept. of Zoology and Geology*, South-East Agric. College, U. of London, Wye, Kent, 1932.
12. Shaw, C. F.—"A Preliminary Field Study of the Soils of China", *2nd Int. Cong. of Soil Sci.*, Vol. 5, p. 399.