CLIMATE AND DISTRIBUTION OF SOIL

MAJOR SOIL PROFILES AND THEIR RELATIONSHIP WITH CLIMATE

A. C. Orvedal, J. Kubota, and Howard M. Smith, Soil Scientists, Division of Soil Survey; Bureau of Plant Industry, Soils, and Agricultural Engineering; Agricultural Research Administration, U. S. Department of Agriculture

When pedologists and engineers talk about soil, they have somewhat different concepts in mind. Soil to the engineer, as a rule, includes any and all unconsolidated earthy materials, at the surface and at great depths as well. Soil to the pedologist, however, includes only that surface portion of the earthy material that has been influenced by pedological soil-forming factors. These factors are climate, living organisms, relief (slope), age, and parent material. All work together in producing the soil. Climate and living organisms are dynamic factors. They act on parent material to form soil as pedologists know it. Climate and organisms must have time to exert their influence, hence the factor, age; and the significance of all these is conditioned by relief, or slope of the land.

The depth to which climate and organisms exert their combined effects on the earthy materials is the soil profile (Fig. 1). This soil profile may be just a few inches deep, or it may be many feet deep. It consists of two or more layers, technically called horizons, that usually differ from each other in several characteristics, e. g., color, texture, structure, pH, and content of organic matter. Below it, in most places, lies parent material - the geologically weathered earthy material (related to the profile) yet unaltered by the combined dynamic forces of climate and organisms. Below the parent material may be other strata of geologically weathered earthy material - totally unrelated to the soil above it - or solid beadrock.

We shall confine our remarks to the soil profile. In doing so, we realize that only part of the material that the engineer considers as soil is being discussed; but the pedological soil profile, after all, is the part that expresses relationships with climate.

If we consider for a moment the proposition that the soil at any given place is the function of a particular combination of the five factors of soil formation, we can readily see that there must be many, many kinds of soil profiles in the world. It is also evident that perfect correlations between soil profiles and any one of these factors, including climate, does not occur. This explains why there is considerable overlap of climatic limits within which a general kind of soil profile is developed.

Climate affects soil formation through the moisture and energy it contributes to an environment (10). It influences genesis directly through temperature (including insolation) and precipitation; but perhaps more important is its indirect effects exerted through vegetation and microörganisms, which collectively form the second dynamic factor of soil formation.

Many broad relationships are recognized regarding the influence of different climatic conditions on soil characteristics (6, 10). For example, one important relationship is the increase, within limits, of soil organic matter with increase in precipitation and decrease in temperature. But important as these relationships are, even with a knowledge of all of them, we are unable to visualize or predict positively from these alone what soils will occur where. For in addition, we need to know what effects the other four factors of soil formation have had in combination. To learn this, many soil profiles in widely different environments had to be examined in situ.

Only after a great number of such examinations has it become possible for soil scientists to generalize with any degree of reliability regarding the kinds of soil profiles that occur under various sets of environmental conditions. By this procedure it has been learned that over broad areas of the world with like climates soil profiles tend to have certain similarities (manifest in the number, thickness, and sequence of soil horizons and in the physical and chemical properties) which reflect the prolonged influence of climate. In general, these manifestations tend to override or show through the many variations in the profiles caused by the influence of the other factors of the environment. Broad generalizations, therefore, can now be made about relationships between climate and soil profiles.

Major Soil Profiles

In order to get some points fixed in our mind about the relationship of soil profiles with climate, we have selected five for discussion, one from each of five broad groups 1/ of soils of the world associated with different climates. The classificational level may be likened to that of races of people; for like these, each is composed of individuals with a common heritage but differing widely in lesser characteristics. The profiles may be likened to individuals selected as representative of each of the numan races, e. g., one to represent the white race, another the negroid.

We must also keep in mind that the profiles we have selected are not the product of climate alone but the product of all five factors working together. The profiles are, however, ones in which the effects of climate are considered to be strongly expressed and to be representative of soils over extensive portions of the world.

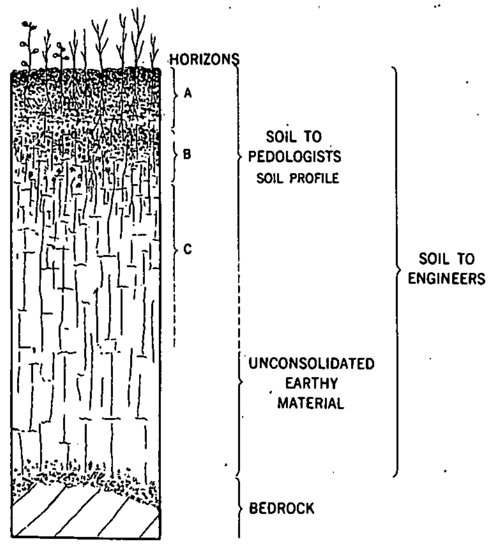

Figure 1. Comparison of Pedologists' Versus Engineers' Concept of Soil

Tundra Soils - These have developed mainly under the frigid climate of the polar regions (Fig. 4) where precipitation is low. (Where precipitation is higher and more snow falls than melts, permanent snowfields occur.) A good example of frigid climate under which Tundra soils occur is that of the Arctic coastal plain of northern Alaska. Here, average annual temperature is between 10 and 15 F., with monthly averages above freezing only three months of the year (highest 40 F.); and average annual precipitation is about 5 in. (13). These soils occur elsewhere, however, under considerably higher precipitation and temperatures, e.g., the Aleutian Islands; but there are no Tundra soils where summer temperatures are high or where the climate is mild enough to support more than a hardy vegetation consisting mainly of low-growing shrubs, mosses, and sedges.

Tundra soils, especially in the more severe frigid climate, are restricted mainly to smooth topography. On rough topography rubbly soils only a few inches deep over bedrock are dominant. Tundra soils occupy only part of the total area where they form the climactic type.

Permafrost is common in or immediately below Tundra soil profiles, but there are exceptions, such as on the Aleutian Islands, where permafrost is absent.

The following is condensed from a description of a Tundra soil profile (near Bethel, western Alaska) by Kellogg and Nygard (9): 2/

1/ With few exceptions, these groups correspond to the zonal suborders of the natural soils classification (1, 12).

2/ See also Figure 2.

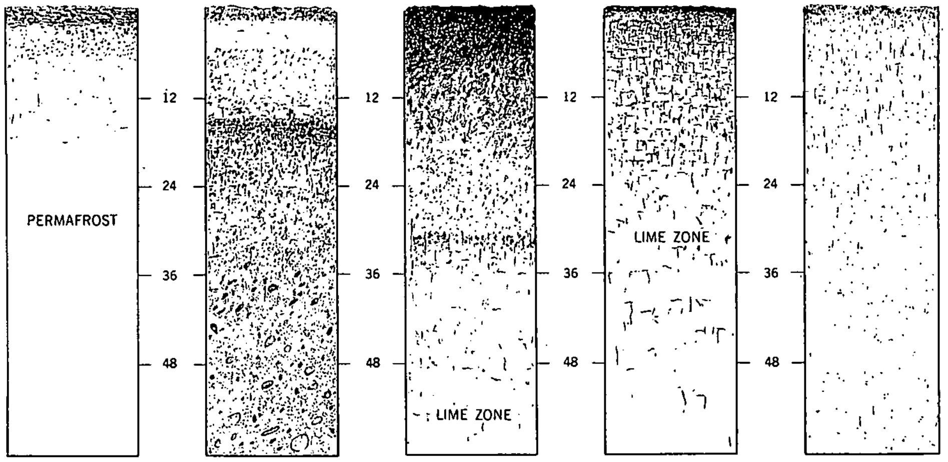

Figure 2. Representative Profiles of Tundra, Podzolic, Chernozemic, Desertic, and Latosol Groups of Soils - Depth is expressed in inches.

A_0 3/	3-0 in. 4/	Tough, fibrous, peaty organic mat with many roots of sedges and grasses.
A_1	0-4 in.	Mucky silt loam, rich in humus and particles of peat. Very friable. Reddish brown. (Wet and cold on August 12.)
B-G	4-15 in.	Very fine sandy loam. Compact in place, but easily friable when removed. Grayish-brown. (Wet and cold on August 12.) Below this depth, the soil was frozen.

Tundra soils express mainly physical effects of climate. The alternate freezing and thawing has produced physical breakdown of soil particles, but only to the grain-size of silt and very fine sand (2, 9). Hence, the clay content of Tundra soils is low.

Another effect of frigid climate is the formation of a peaty mat on top of the mineral soil. This forms in spite of the small annual additions provided by plants because the rate of decomposition is even slower than the rate of formation. This mat in many places attains a thickness between 6 and 12 in. (9), considerably thicker than in the profile just described. Most of the organic matter remains in a raw state. That which gives the upper part of the mineral soil a mucky character is probably due to grinding action resulting from freezing and thawing and not from decomposition.

Little or no leaching has occurred in Tundra soils nor do they appear to have consistent textural differences within the profile. Variations in texture may occur somewhat erratically, probably due to shifting of materials by frost action.

Associated with Tundra soils are several characteristic surface features. Ponds and lakes are innumerable. Mounds, several inches to a few feet high produce a hummocky microrelief. Soil polygons, soil blisters, and other phenomena resulting from frost action are common (2, 9).

Tundra soils present manifold problems to the highway engineer. They are prevailingly wet (low precipitation notwithstanding), and because of permafrost, adequate drainage is difficult if not impossible to provide. Where permafrost is close to the surface, as is common in most areas of Tundra soils, frost action, including solifluction, assumes gigantic proportions (2). Any disturbance of the soil, even a very minor one, upsets the delicate thermal equilibrium established over the years, and the ultimate result is

3/ Explanation of horizon designations appear in many publications including the 1938 Yearbook of Agriculture (9) and the Soil Survey Manual (7).

4/ The zero line for soil measurements is the top of the mineral soil. Hence, the designation 3 to 0 means that the organic mat above the mineral soil is 3 inches thick.

quite likely to spell failure for conventional highway structures.

Podzolic Soils - Moving from the frigid to the temperate regions, we get a corresponding gradation from the Tundra to the Podzolic group of soils. These are our forested soils covering extensive parts of the world (Fig. 4). In most places the winters are characterized by snow, and freezing of the ground; the summers are warm with a reasonably good distribution of rainfall. Average annual precipitation, however, varies from about 15 to 50 in. - enough to produce much leaching.

Coniferous or deciduous trees, or mixtures of the two, with varying amounts of shrubs and other low-growing plants form the native vegetation. Leaves and twigs fall annually on the ground. Decomposition, however, is too slow to overtake deposition, and as a result an organic mat ranging from a fraction of an inch to several inches thick lies on the mineral soil. Such decomposition as does take place yields acids that assist in the leaching of the surface mineral soil.

In this environment soils are developed which are acid in reaction and have an organic surface mat, a platy-structured gray surface soil (A_2 horizon) from which much clay has been removed, and a blocky structured brown subsoil (B_2 horizon) in which clay has accumulated. The clay content of the subsoil is not only much greater than that in the surface soil above, but also significantly greater than that in the parent material below (Fig. 3).

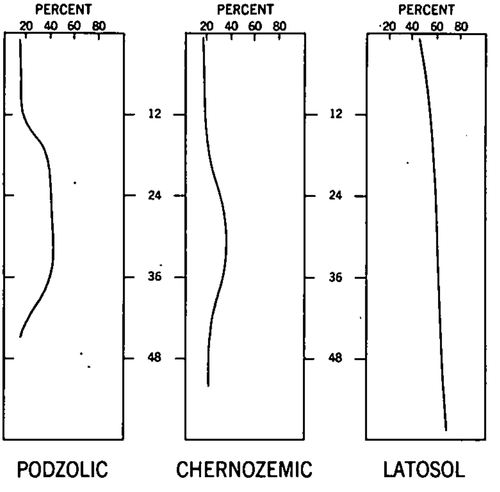

Figure 3. Variation of Percent Clay (Less than 2 Micron) in Selected Profiles of Podzolic, Chernozemic, and Latosol Groups of Soils - Depth is expressed in inches.

The following is a description of a Miami silt-loam profile (5) in Indiana 5/:

A_1	0-2 in.	Very dark brownish-gray silt loam. Granular structure.
A_2	2-5 in.	Light brownish-gray silt loam. Weakly developed platy structure.
A_3	5-11 in.	Pale yellowish-brown silt loam.
B_1	11-15 in.	Light yellowish-brown heavy loam. Moderately developed subangular blocky structure.
B_2	15-30 in.	Dark-brown clay loam. Strongly developed subangular blocky structure.
B_3	30-36 in.	Dark-brown clay loam. Subangular blocky structure.
C_1	below 36 in.	Glacial till: olive-gray loam with limestone and dolomitic-limestone fragments.

This profile fairly represents many Podzolic soils of northeastern United States. The Podzolic profile, considered on a world-wide basis however, varies from the above in having an organic mat on the surface, more grayish A_2 horizon, and less overall profile depth.

A feature of Podzolic soils important to highway engineering is the usually high content of clay in the B horizon (Fig. 3) in contrast to that of the A horizon above and the parent material below. Furthermore, the clay of Podzolic soils tends to be of the highly active type, a fact which makes the clay accumulation in the B horizon all the more important. A relatively small amount of this kind of clay concentrated in any horizon can have a profound effect on the engineering properties of soils. The clay usually is of the expanding lattice type (montmorillonite and hydrous mica groups), the kind that swells

5/ See also Figure 2.

upon wetting and shrinks upon drying. It is highly plastic when wet and hard when dry and is highly subject to frost action. In humid regions where soils become wet many times during the year and usually freeze in winter this kind of clay, in high concentrations, poses difficult problems indeed for highway engineers.

Chernozemic Soils - These are the grassland soils of our Great Plains and similar areas elsewhere (Fig. 4). They occur in subhumid to semiarid temperate, continental type of climate which is characterized by hot summers and, in many places, cold winters. Precipitation at corresponding latitudes is lower for Chernozemic than for Podzolic soils; it ranges from approximately 12 to 35 inches annually, with much of it occurring in late spring and summer. Chernozemic soils, however, are much less leached than Podzolic soils. Generally some freezing occurs in winter.

These soils support grasses which return organic matter annually not only as leaves and stems above the soil but also as fibrous roots within the soil. Organic matter accumulation, as a result, is considerable and continues until equilibrium between addition and decomposition is attained. A 5- to 8-percent level of organic matter in the surface soil is representative where the soil remains undisturbed by cultivation.

Unlike the Podzolic soils previously described where the organic matter occurs mainly as a mat on the surface and is poorly integrated with the mineral soil, the organic matter in the Chernozemic soils is well integrated with the mineral components to a depth of 1 to 3 feet. The high organic matter content, which gradually decreases with depth, gives the Chernozemic soils their black and dark brown colors.

A somewhat less noticeable but yet evident profile characteristic of many, though not all, Chernozemic soils is the presence of a subsoil somewhat heavier in texture than the surface layer above and the parent material below. Unlike the Podzolic soils, however, Chernozemic soils have no bleached or light-colored horizon of removal (A_2). In or below the subsoil can be found frequently a layer of calcium carbonate deposited as concretions or surficial coating on the soil particles.

The following description obtained in Nebraska illustrates the major horizon features of a Chernozemic soil profile: 6/, 7/

A_{11}	0-1-1/2 in.	Very dark grayish-brown silt loam. Mulch-like.
A_{12}	1-1/2-12 in.	Dark grayish-brown silt loam. Crumb or granular structure.
B_{21}	12-15 in.	Grayish-brown silt loam.
B_{22}	15-30 in.	Grayish-brown silty-clay loam. Ill-defined prismatic structure.
B_{23}	30-40 in.	Grayish-brown silty-clay loam. Ill-defined blocky structure.
B_{24}	40-50 in.	Yellowish-brown silt loam. Lime carbonate deposits occur as concretions, aggregates, or film-like surface coating.
C_1	below 50 in.	Loess; yellowish-brown calcareous-silt loam.

This description and the clay distribution curve (Fig. 3) show textural differences in the soil profile. Although clay concentration in the B horizon is less than in Podzolic soils, it is high enough to warrant consideration by highway engineers. Since the clays of Chernozemic soils, like those of Podzolic soils, are likely to be of the active type, small variations in clay content may cause big variations in behavior, including frost action.

Chernozemic soils, as a rule, have a relatively well developed granular and prismatic structure. If worked while wet, however, the soil aggregates readily disintegrate, causing the soil to become puddled, which is evidenced by slipperiness or stickiness, depending upon the moisture content. If the soil is severely disturbed after drying, the aggregates become pulverized and the soil loose and powdery.

6/ Condensed and slightly revised from the standard description of the Holdredge series, Division of Soil Survey, Bureau of Plant Industry, Soils, and Agricultural Engineering, U.S. Department of Agriculture.

7/ See also Figure 2.

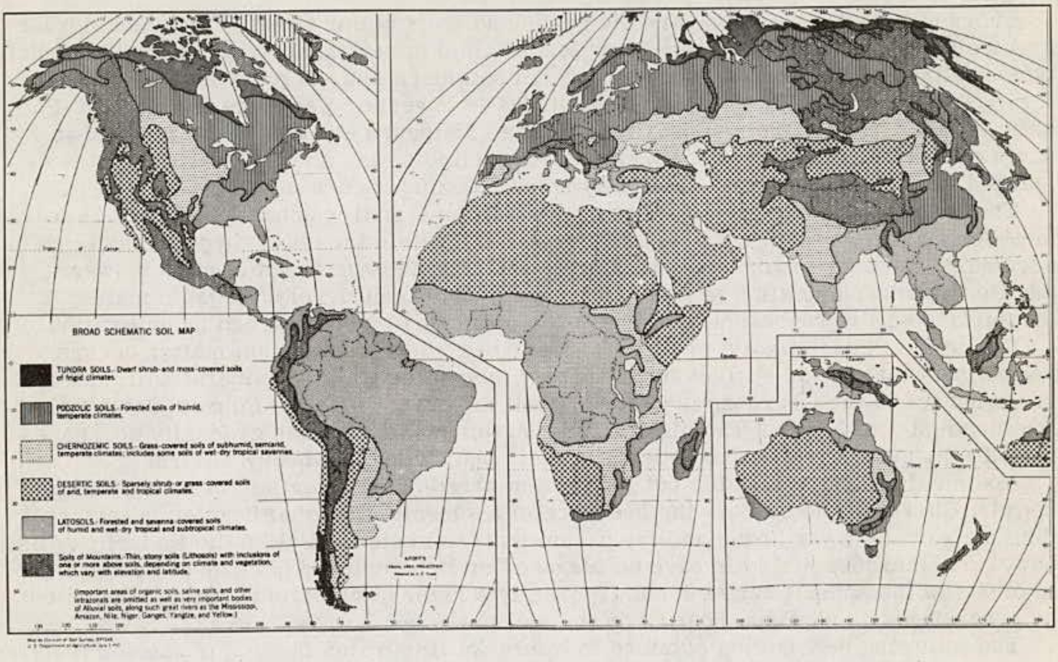

Figure 4. Broad Schematic Soil Map of the World

Variations from the representative soil profile presented occur particularly in the directions of the Desertic and Podzolic soils. The semiarid climactic members generally have lighter colored surface horizons, have lime accumulations nearer the surface, and have only little or no clay accumulation in the subsoil. In contrast, the subhumid temperate members are deeper, may have greater clay accumulation in the B horizon, and are deeper to the zone of lime accumulation, which is also less conspicuous.

Included in this group are the dark-colored soils of the alternately wet-dry tropics (Fig. 4), which support a savanna type of vegetation. These soils are comparable in color, but differ markedly in behavior. They are dominantly heavy clays which crack deeply upon drying and puddle readily upon wetting.

Desertic Soils - In the desert regions of the world (Fig. 4), soils with strongly expressed genetic profile horizons are less extant than soils with weakly expressed horizons, soils with unrelated ones, or soils with no horizon differentiation at all. This is because the processes of physical weathering under desert climates are dominant over chemical and biological ones. The unconsolidated earthy materials thus produced ordinarily do not attain much depth in situ over the parent rocks. More commonly, the deeper accumulations of these have been transported from the place of origin by water or wind. These deposits are sorted or stratified with regard to particle size and their dry surface-layers are altered more or less constantly by fresh additions of materials or by shifting about in the wind. Wind action piles up vast seas of unstable sand dunes in many places.

It is only on relatively small portions of basins and plains, where deep earthy materials have been left undisturbed sufficiently long, that pedogenic soil horizons are strongly expressed. An example of Desertic soil profile, such as one can expect to find in these places, is that of Fruita very-fine sandy loam, a soil that may be observed on the alluvial fan benches north of Fruita in Mesa County, Colorado. It is described as follows: 8/, 9/

A_{11}	0-1/4 in.	Very-pale, brown, slightly-hard vesicular-crust of fine sandy loam.
A_{12}	1/4-2 in.	Very-pale, brown, loose-granular fine sandy loam.
A_3	2-8 in.	Light-brown, very-fine, sandy loam with blocky structure.
B_{21}	8-15 in.	Light-brown calcareous loam with coarse, blocky structure. Very friable when moist.
B_{22}	15-20 in.	Pale-brown calcareous loam, slight amount of segregated lime in thin veins or small white mottlings. Slightly hard when dry and very friable when moist.
B_{ca}	20-40 in.	Pale-brown calcareous loam with 20 to 70 percent segregated lime in mottlings and 2- to 10-inch splotches; lime segregation decreases in lower part.
C_1	40-72 in.	Pale-brown calcareous loam; hard and massive when dry; friable when moist.
D	below 72 in.	Bedrock at varying depths below 72 inches.

Salient features of this profile considered characteristic of desertic soils (3, 4, 11) are: (a) The thin surface crust (A_{11}, above); in places this crust may be covered or embedded with a dense concentration of small pebbles coated with a dark-colored "desert varnish" - a thin film composed of oxide of iron and manganese together with a slight amount of organic matter; the pebbly crust is often referred to as "desert pavement." (b) A slight increase in the clay content of the B_{21} and B_{22} horizons; the clay of desertic soils is commonly of the expanding type and sticky when wet. (c) The segregated lime in the B_{ca} horizon; in many desertic soils, hardpans or crusts of indurated lime carbonate, gypsum, and other salts occur erratically in this horizon and perhaps even in lower horizons; these may be only a few inches or several feet thick but, in places, may consist of several thin layers separated by earthy material; lime crusts are frequently referred to as "caliche" in this county. (d) A very low content of organic matter through the profile; ordinarily this amounts to less than 0.5 percent, but it may be as much as 1.0 percent or slightly more in the upper part of horizon A, indicated by the light colors in the example profile and substantiated by laboratory data.

The climatic factors of precipitation, temperature, and wind in the desert vary greatly in extremes from those of more humid regions. Low precipitation (usually less than a 10-in. annual average) is responsible for greatly slowed chemical action and low biologic activity in the soil, including the slow and sparse vegetative growth. Thus only small amounts of organic matter are produced, and little of this is decomposed and incorporated with the soil. Most of the organic matter left on the surface by plants is rapidly desiccated in the dry, hot air and blown away by the wind.

Wind is a significant factor in the formation of the thin surface crust (A_{11} above) including the pebbly "desert pavement." It packs the soil surface and sweeps it free of loose and movable small soil particles. Pebbles too heavy to be blown away accumulate and form the "desert pavement."

Movement of solubles and fines from the surface to lower soil horizons is slight in desertic soils because of low precipitation. The clay enrichment in the B_{21} and B_{22} is

8/ Condensed and slightly revised from standard series description of Division of Soil Survey, Bureau of Plant Industry, Soils, and Agricultural Engineering, U.S. Department of Agriculture.

9/ See also Figure 2.

thought to be largely a result of hydrolysis in place of the clay minerals rather than of removal from horizons above. Some of the lime concentration in the B_{ca} horizon may have leached from overlying horizons; but another possible source is from the ground waters below. Charged ground water may rise by capillarity or hydrostatic pressure into the lower part of the soil where it evaporates and deposits the salts.

Probably the feature of these soils of greatest significance to the engineer is the presence of the hardpans or crusts of lime carbonate and other salts in the B_{ca} horizon. Although they occur erratically in desertic soil profiles, they are of great usefulness for road and airfield surfacing.

Latosols 10/ - Latosols form the dominant soils in the humid and subhumid tropical parts of the world (Fig. 4) where the average annual temperature is in the neighborhood of 70 to 80 F. with little or no seasonal variation and no freezing and the average annual rainfall ranges between 30 and 80 in. or even more. Their vegetative cover is either forest or savanna.

Latosols reflect profound effects of climate as expressed through intense chemical and biological activity. Results of physical activity are minor, almost insignificant, when compared to those of chemical and biological. The change in chemical composition during the formation of latosols has been so great that their present composition shows practically no similarity to the rocks from which the parent material originated. Latosols have low silica-sesquioxide (oxides of aluminum and iron) ratios in the clay fraction, have low activities of the clay, relatively low base-exchange capacities, a relatively-high degree of aggregate stability, and a red color or reddish shades of other colors (8).

A profile description by Kellogg (8) of an earthy rod latosol (one of several kinds of latosols) in Belgian Congo, Africa, where average annual rainfall is about 56 in. follows: 11/

A_1	0-4-1/2 in.	Dark, reddish-brown, granular, clay loam to fine sandy clay, held firmly by grass roots. (Nearly black when wet.)
A_{30}	4-1/2-10 in.	Dark, reddish-brown, friable, granular-clay loam to clay, held by grass roots.
A_{31}	10-21 in.	Dark, red-clay loam to clay, easily friable to fine granular.
A_{32}	21-32 in.	Like the above but only slightly lighter in color.
B_2	32-42 in.	Red, friable-clay loam to clay.
C	42-80 in.	Red, very softly granular, mellow clay loam to clay.

Analyses of samples from this profile show a gradual increase in clay from 45 percent at the surface to 60 percent in the lowest layer (Fig. 3). Silt content is between 9 and 10 percent throughout, and the sand content decreases with depth.

High-clay and low-silt content are characteristic of many latosols. Sand content of these soils varies, apparently depending upon the relative amount of quartz in the parent material. Base-exchange capacity is low in comparison with soils of corresponding clay contents in temperate regions and is an indication of low activity of the clay. Mineralogically, latosols are high in kaolinite and oxides of iron and aluminum.

Extreme friability, granular structure, and high porosity are outstanding physical characteristics of earthy red latosols. These soils, in spite of the fact that they may consist of 45 to 60 percent or more of clay, have permeability to water approaching that of sand. The structure is stable and persists even after heavy rains, but it probably will be destroyed, at least temporarily, by working with heavy machinery when wet.

All latosols of the tropics are not as friable and porous as the profile we described,

10/ Soils formerly called lateritic, red lateritic, red loams, etc., are now termed latosols (8).

11/ See also Figure 2.

but they exhibit strong tendencies in that direction; and by comparison with high-clay desertic, podzolic, and chernozemic soils, are relatively more friable, more porous, and have greater permeability to water. Latosol profiles also tend to be deeper than others. Depths of 100 in. are common, and the parent material over bedrock may be many dozens of feet thick.

Many latosols and some associated soils, especially ground-water laterites, are composed, in part, of material called laterite, which is a term applied to the sesquioxide-rich, highly-weathered, clayey materials that change irreversibly to concretions, hardpans, or crusts upon drying, and more or less mixed with entrapped quartz and other materials, form the hardened relicts of such material (8). This laterite may occur in or below the profile of latosols; but it always occurs in the profiles of ground-water laterites.

In regard to highway construction latosols present no problems due to frost action since there is no freezing where they occur, except on fringe areas adjoining podzolic soils. Highway design needs to take advantage of the peculiarities of the permeable red clays, which do not behave as clays of temperate regions the possible use of laterite for both subgrade and surfacing materials should not be overlooked.

Summary

Tundra soils have developed under frigid climates with low precipitation. Climatic effects have been largely physical. Tundra profiles are relatively shallow, tend to be high in silt and low in clay, tend to be uniform in texture throughout, usually have permafrost in the lower part, and have a tough, fibrous organic mat on the surface.

Podzolic soils have developed under humid temperate climates where chemical as well as physical effects are strongly expressed. The soils are leached and acid in reaction. The contrast in texture between the surface soil and subsoil layer is the strongest of all groups, the subsoil generally being much heavier than the surface above and also significantly heavier than the parent material below. Organic matter is present as a mat up to several inches thick on top of the mineral soil, but its content is low within the mineral soil.

Chernozemic soils have developed mainly in subhumid and semiarid, temperate climates. They express both physical and chemical effects of climate. They show only slight leaching and hence are near neutral or only slightly acid in reaction. They show less textural variations in the profile than podzolic soils, although a significant accumulation of clay in the subsoil is present in many. Organic matter is well integrated with the mineral soil throughout the upper foot or two, and this is in contrast to the podzolic soils, where an organic mat occurs on the surface.

Desertic soils have developed under arid climates, and the climatic effect has been dominantly physical breakdown of parent materials. Desertic soils are unleached and hence usually alkaline in reaction and may contain free salts. They have only slight textural variations within the profile, but caliche in the subsoil is a common feature.

Latosols have developed under humid and wet-dry tropical climates. They show very strong chemical and biological effects of climate, but only weak physical effects. Latosols are deep, highly leached, prevailingly red in color, high in clay, low in silt, friable, and permeable. Unlike the podzolic soils, the latosols show little or no clay accumulation in the subsoil, but show a gradual increase in clay content from the surface downward.

References

1. Baldwin, Mark; Kellogg, Charles E.; and Thorp, James, Soil Classification, U. S. Dept. Agr. Yearbook (Soils and Men), pp. 979-1001, 1938.

2. Black, R. F., Permafrost, Applied Sedimentation (Trask, P. D., editor), John Wiley and Sons, Inc., New York, pp. 247-275, illus., 1950.

3. Brown, I. C. and Drosdoff, M., The Chemical Character of Certain Desert

Soils in Relation to Their Genesis and Morphology, Soil Sci. Soc. Amer. Proc., Vol. 3, pp. 269-273, illus., 1938.

4. Brown, I. C. and Drosdoff, M., Chemical and Physical Properties of Soils and Their Colloids Developed from Granitic Materials in the Mojave Desert, Jour. Agr. Research, Vol. 61, No. 5, pp. 335-352, illus., 1940.

5. Brown, I. C. and Thorp, James, Morphology and Composition of Some Soils of the Miami Family and the Miami Catena, U. S. Dept. Agr. Tech. Bull. 834, 55 pp., 1942.

6. Jenny, Hans, Factors of Soil Formation, Mc-Graw-Hill Book Co., Inc., New York, 281 pp., illus., 1941.

7. Kellogg, Charles E., Soil Survey Manual, U. S. Dept. Agr. Misc. Pub. 274, 1936 pp., illus., 1937.

8. Kellogg, Charles E. and Davol, Fidelia D., An Exploratory Study of Soil Groups in the Belgian Congo, Inst. Nat. L'Etude Agron, Congo Belge Pub. (INEAC), Sci. ser. 46, 73 pp., illus., maps, 1949.

9. Kellogg, Charles E. and Nygard, Iver J. (in press), Exploratory Study of the Principal Soil Groups of Alaska, U. S. Dept. Agr. Monograph 7, illus.

10. Muckenhirn, R. J.; Whiteside, E. P.; Templin, E. H.; Chandler, R. F., Jr.; and Alexander, L. T., Soil Classification and the Genetic Factors of Soil Formation, Soil Sci., Vol. 67, No. 2, pp. 93-106, 1949.

11. Nikiforoff, Constantin C., General Trends of the Desert Type of Soil Formation, Soil Sci., Vol. 43, No. 2, pp. 105-131, illus., 1937.

12. Thorp, James and Smith, Guy D., Higher Categories of Soil Classification: Order, Suborder, and Great Soil Groups, Soil Sci., Vol. 67, No. 2, pp. 117-126, 1949.

13. United States Weather Bureau, Climatic Atlas for Alaska, Weather Information Branch, Headquarters Army Air Forces, Rept. 444, 229 pp., illus, 1943.

CLIMATIC ASPECTS OF FROST HEAVE AND RELATED GROUND FROST PHENOMENA

Dr. Paul A. Siple, Military Geographer and Chief,
Environmental Research Section, Department of the Army

Synopsis

Frost heave is a freezing-ground phenomenon created by the compounding and sequencial influences of several climatic and other environmental factors causing ground heat loss. The most important of these factors are: radiation, convection, conduction, evaporation, vegetation and snow cover, soil type, and accumulation of soil water in the "vernal active zone." (Spring freeze-thaw zone above winter frozen sub-soil.)

By the use of climatic and geographic data, already available, it is possible to map the distribution of frost-heave elements and to predict the timing and severity of heave forces for areas through which highways are projected.

An index using the percentage of the total annual hourly frequency of temperatures below 30 F., the temperature difference between the freezing point and the temperature of the minimum 1 percent frequency level, and an adjustment for surface insulation cover appears to provide a means of predicting probable average maximum depths of winter frost penetration. Similar indices may be possible for the determination of probable time and force of heave by consideration of soil type, precipitation, and accumulation of soil moisture to depths favoring frost heave.

An understanding of the climatic mechanism of frost heave makes it possible to establish positive control measures to protect highways and other structures. Such control measures include drainage and insulation techniques heretofore commonly neglected. Highways are generally good