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COORDINATED MAPPING OF GEOLOGY AND SOILS FOR LAND-USE PLANNING

Prepared in cooperation with the
Soil Conservation Service of the U.S. Department of Agriculture

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INTRODUCTION

Pedology and geology, the first the science of soils and the other the more comprehensive science of the earth, have been from inception involved with the orderly management and use of natural resources. Pedology arose from a desire to increase the fertility of soils and improve soil husbandry; geology began with curiosity about the history and physical processes of the earth and, subsequently,broadened to provide practical information on the occurrence and distribution of mineral and water resources.

Both sciences are concerned with erosion, weathering, and surficial earth materials, and their methods of study are similar. Geology's scope, however, extends from land surface to the core of the earth, while pedology is limited to materials at or near the surface, the agents that act on the materials, and the changes exerted by these agents. Each science benefits from the discoveries of the other.

In the past 100 years a vast amount of information on the geology and soil characteristics of many regions has been published, most of it directed to technicians engaged in agriculture, mineral extraction, engineering, or related fields. Fairly recently, however, a new audience for such information has developed. The extremely rapid growth of urban areas has led to the creation of planning agencies to formulate comprehensive programs for orderly expansion and regional land development. Properly coordinated and adequately interpreted information on which the planners can rely is urgently needed.

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Of particular importance to planners, for instance, are limitations the land imposes on many potential uses. Planning boards may be unaware that some of the land they are making plans for is frequently flooded, poorly drained, or presents particular construction problems. They may also overlook the advantages of available soil, water, and mineral resources unless such information is brought to their attention. For the planner to make use of the scientific data available, however, he should have a basic understanding of its significance and should know what to ask for, whom to ask, and, with advice from those providing the information, how best to apply the data. The more he knows about the physical environment of the area, the more likely he is to gain support for his final plan. When such facts are available, conflicts that may arise between factions (such as "preservationists" and "developers") may often be resolved and the land put to the most advantageous use.

To furnish some of the background needed by planners we have incorporated in this note (1) basic information on the nature and significance of soils and related geologic data, (2) a description of techniques used for coordinating data gleaned from studies of the soils and geology of an area, and (3) a discussion of how this information can be adapted to land-use planning.

THE PHYSICAL SYSTEM

The Earth's Crust

The portion of the earth's crust significant to the layman is that in which his activities are centered. Although technological advances have allowed deeper and deeper penetration of the crust, particularly for mineral fuels, human activity is greatest at the earth's surface and at very shallow depths. For planning, only general information is normally needed about the deep layers of the earth, but information about the earth's surface must be precise and detailed. The following brief discussion of the basic elements of geology and pedology explains some of the concepts earth scientists must explore in detail in producing useful information for the planner.

The earth consists of three concentric zones--the central core, the mantle surrounding it, and the crust. The continental crust is composed of relatively light colored sedimentary, metamorphic, and granitic igneous rocks (fig. 1).

The principal sedimentary rocks are sandstone, shale, limestone, and dolomite. The first two are composed of fragments eroded from pre-existing rocks and redeposited elsewhere by water, wind, or ice. Limestone and dolomite are composed of the remains or products of aquatic animals,but some have been chemically precipitated from solution. Sedimentary rocks are laid down in layers and are thousands of feet thick in some areas. Each layer generally has distinctive characteristics and many can be traced laterally for long distances. The thickness and other characteristics of sedimentary rocks, therefore, can often be predicted in a new area of study because the strata have been identified and described elsewhere. Sedimentary rocks are the most common rocks found at land surface.

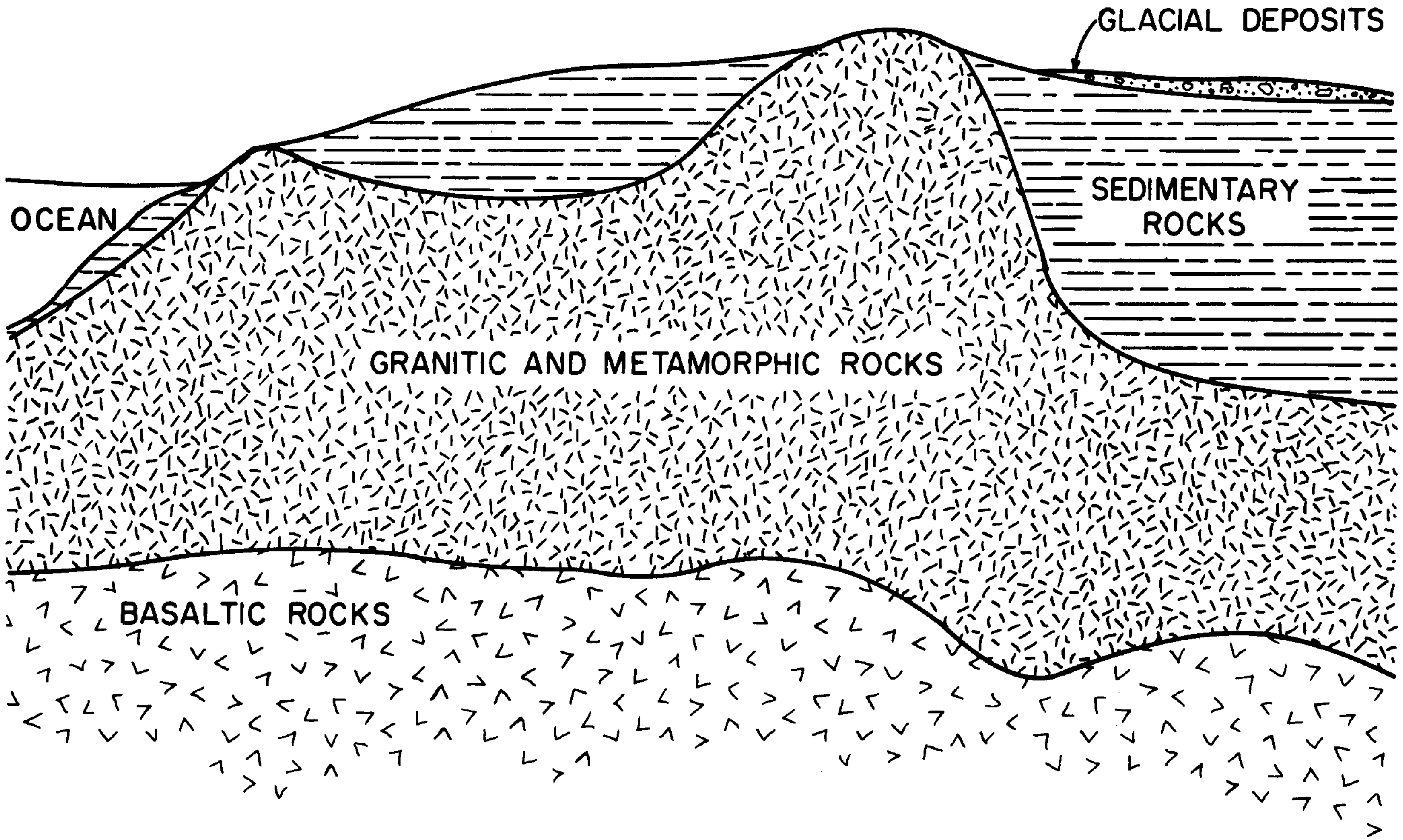

Fig. 1 - General diagram of the crust of the earth.

The sedimentary rocks in the northern midcontinent area of North America are overlain by unconsolidated sediments, including river silts, sand and gravel, wind-blown silts (loess) and sands, lake sediments, and clay and rock debris left by the melting of the continental glaciers.

Glacial deposits in the Upper Mississippi Valley and Great Lakes region are locally more than 600 feet thick, and they average 100 feet or more thick. Much of Illinois was repeatedly covered by massive continental glaciers during the last (Pleistocene) geologic episode. Each time the ice melted, layers of unconsolidated rock material were deposited, the younger layers overlapping the older ones. The bulk of the glacial material—unsorted clay, silt, sand, and rock fragments—was either directly deposited by the melting ice or was carried away and deposited elsewhere by streams formed from the meltwater. Because the source areas of the glaciers shifted from time to time, and because climatic conditions differed from one region to another, the deposits of the various glaciers have different physical and mineralogical properties and can be distinguished from each other.

The uppermost layer of earth material is the relatively thin, nearly continuous blanket of unconsolidated mineral and organic material called soil. Soil develops anywhere physical, chemical, and biological agents act on the surficial rock material and so modify it that it can support rooted plants. Each soil has its own set of characteristics observable in the field or measurable in the laboratory. Many soil characteristics are determined by the type of material on which it develops; others are due to climate, living matter, topographic relief, and time.

These, then, are the basic elements of the earth's structure. To define the complete physical system, however, the role of water must be included.

Hydrology

Hydrology is concerned with the distribution of water in the air, on the earth's surface, and in the earth's crust. Here we are concerned mainly with water on the surface of the continents and at relatively shallow depths below.

At various depths below land surface, ground water fills (1) the open (pore) spaces between unconsolidated rock fragments and in granular consolidated rocks, (2) the fractures in the rock, and (3) the openings made by slow dissolution of crystalline and nonporous rocks. The pore space in a given volume of rock is determined by the size, shape, mineral constituents, and arrangement of the particles that make up the geologic materials. The arrangement, number, and size of the pores in these materials are the result of geologic processes of rock formation and alteration. The ability of a rock to transmit fluid—its permeability—depends on the interconnection and size of these pore spaces and on the hydraulic gradient. As rock types and surficial deposits vary laterally and vertically, the distribution of ground water also varies. Earth materials generally become denser with increasing depth due to consolidation, compaction, cementation, and crystallization, and they contain less water, thus limiting the depth of usable ground-water resources. In Illinois the bedrock formations yielding fresh water are less than 3000 feet deep—very much less in much of the state—and the most highly productive ground-water reservoirs in glacial materials are usually less than 400 feet deep. Although bedrock formations vary laterally in porosity and permeability, the variation is not as great as in unconsolidated deposits. The need for detailed study of the geologic materials in evaluating their ground-water potential, therefore, decreases with increasing depth.

The ground-water system is a dynamic system because the water is constantly in motion, although usually at a very slow rate. Water seeps into the ground, descends to the water table, and flows slowly in the direction of decreasing elevation to a point of discharge. Points of ground-water recharge and discharge and general flow directions must be considered in planning uses of the land.

Surface water—from precipitation, melting snow and ice, or springs—flows down stream networks to the oceans, accumulates in lakes or ponds, or returns to the atmosphere or the ground-water reservoir. Uncontrolled surface flows are annually responsible for millions of dollars in flood damage and erosion of valuable land. Controlled surface flows supply power and water for municipalities and industrial developments throughout the world. If surface water is to be managed, geologic and hydrologic data on the source, quality, and quantity of water carried by the stream networks must first be collected. Next, data on the geology and soils in the vicinity of the stream channels must be amassed and a determination made of how the natural earth materials will behave if man-made alterations of the surface water system are effected.

DEFINING THE GEOLOGIC SETTING

To determine the earth materials present in an area and define their characteristics, specific types of data must be collected from both the surface and subsurface. For example, in the past 70 years the sequence of rock strata and the types of rock included in the 2000 to 3000 feet of sedimentary rock above the denser, igneous rock in northern Illinois have been studied from water well logs and samples procured by drilling or from outcrops. As a result, the rock type, mineralogy, texture, color, and fossil content of the rocks of that region and their position within a recognizable sequence are now well defined.

Deposits of unconsolidated earth materials left by the glaciers, streams, and wind also are differentiated by use of logs and samples and by the land forms, such as end moraines and terraces, in which they occur. Discrete geologic units can thus be recognized and their lateral and vertical boundaries defined. From limited exposures of materials at the surface, geologists can infer the sequence and character of materials below land surface with some degree of accuracy. Soil maps are frequently used in such extrapolations. However, geologists need data from the subsurface to enable them to describe in detail the thickness and extent of mineral resources, the flow paths of ground water, and even the presence of strata that might present problems to engineers and planners. Pedologists also use subsurface data in their studies of the parent materials of soils.

The soil is visible at the surface and can be mapped in detail. A soil auger or other soil sampling tool is sufficient for exposing the soil profile, or solum, to the soil scientist. Because the soil is at the surface, samples for detailed laboratory analysis can usually be collected whenever desired. By examining the solum, a pedologist can observe soil characteristics and differentiate soils. He can also determine the location and distribution of each soil in an area. Soils developed in localities of naturally poor drainage can be separated from naturally well drained soils, and fine-textured soils can be distinguished from coarse-textured soils. Soil units can be mapped to any scale, a scale of 4 inches to the mile being most often used for field mapping and for published reports of areas with complex soil patterns.

INTERRELATION OF GEOLOGIC AND SOILS INVESTIGATIONS

Coordinating Geologic and Soil Mapping

Coordinating pedologic and geologic data for application to land-use planning was first promoted by J. E. Hackett when he was on the staff of the Illinois State Geological Survey. He developed a way of presenting the data on maps that would be useful to planning groups. That the approach was workable was proved by the success of recent work in northern Illinois (Hackett and McComas, 1969). The coordinated program included field study, mapping, sampling, and pertinent laboratory analyses. Three basic steps are involved in producing and coordinating soil and geologic maps.

First, the distribution and character of the near-surface geologic units (fig. 2) are determined. Soils are developed on unconsolidated materials or rocks exposed to the soil-forming processes, and, as these parent materials exert a strong influence on the character of the soil that develops, specific data are collected on their characteristics. In the once-glaciated portions of northern Illinois, these properties include general lithology and, more specifically, grain size, clay mineralogy, and carbonate content of the tills and other fine-grained materials. A considerable bank of data is now available and is routinely used in determining the stratigraphy and distribution of the glacial tills in Illinois.

Second, the soils are classified and mapped according to their individual characteristics, which are determined by field observation and laboratory analysis. Because parent material is one of the factors that determines a soil's characteristics, soils can be established for each geologic unit. Often, differences between soils developed on different geologic units are not great enough to justify separations for agronomic uses. However, it is becoming apparent that these differences are frequently significant to other land uses and should be noted during the soil mapping.

Finally, when a soil survey for a specific area is completed, the soils mapped on each parent material can be grouped into sequences of soils that define the distribution of each geologic unit (fig. 3). A detailed geologic map is then drawn that uses the boundaries of soils developed on each parent material as the boundaries of that geologic unit (figs. 2, 3). Conflicts or problems may arise during the soil mapping or in the preparation of the detailed geologic map, especially where geologic conditions are complex and difficult to generalize. Additional field and laboratory studies by the geologist and soil scientist are then necessary, and most of the problems can thus be resolved cooperatively.

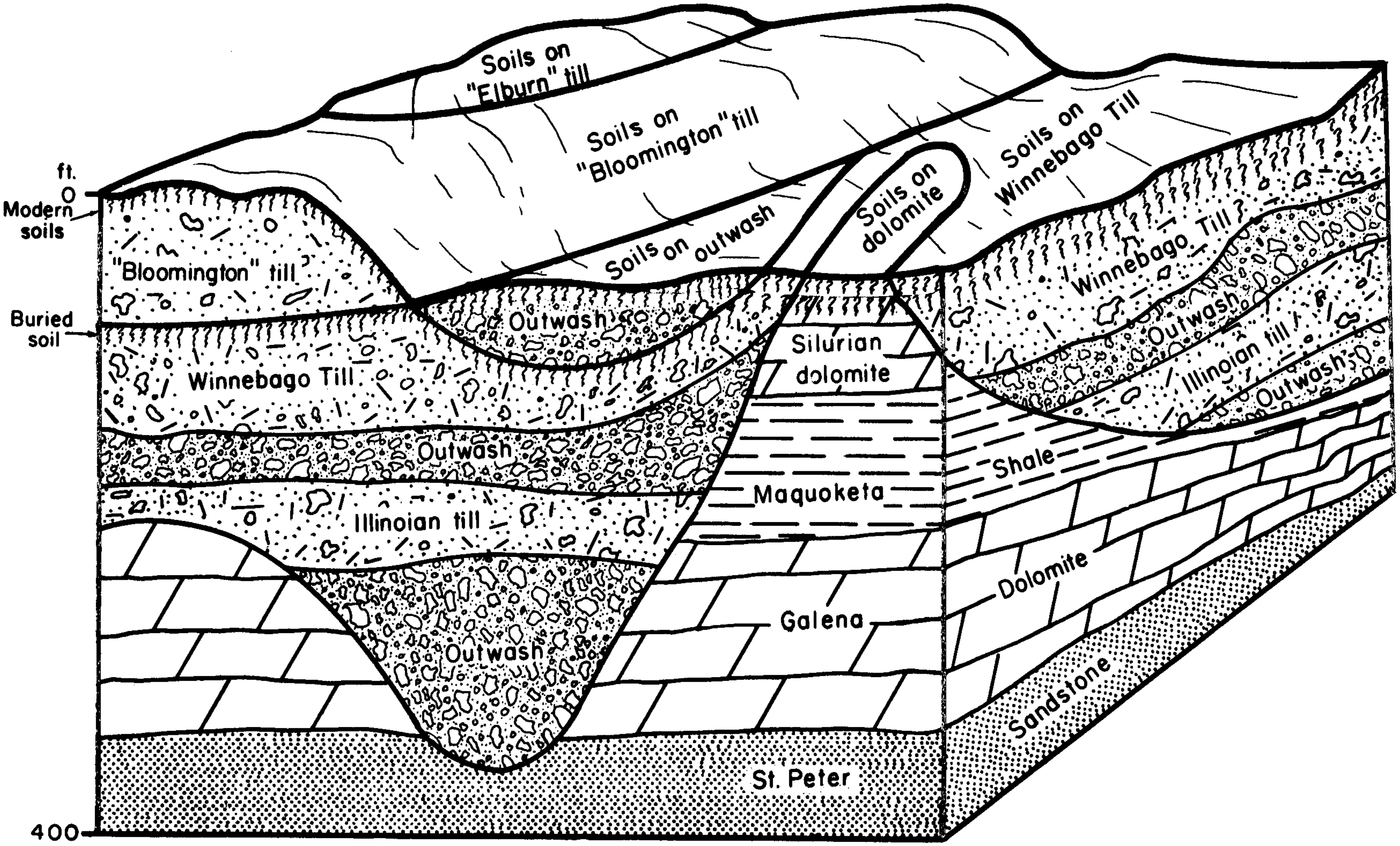

Fig. 2 - Block diagram of the geologic framework of a section of the earth showing different soils developed on the various geologic units.

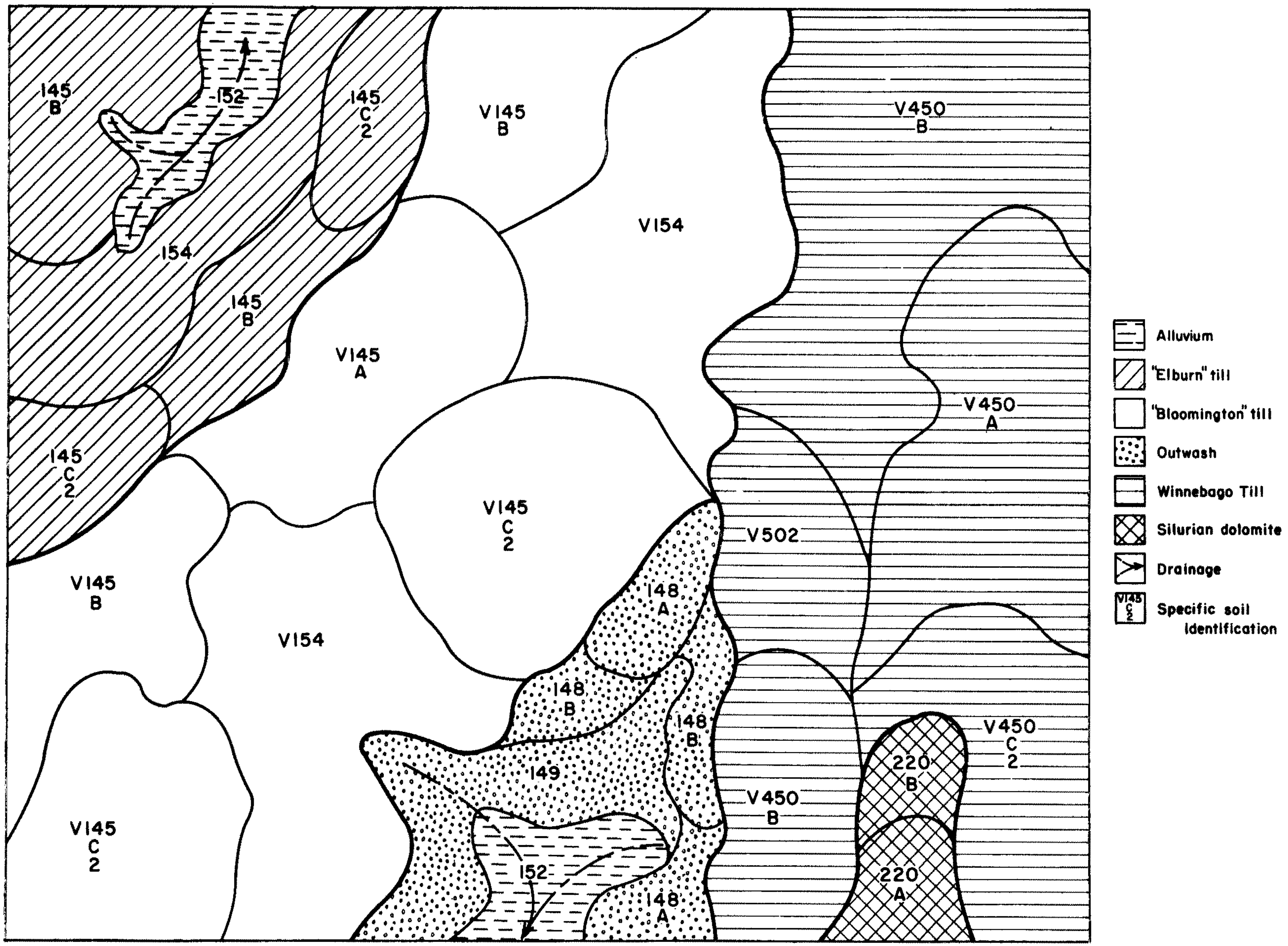

Fig. 3 - Soils developed on surficial deposits shown in figure 2 and their relation to those geologic units. Each number-letter code indicates a soil type developed on a specific geologic parent material.

The completed geologic map produced in this manner has the advantage of the detail that is routinely achieved in soil maps, while the soil map has the advantage of having incorporated the dimension of depth from the geologic studies, which is vital in many land-use applications. The preparation of interpretative maps for land-use applications can then proceed with confidence.

Determining Specific Characteristics of Units

To be most useful for planning applications, soil and geologic units are investigated for more specific characteristics after the mapping has been completed and the sequence and pattern of materials established. Each of the units on both maps is relatively consistent; therefore, the characteristics of each unit, once determined from an adequate sampling program, can be extrapolated for the entire area covered by that unit.

The definitions and descriptions of the soils that are given on the maps can be interpreted to yield agricultural information such as organic matter level, available nutrients, yield potential, and data relevant to soil management (see Ray and Washer, 1965). However, for urban and other nonagricultural applications additional information is required. For example, interpretations of engineering characteristics of an earth material require data on properties that affect strength and compressibility, such as the shrink-swell ratio and Atterberg limits (Thornburn, Morse, and Liu, 1966; Smith, 1968), whereas interpretations of hydraulic characteristics require data on soil properties that affect permeability, depth to saturation, and moisture content. These data are obtained from field and/or laboratory studies of samples (taken to accord with the mapped soil units) by specialists in soil mechanics, soil physics, or soil chemistry. Predictions can be made about a soil's engineering characteristics by comparing its physical characteristics with those of similar soils that have developed on similar parent material and for which the engineering properties are known.

Geologic data to supplement the geologic map are collected in a like manner. Specialists investigate the various mapped units. The engineering geologist determines various properties of each unit, including strength, compressibility, permeability, and Atterberg limits. The ground-water geologist investigates each unconsolidated surficial unit and bedrock unit in terms of its potential for storing and yielding water and also determines areas of recharge and discharge of ground water and its general direction of flow. Information about the soil and topographic setting is extremely valuable in this task, inasmuch as hills and ridges with well drained, dry soils are usually recharge areas, whereas lowlands with hydromorphic,or water-logged, soils are usually discharge areas. The clay mineralogist determines such properties of the clay as its drying and burning characteristics. The sand and gravel deposits and other shallow mineral resources must also be examined to determine their thickness, areal extent, texture, and mineralogy. Deep bedrock formations containing mineral fuels and metals are evaluated from data from well borings and extrapolations of surface information. Usually, great detail about the deeper bedrock units is not essential for land-use planning.

Interpreting Integrated Soil-Geologic Data

Soil-geologic data for surficial units are used in the preparation of maps that interpret the facts in terms of specific land uses. The soil interpretative maps and the geologic interpretative maps are prepared separately because the soil scientist is best qualified to interpret soil data and the geologist is best qualified for interpretations of the geology. Both the geologic and soil maps are drawn to the same scale, and, since unit boundaries coincide, planning groups can superimpose the maps for planning studies.

Among the many kinds of interpretative maps made from soil maps are those indicating areas with best agricultural productivity, limitations for septic filter fields, water-related hazards, and limitations for building and foundations. Recently guide maps were developed for McHenry County, Illinois, by the Department of Agriculture Soil Conservation Service, in cooperation with the McHenry County Soil and Water Conservation District, the Illinois Agricultural Experiment Station, and the McHenry County Regional Planning Commission (Quay, 1968), stressing conservation and productivity areas and soil limitations for urbanizing areas. Interpretative maps are made by rating each soil according to the factors that impose limitations for a specific use.

In northern Illinois some geologic and hydrologic factors that are pertinent to land-use planning are the presence of recoverable mineral resources, availability of surface water and ground water, construction conditions and hazards, and conditions relating to waste disposal (Hackett and McComas, 1969). Maps evaluating such information are prepared on the basis of the nature and properties of the various geologic units. Criteria are established for grading a geologic unit with regard to its value as a mineral resource and as a potential source of ground water. Criteria in the case of mineral resources are based on specifications of the largest users of the commodity. For example, the Illinois Division of Highways, which uses great quantities of sand and gravel, has set standards for texture, shale and chert content, and compressibility of that commodity. The value of commodities such as sand and gravel, rock, and clay is also limited by the volume of the deposit, its accessibility, and its proximity to a market.

Criteria used for rating areas for ground-water availability are the thickness and extent of aquifers, their porosity and permeability, quality of water, and their depth below the surface. In the evaluation of a surficial geologic unit as a site for solid or liquid waste disposal, the potential for pollution of ground water or surface water is used as the limiting factor. The principal consideration is how fast waste-affected water can reach ground-water supplies. The longer the path the fluid travels and the slower it travels, as it does in clays, the lower the pollution level of the water that finally reaches the ground-water reservoir.

Criteria for rating areas suitable for general construction are based on foundation conditions, flood-hazard potential, depth to ground water, depth to bedrock, and availability of aggregate close to the construction site.

With the basic interpretative maps that were prepared from soil data and geologic information, the planner can consider the significant control elements of the physical environment along with the human factors in comprehensive areal planning.

SUMMARY

With the present trend to more comprehensive regional planning, detailed data on the physical environment are needed. These data can be acquired through integrated investigation of the soils, geology, and hydrology of the region. Integrated studies of soil and geology should include field observations, sampling, and laboratory analyses from which soil and geologic maps can be developed. On these maps the soil and geologic units have coincident boundaries.

The soil and geologic maps are interpreted by pedologists and geologists in terms of the suitability of the land for specific land uses. Interpretation is in the form of maps showing conditions relevant to a particular use. The planner can use these maps to help him recognize the limitations, hazards, and natural resources of the physical environment of the area for which land-use plans are being made.

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