Soil-geomorphology emerged as a distinct subdiscipline at the interface of pedology, geology, and geography only in recent decades and remains an active and evolving field of study (e.g., Birkeland 1974; Birkeland 1984; Birkeland 1999; Gerrard 1992; Daniels and Hammer 1992). Technically, soil-geomorphology is “the application of geologic field techniques and ideas to soil investigations” (Daniels and Hammer 1992, 1) or, more simply, “an assessment of the genetic relationships of soils and landforms” (Gerrard 1992, 2). More broadly defined, soil-geomorphology involves study of the coevolution of soils and landscapes, and can include the use of soils for reconstructing paleoenvironments and paleolandsapes and for dating or estimating age (Boardman 1985; Catt 1986; Knuepfer and McFadden 1990; Birkeland 1999). Judging from the number of books by a diverse group of earth scientists using the terms “soils and geomorphology” in their titles, it has already attracted a wide following (e.g., Birkeland 1984; Birkeland 1999; Daniels and Hammer 1992; Gerrard 1992).

Soil-geomorphic research is diverse and carried out by individuals with differing disciplinary backgrounds and viewpoints, but a common link among all is the concept of the soil and the relationship of soils to the factors of soil formation and landscape evolution (Arnold 1983; McFadden and Knuepfer 1990, 197; Daniels and Hammer 1992, 1; Gerrard 1992, 2–5; Johnson 1993; Birkeland 1999). Soil-geomorphology has many links to pedology, particularly its field focus on soil-forming processes and on the spatial relationships of soils. As an academic field, however, it tends to be institutionally located in geology or geography departments rather than with pedology, which is generally found among the soil science subdisciplines in agronomy.
Soil Survey and Soil-Geomorphology

Soil Taxonomy, Soil Horizon Nomenclature, and Soil-Geomorphology

The development of Soil Taxonomy (Soil Survey Staff 1975) undoubtedly has been the SCS/NRCS’s most influential contribution to pedology, both nationally and internationally. It is probably one of the most significant advancements in the field in the second half of the twentieth century. Because it is the official classification system of the SCS/NRCS and the National Cooperative Soil Survey, and because of the links between these entities and academic soil science and agronomy programs, Soil Taxonomy was almost immediately adopted by the bulk of soil investigators in the United States (Birkeland 1984, 42; Birkeland 1999, 49; Hallberg 1984, 55). It became the lingua franca for all U.S. pedologists.

Some geoscientists initially rejected the new terminology of the original Seventh Approximation (Soil Survey Staff 1960) (e.g., Hunt 1972, 180–182; Morrison 1978, 100–101), but most investigators quickly recognized the utility of a widely used, well-organized, comprehensive set of well-defined, mutually exclusive, largely nongenetic terms for describing and classifying soils. The advent of this soil classification system has had many advantages for soil-geomorphology. The newer system eliminated some of the ambiguity in classification and horizon nomenclature in the older, 1938 system (Buol et al. 1997, 32–33; Bartelli 1984), and the concept of the diagnostic horizon, probably the most useful aspect of the new system, provided an efficient means of communicating a wealth of information about a soil or components of a soil-stratigraphic unit.

Because diagnostic horizons are quantified, soil development, and by inference landscape development, can be quantified to at least a general level. For example, identification of an argillic horizon in a soil indicates that a specified, minimal amount of clay was illuviated. Further, because of the quantitative nature of Soil Taxonomy, labs have generated reams of data on soils throughout the country (e.g., the USDA National Soil Survey Center/Soil Survey Laboratory database). Researchers can return to the data and use it for additional purposes.

Adoption of the Soil Survey Manual (Soil Survey Staff 1951; Soil Survey Division Staff 1993) to meet the requirements of a nationwide soil survey for standardized and detailed soil profile descriptions also assured a vast amount of nationally comparable information on field properties of soils. The well-known, well-defined standardized set of genetic horizons (the master horizons and subhorizons such as A and Bt) for field descriptions in soil survey has proven to be one of the most widely used and convenient systems of shorthand field nomenclature in the geosciences (e.g., AGI 1982). This information allowed soil geomorphologists to create a variety of soil development “indices” as a
way of semiquantitatively expressing soil development for purposes of correlation or to assess soil development as a function of the soil-forming factors (Bilzi and Ciolkosz 1977; Harden 1982; Harden and Taylor 1983; Schaeztl and Mokma 1988).

Soil Taxonomy has created some disadvantages for soil-geomorphology as well. Most generally, the considerable efforts during the 1960s and 1970s that went into developing and refining the new classification system that became Soil Taxonomy seem to have stifled other pedologic research (Swanson 1993; Paton et al. 1995, 1). The SCS supported several extensive soil-geomorphic research projects from the 1950s to the 1970s, but otherwise most governmental and academic pursuits in pedology focused on classification as an end in itself (Runge and McCracken 1984; Daniels 1988; Daniels and Hammer 1992, xvi; Swanson 1993). This focus, and the absence of geologists and physical geographers in soil science departments, may help explain why soil-geomorphology evolved largely in geoscience departments throughout those years.

Applying the USDA-approved diagnostic and genetic horizons in soil-geomorphic research has had a few disadvantages as well. Most problems stem from the need for arbitrary rules or decisions inherent in any attempt to categorize and classify parts of a continuum. For example, the amount of illuvial clay in a soil can be an excellent indicator of landscape stability and landscape age (Birkeland 1999). For a horizon to qualify as argillic, however, only a small amount of illuvial clay must be present. Therefore, identification of a subhorizon as argillic conveys some information about a minimal degree of pedogenesis, but within the designation of argillic there can be a significant range of clay content, potentially masking important soil-geomorphic distinctions.

As another example, soil-geomorphologists working in dry environments have found the concept of the K horizon as a master soil horizon very useful (Birkeland 1999; Machette 1985; Harden et al. 1985; Birkeland et al. 1991; Reheis and Kuhl 1995). It serves as a convenient field designation that provides a qualitative assessment of a zone of massive carbonate accumulation, which is typically found on older geomorphic surfaces and represents the culmination of the time-dependent evolutionary process of calcic soil development. The SCS, however, never adopted the K horizon as part of the official nomenclature for genetic horizons (Soil Survey Division Staff 1993). One of the reasons the K horizon designation was not adopted was to avoid setting a precedent that might lead ultimately to renaming other horizons; Bt horizons would become T horizons, for example (personal communication, K. Flach to P. Birkeland 1989).

The soil classification system itself has proven of less utility in soil-geomorphology than have the diagnostic and genetic horizons. The system was designed to facilitate classification for soil survey and land-use purposes, and is geographically biased toward the agriculturally productive soils of the midlatitudes. It was not designed to be a tool in soil-geomorphic or other geoscientific research. The taxonomy serves as a very useful nomenclature for referring to or describing surface soils, conveying a tremendous amount of relatively specific information.

Some studies have shown that soil taxonomy can be applied to soil-geomorphic research (Birkeland 1999, 31, 39). Taxonomic classification can be used in soil geomorphology to describe facies or lateral variations in a soil-stratigraphic unit. For example, L. Gile and coworkers used taxonomic classification to identify pedogenic variability (soil facies) within soil-geomorphic units (which could also be soil-stratigraphic units) in a variety of alluvial and eolian deposits in south-central New Mexico (e.g., Gile et al. 1981) (see Figure 9.1) and in northwestern Texas (Gile 1979; Gile 1985). Sometimes the classification differentiates soils of different ages in a chronosequence. For example, the sequences Hapludoll-Argiudoll-Paleudoll or Cambid-Haplargid-Paleargid can denote development in the thickness, clay content, and color of the argillic horizon with time. Long-term pedogenic pathways can even express themselves at the order level of soil classification, e.g., Entisol-Inceptisal-Alfisols-Ultisols-Oxisols.

On the other hand, the degree of specificity and the rules and requirements in Soil Taxonomy have serious drawbacks for soil-geomorphology uses. As Hallberg (1984, 53) notes, “classification involves . . . the Tyranny of the Pigeonhole.” He further points out (Hallberg 1984, 57) that “. . . the institutional, or bureaucratic implementation of the U.S. system of soil taxonomy . . . has often had the effect of making [it] inflexible; its implementation often rigid and legalistic.” In other earth sciences, in contrast, there are a number of “scientific codes or guidelines put forth by professional societies, which are freely debated in the scientific literature [and at] professional meetings” such as the Code of Stratigraphic Nomenclature (e.g., NACOSN 1983).
in geology (Hallberg 1984, 57). Because many soil-geomorphologists are trained in geology or physical geography, we often alter terms from Soil Taxonomy to suit our needs. For example, we might provide adjectives such as “weak argillic horizon” (Btj or juvenile Bt in field nomenclature) for horizons that barely meet argillic criteria.

Roger Morrison, one of the pioneering soil-geomorphologists in the western United States, and one of the few workers who attempted to establish principles of Quaternary soil stratigraphy (Morrison 1967; Morrison 1978), further notes that “Soil Taxonomy suppresses or distorts certain pedologic distinctions which can be important to geologists by various legalistic and narrow restrictions; for example, the thickness limitations for most epipedons and diagnostic subsurface horizons...and the minimum allowable concentration of CaCO3 for calcic horizons” (Morrison 1978, 100).

A specific example of this problem can be found among surface soils across the high plains of Texas and New Mexico, where a group of well-developed soils formed in Pleistocene eolian sediments. Two of the more common surface soils are the Amarillo and Acuff series, both with thick, well-expressed argillic and calcic horizons. The only significant difference between these soils is the thickness of the A horizon: the Amarillo has a thinner A, the Acuff a thicker A (Mathers 1963; Allen et al. 1972; Stoner and Dixon 1974; Blackstock 1979; Holliday 1990). Otherwise, they are the same soil geomorphically and stratigraphically. These differences in A horizon thickness probably are due to wind erosion (Holliday 1990), but this single difference between otherwise identical soils results in their classification in two orders: Paleustolls (Acuff) and Paleustalfs (Amarillo).

Some of the terminology of Soil Taxonomy may cause confusion for soil-geomorphologists. Occasionally, terms given nongenetic definitions in Soil Taxonomy may hold genetic implications in soil-geomorphology research. For example, the “Pale” prefix at the Great Group level should indicate old soils in a soil-geomorphologist’s view, but the definitions of Paleboroll and Paleboralf refer to the depth to the top of the argillic horizon. This probably has more to do with geomorphic position than soil age. In any case, defining how old is “old” would further impose arbitrary distinctions that would serve no useful purpose. In another example, the Fluvent suborder was designed to include floodplain soils with multiple buried A-C profile, but the definition omits landscape setting and thus Fluvents can occur in eolian deposits such as sand dunes.

The study of buried soils, especially for stratigraphic correlation and for environmental reconstruction, is probably the oldest and perhaps the best-known component of soil-geomorphology and serves well to illustrate some of the difficulties of applying Soil Taxonomy in soil-geomorphic research. The study of buried soils requires application of essentially the same level of care and attention to detail as the study of surface soils, including use of much of the same terminology. Applying both the diagnostic horizon nomenclature and taxonomic classification to buried soils is significantly more problematic, however, because of erosion of near-surface horizons or of postburial diagenesis of the soils, which are both greater the longer the soil or sediment has been buried, and because Soil Taxonomy is explicitly designed for surface soils only.

Components of buried soils can be described in terms of diagnostic horizons, but the characteristics of the horizon may be different from...
its preburial state. Erosion or compaction changes horizon thickness, for example, which is a significant component of the requirement for mollic and calcic horizons. Color of a mollic epipedon, also a classificatory requirement, usually changes after burial due to oxidation of organic matter. Furthermore, pedogenesis in the deposits that bury a soil may modify the buried soil in a process known as “soil welding” (Ruhe and Olson 1980); a calcic or argillic horizon can be superimposed over a buried mollic or argillic horizon, for example.

Because the genetic and diagnostic horizons are well defined and widely used, all investigators must take care to apply the terminology appropriately. Zones in buried soils that are reddish and high in clay have been identified as argillic horizons (Retallack 1986; Retallack 1988; Retallack 1990; Lehman 1989) but with no clear documentation for clay translocation (see discussion in Dahms and Holliday 1998; Dahms et al. 1998). Patterson (1991) documented the diagenetic origin of some of these zones in Eocene sediments in Wyoming. Furthermore, mollic epipedons have been designated in the absence of adequate color, thickness, base saturation, or organic carbon requirements in soils affected by millions of years of diagenesis (Retallack 1990; Retallack 1993; Retallack 1997); it is therefore questionable whether the term “mollic,” with all that it implies, should be used for these soils (Dahms and Holliday 1998; Dahms et al., 1998).

Taxonomic classification often is possible if a complete buried profile is preserved and the burial was recent, but the classification will differ from the preburial classification over the long term. Burial changes characteristics of the diagnostic horizons and almost always changes soil moisture and soil temperature, environmental characteristics necessary for much classification. Significant changes in soil and water chemistry can also accompany or follow burial and can significantly affect classificatory characteristics such as base saturation. Further problems can be encountered when classifying buried soils in terms of horizons and taxonomy for paleoenvironmental interpretations because few types of horizons or taxonomic categories are associated with unique environmental conditions.

Because of the difficulty of applying Soil Taxonomy to the classification of buried soils, alternative classifications have been proposed (Mack et al. 1993a; Nettleton et al. 1998). Interestingly, they use terms, concepts, and a structure from or similar to Soil Taxonomy. Which system, if any, becomes the lingua franca of paleosol studies awaits extensive field testing.

SOIL SURVEYS AND SOIL-GEOMORPHOLOGY

The soil survey work of the SCS/NRCS is probably the agency’s best-known activity. This work has produced tremendous amounts of data on soils from throughout the United States, exemplified by the USDA National Soil Survey Center/Soil Survey Laboratory database. The most widely known and widely used products of the soil survey research, however, are the many published soil surveys themselves. They contain a wealth of information regarding soils and land-use capability, and many include descriptions of soil properties of interest to engineers. In some cases, they also contain data of relevance to soil-geomorphic studies. For example, soil surveys in the midwestern United States often characterize loess deposits, and these data have been used in soil-geomorphic studies of loess thickness and origin, soil erosion, and textural controls on soil-geomorphology (Fehrenbacher et al. 1986b; Fehrenbacher et al. 1986a; Mason 1992; Mason and Nater 1994; Mason et al. 1994). The surveys also are a remarkable source of maps and aerial photographs.

For a variety of reasons, however, soil surveys have not been used to any significant degree in soil-geomorphic research, probably because the purpose of the soil surveys is for assessing land capability and management, especially in agricultural contexts. The soil surveys were never intended as geoscientific resources. As Swanson (1990a, 17) notes, however, “In the course of mapping, soil scientists learn much about the nonsoil properties of the landscape. Some of these properties are described in a general way in the soil survey report; however, much of the information does not find its way into the manuscript and is subsequently lost.” As a result, data on regional geomorphology and geology in the surveys often are secondary and skimpy at best and, in most cases, are a very minor component of the survey. Discussion of all five factors of soil formation typically occupies no more than two to three pages out of perhaps 50 to 100 pages of text in a soil survey, with only a few paragraphs on the most general characteristics of the geology and geomorphology (e.g., Huckle et al. 1974; Blackstock 1979; Rector 1981).

Admittedly, however, there are many regions in the U.S. where only minimal data on surficial geology and geomorphology were available prior to the soil surveys. Soil surveys sometime contain more substantive discussions of geomorphic and geologic characteristics of the soil
landscape in regions with a long history of surficial geological studies, such as the glaciated Midwest (e.g., Hole 1976) or where intensive soil-geomorphic studies were carried out (discussed below) prior to the soil survey work (e.g., Geric 1985; Branham 1989).

Further inhibiting soil-geomorphic applications of soil surveys is the emphasis on the soil series and the lack of emphasis on the soil-forming factors. The soil series, though the lowest level of soil classification, is the basic mapping unit of soils surveys and typically is the highest level of grouping “soil individuals” (Swanson 1990b). As the soil surveys developed through the twentieth century, genetic and factorial relationships among series as well as the aforementioned geologic and “physiographic” aspects, were expressly de-emphasized (Simonon 1997), despite Jenny’s (1946) work that showed a good relationship.

With publication of Soil Taxonomy, soil series were defined strictly as subdivisions within the classificatory system and were intended to

“record pragmatic distinctions, i.e., to be keyed to soil usefulness” (Simonon 1997, 80). The result is that mapping units (soil series) are rarely related to one another except taxonomically. “To illustrate, the soil classification relates an Aquet in a certain map unit to other Inceptisols throughout the world. But it does not address the relationship between the map unit containing the Aquet and other map units that occur adjacent to it in the survey area” (Swanson 1990b, 52). There are a few notable exceptions to this approach in soil mapping, such as F. D. Hole’s work in Wisconsin (e.g., Hole 1976) (see Figure 9.2).

Moreover, some series may include a variety of soils that are genetically and geomorphically distinct, a notable problem in valley landscapes because of the inherent variability over short distances of valley fills and geomorphic surfaces, compounded by the lack of adequate landscape models in use by soil mappers. Examples include some soils on the floors of dry valleys on the southern high plains that are mapped as the Berda Loam, a series which can include a group of geomorphically and stratigraphically distinct soils (Holliday 1985), and the Napier series applied in the thick loess region of western Iowa (Bettis 1995). On the other hand, a group of series may comprise what is geomorphically one soil (i.e., a single soil-stratigraphic unit), as seen on the southern high plains surface (Holliday 1990).

There are several other reasons why soil-geomorphologists have not readily used soil surveys in their research to any great extent. An important one is the different spatial perspectives of geoscientists versus pedologists. Geomorphologists and stratigraphers, on the one hand, tend to view the world horizontally, emphasizing features such as geomorphic surfaces and landforms, as well as three-dimensionally, studying stratigraphic units. Few of these specialists include the soil in their studies. Many pedologists, on the other hand, traditionally tend to view soils as “independent entities occurring at specific points” (Daniels and Nelson 1987, 289) and focus on the vertical dimension of soils.

Pedology field training and field experience often deals with soil pits and soil profiles rather than soil landscapes (Daniels and Hammer 1992, xv–xvi), probably because 1) so much training and research in pedology involves digging soil pits or taking soil cores for mapping and studying profiles for taxonomic classification (Swanson 1990a; Paton et al. 1995, 1), 2) Soil Taxonomy defines soils as single points (Daniels and Hammer 1992, 77), and 3) many soil-forming processes promote downward movement. For example, in histories and historical perspectives on soil
survey and soil classification, some of the key players in the postwar decades (Arnold 1984; Bartelli 1984; Simenson 1987) emphasized the soil profile, the pedon and polypedon, and the “soil individuals.”

Though landscape position is an important component of field investigations of soils, soil surveys in recent decades have de-emphasized viewing or investigating soils as components of landscapes, i.e., dealing with soils as three-dimensional, contiguous bodies (Daniels and Nelson 1987; Daniels and Hammer 1992, 77; Paton et al. 1995, 5–8). Soil surveys place even less emphasis on the soil parent material or on soil evolution through time (i.e., as four-dimensional bodies formed in sediment or rock) (Daniels and Hammer 1992, 10, 77; Simenson 1997). The underemphasis on the landscape and soil parent materials probably is because taxonomic classification emphasizes “soils as units unto themselves” (Daniels and Hammer 1992, 77) or “soil individuals,” a view which developed along with the arbitrary subdivision of soils into pedons and the resulting separation of soils and pedons from natural landscapes (Knox 1965; Daniels and Hammer 1992, 77). Exceptions to this view of soils include some of the early soil survey work, where different soil series were identified if the parent material changed (Simenson 1997) (predating the concepts of the pedon and soil individuals), soil surveys in areas of substantial soil-geomorphic research (e.g., Gerig 1985; Brannah 1989), and soil surveys by geologically trained investigators such as Francis D. Hole (e.g., Hole 1976) (see Figure 9.2), one of the country’s preeminent pedologists whose formal education was in geology rather than soil science (Tandarich et al. 1988).

There are a few examples of soil surveys being used to make Quaternary geologic maps. One is a map of the San Joaquin Valley, California (Birkeland 1999, Fig. 2.4). It was made by combining information from the soil maps, basically using soil series to denote general geologic age and geomorphic relationships. Another example is where Maat (1992) mapped various ages of dune sand, combining information from soil maps, geomorphic relationships, and radiocarbon ages (Birkeland 1999, Fig. 2.5).

**IMPACT OF THE USDA SOIL-GEOMORPHOLOGY PROJECTS**

Soil Taxonomy and soil mapping are clearly the most widely known contributions of the SCS/NRCS to pedology, but the U.S. Soil Survey also supported some of the most intensive, systematic investigations of soil-geomorphology in North America. Effland and Effland (1992, n.d.) have described these investigations and their origins and support within the soil survey. The SCS/NRCS’s initial involvement in soil-geomorphic research began in the 1930s as a component of erosion studies. Significantly, scientists in disciplines other than pedology initiated the work. This early research arose from the recommendations of the eminent geographer Carl O. Sauer, a member of Franklin Roosevelt’s Presidential Science Advisory Board, that pedology, geology, and climatology should be integrated in land research. The SCS implemented Sauer’s proposal by establishing a Division of Climatic and Physiographic Research and appointing the noted climatologist C. Warren Thornthwaite as head. The projects administered by Thornthwaite produced valuable data, but were limited by declining funds, lack of baseline data on soils and geomorphology, and the onset of World War II.

Soil-geomorphic research in the SCS resumed in 1933 in a program created under the impetus of Charles D. Kellogg and Guy D. Smith. They “. . . advocated a fully developed multi-site series of soil-geomorphology studies as the basis of a research program in support of the soil survey” (Effland and Effland 1992, 204). Seven soil-geomorphology studies were authorized over the next 25 years. In 1953, Robert V. Ruhe was hired to begin the first of these studies and to direct the entire soil-geomorphology research program, which he did until leaving the SCS in 1970.

Ruhe’s unique contribution to the study of landscape evolution was to emphasize the characteristics and geomorphic distribution of soils in studies of landscapes and thus lay the foundation for the development of modern soil geomorphology. From a pedologic standpoint, “. . . Ruhe was instrumental in pioneering the process and quantification of landscape studies and integrating them into modern soil science studies” (Olson 1997, 415; see also Olson 1989). Ruhe’s view of landscape evolution began to gel during geomorphological research in the Belgian Congo from 1951 to 1952 (Ruhe 1954a; Ruhe 1956a). He was heavily influenced by Lester King’s pedimentation concepts (slope backwearing) (King 1949, 1950, 1953) and especially by Milne’s catena concept (Milne 1953a, 1953b).

An unusual aspect of Ruhe’s approach was to “. . . completely separate descriptions of the soil, and the geomorphology and geology in a study area . . .” (Effland and Effland 1992, 204), then later integrate them to interpret the land-
success of those two studies is arguably because both geologists and geomorphologists were involved.

THE IOWA PROJECT

The soil-geomorphology studies initiated in Iowa by geologist Robert V. Ruhe were the prototype for modern landscape evolution and soil geomorphology research. The Iowa Project involved soil-geomorphic studies in three stratigraphically, geomorphically, and pedologically distinct parts of the state, with sites in southwestern, north-central, and eastern Iowa.

The southwest Iowa study area, where the project was initiated in 1953, was the site for the study of the relationships among Quaternary stratigraphy, geomorphology, and soils in 58 railroad cuts along a 72-kilometer transect between the towns of Bentley and Adair (Ruhe et al. 1967; Ruhe 1954b; Ruhe 1969). An expansion in 1955 added the Greenfield quadrangle area of southwestern Iowa to the study and brought R. B. Daniels to the project team as a soil scientist. The study area extended from the Loess Hills region eastward into the southern Iowa drift plain (Prior 1991), within the region of the classic pre-Illinoian (Kansan and Nebraskan) glacial sequence (Ruhe 1969; Halberg 1986). Across the area, late Wisconsin loess thinned from about 15 meters in the west to 9 meters in the east, burying older landscapes and soils developed in Illinoian loess and pre-Illinoian glacial deposits. Soil development also varied from west to east, with deeper calcification and more intense oxidation to the east. A significant result of this research was demonstrating that the soil variability was not just related to the west-east climate gradient, but was also due to the eastward fining of the loess and due to the lower sedimentation rates to the east.

The Iowa Project's recognition of the soil landscape and stepped erosion surfaces (Ruhe 1960) laid the conceptual groundwork for modern soil geomorphology. These concepts hold that because weathering takes place from a land surface, soils and the landscape elements on which they occur are intimately linked. Professional papers and field trips resulting from the southwest Iowa study demonstrated the critical role of soil-morphologic and soil-geomorphic studies in elucidating the geomorphic history of landscapes. It also began the melding of geomorphology and pedology, which led to the development of the subdiscipline of soil-geomorphology.
The concept of "stepped erosion surfaces," which increase in age as they ascend toward divide areas (Ruhe 1956b; Ruhe et al. 1967), was one of the most far-reaching and influential geomorphic concepts developed during the southwestern Iowa study. The relative ages of these geomorphic surfaces were demonstrated on the basis of lithostratigraphic, soil stratigraphic, and pedologic arguments rather than solely on the basis of topographic relationships. Principles of ascendancy and descendancy were applied to hill slopes to establish relative age relationships among the stepped surfaces (Ruhe 1975). This premise, that a slope element is younger than the higher surface to which it ascends but the same age as the sediments to which it descends, is a fundamental relative dating concept in modern geomorphology.

The term "pedisement," referring to the surficial sediment above the stone line on a pediment, was first introduced to American geoscience as a result of this study (Ruhe 1956a; Ruhe et al. 1967). Ruhe demonstrated the morphostratigraphic linkage of the pedisement, stone line, and pediment, bringing together slope evolution concepts developed in arid, humid, and tropical landscapes (Bryan 1940; King 1953; Ruhe et al. 1967). Another important concept introduced during the southwest Iowa Project was the "hillside profile," a commonly used system describing the components of a slope profile, which include summit, shoulder, backslope, footslope, and toeslope (see Figure 9.3) (Ruhe 1960).

The north-central and eastern Iowa soil-landscape study began in 1960 (Ruhe 1970), examining landscape history and the relationships among geologic deposits, geomorphology, and soils on a young, glaciated till plain in the north-central part of the state (late Wisconsin Des Moines Lobe) and on what was then interpreted as an earlier Wisconsin ("Iowan") till plain in eastern Iowa (Ruhe 1969). The study involved G. F. Hall, R. C. Schuman, and E. Robello (who relieved Schuman) from the SCS Washington staff as active participants and also trained many students who later became prominent pedologists and soil geomorphologists, including G. H. Simonson, T. E. Fenton, P. H. Walker, and W. J. Vreeken.

Using extensive transects of borings at five "bogs" (fens) associated with different moraines of the Des Moines Lobe, the team studied stratigraphic, sedimentologic, pedologic, chronologic, and palynologic relationships (Walker 1966). Investigators related the Holocene history of slope evolution and basin infilling to vegetation and inferred climatic changes and established linkages among vegetation cover, soil erosion, and sedimentation that have strongly influenced Holocene landscape evolution concepts in recently glaciated humid to subhumid continental regions (Gerrard 1992). The study also demonstrated that the effects of regional climate and vegetation change on the soil-geomorphic system produced a predictable sequence of slope sediments and basin fills that strongly influence the geography of surface soils (see Figure 9.4). Using the principle of ascendancy and descendancy, in combination with radiocarbon ages on basin fills, the work showed that the region's slopes, and the soils formed on them, were less than 3,000 years old (Walker 1966; Walker and Ruhe 1968).
fore much younger than the underlying drift and closely related in time to the overlying loess. The Iowan Drift plain was shown to consist of a series of discrete multilevel erosion surfaces that step down from divides to an integrated drainage net (Vreeken 1975; Hallberg et al. 1978). The concept of stepped erosion surfaces developed in southwest Iowa also provided the key to understanding and predicting the distribution of geologic materials and soils in the Iowan region.

In addition, the Iowa Project confirmed the effectiveness of radiocarbon dating and of core-drilling transects in landscape evolution studies, which had significant impacts on the direction of subsequent soil-geomorphology research, especially in the midcontinent of North America. Radiocarbon dating has become a standard method for correlation and for assessing rates of soil development in many soil geomorphology studies, while core-drilling has permitted studies in areas where natural exposures are rare or excavations are impractical (e.g., Holliday 1995; Mandel 1995; Bettis and Autin 1997).

Soil-landscape models produced during this project greatly benefited the soil survey by significantly increasing the predictive capabilities of soil mapping. Indeed, Ruhe's soil-landscape model was still applied in relatively recent soil surveys in Iowa (e.g., Branham 1989). Reciprocally, geomorphology also benefited from soil surveys that incorporated soil-landscape models and thereby provided continuous spatial data on soil-geomorphology.

### The New Mexico Desert Project

The New Mexico soil-geomorphic studies, universally known as the Desert Project, ran from 1957 to 1972. The Desert Project was the longest sustained study of desert soils to date, and it lives on through recent publications of the New Mexico Bureau of Mines and Mineral Resources (e.g., Gile et al. 1995). It had and continues to have a significant influence on geomorphological research in deserts. Robert Ruhe served as the initial leader of the Desert Project, developing the overall research strategy and publishing some of the earlier results (Ruhe 1962; Ruhe 1964b; Ruhe 1967). Beginning in the early 1960s, however, pedologists Leland H. Gile, recruited by Ruhe out of the Ph.D. program at Cornell University, and Robert B. Grossman and geomorphologist John W. Hawley became the key investigators. Hawley, after working as a geologist for the state of Nevada and replacing Fred Peterson on the Desert Project in 1962, was the only principal researcher, besides Ruhe, in the soil survey's soil-
geomorphology projects who had formal, graduate training and experience in geology and geomorphology. This teaming of formally trained pedologists and geomorphologists may in part account for the success of the project.

Although SCS scientists initially proposed the desert region near Tucson, Arizona, as the desert soils and geomorphology research study area, complications arose that led to the selection of the area in and around Las Cruces, New Mexico, where investigators could call on support from an office of the Agricultural Research Service, the Jornada Experimental Research Station, and New Mexico State University’s College of Agriculture. Ultimately, the area provided an ideal setting for desert soil-geomorphic research. Extensive geomorphic surfaces on terraces of the Rio Grande and alluvial fan remnants of nearby piedmonts, all mostly associated with lithologically similar parent materials, enabled development of soil chronosequences. Some surfaces spanned a wide enough range of elevations to provide pronounced climatic and vegetation gradients, allowing evaluation of these factors in pedogenesis. In addition, variation in bedrock types allowed for studies of soil development on alluvium derived from local lithologies such as limestone, in comparison with soils formed on the more common gravelly arkosic sediments.

Most of the data from the Desert Project was published in the massive, 984-page Desert Project Soil Monograph (Gile and Grossman 1979), and the key soil-geomorphic relations (including maps), concepts, and conclusions were included in the Guidebook to the Desert Project (Gile et al. 1981). These publications vividly illustrate the role that soil-geomorphic research can play in soil survey. Klaus Flach, the assistant administrator for the soil survey at the time, noted that such soil maps are unlike those that typify a standard soil survey precisely because the emphasis of the project was soil-geomorphic research (Gile and Grossman 1979, iv).

The finely drafted, high-resolution soil maps from selected areas superbly illustrate how soils are related, however subtly, to diverse desert landforms. The maps are superimposed on vertical aerial photographs and often include diagrammatic cross sections of the most important study sites and the locations of pedons. In some cases, block diagrams were included to better display the relations of surface age, geomorphic position, and soil type. These diagrams are particularly effective in revealing the underlying cause of variation in soil proper-

Figure 9.4 The classic illustration of the stages of carbonate accumulation in high-gravel and low-gravel parent material for south-central New Mexico. (Source: Fig. 5 in Gile, Leland H., Fred F. Peterson, and Robert B. Grossman. 1966. Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Science 101:347-360)
petrocalcic horizons as a function of time and parent material, proceeding from stage I to stage IV (see Figure 9.5; see also Figure 9.12). Subsequent research also demonstrated the importance of landscape position on carbonate morphology (Gile et al. 1981). In their discussion of the “stage concept,” Gile et al. (1966) demonstrated that these stages reflected a time-dependent evolutionary process of calcic soil development. Recognition of this time dependency provided a powerful means to estimate the age of alluvial fan and terrace deposits of desert regions because they seldom contain materials suitable for the numerical dating techniques available in the 1960s to 1980s. Development of this new technique was particularly significant because dating is one of most critical types of information required in the solution of many geoscientific problems in geomorphology and related earth sciences.

In the year preceding publication of this important paper, the Desert Project team had introduced the K horizon as a new master horizon (Gile et al. 1965). They recognized that a zone of massive carbonate accumulation (a K horizon) was primarily observed on the older geomorphic surfaces in the region (usually late Pleistocene and older) and represented the culmination of calcic soil development (stages III and IV). They also showed that the K horizon, once formed, had a profound influence on subsequent soil development and landscape evolution.

Many earth scientists working in deserts, especially North Americans, quickly adopted the concept of morphologic stages of carbonate accumulation and the K horizon. Both the stage designations and the K horizon were very handy shorthand field designations that conveyed a lot of qualitative information regarding the morphology and amount of carbonate accumulation and also provided clues to relative soil and landscape age. As mentioned above, the SCS/NRCS did not accept the K horizon (Soil Survey Division Staff 1993), designating such a soil horizon as a Bk or Bkm horizon. According to the Soil Taxonomy, soils with stage II and III horizons are calcic horizons, whereas a stage IV horizon is usually a petrocalcic horizon.

Another very significant result of the Desert Project research was demonstrating the importance in arid region soil genesis of dust and other external additions to soils. The entrainment and progressive accumulation of calcium derived from dust (and to a smaller extent, rainwater) was the key to explaining the remarkably systematic development of horizons of carbonate accumulation. Prior to the Desert Project studies, scientists attributed many key aspects of desert soils to slow chemical weathering of calcium-containing silicate minerals that, given the limited depth of leaching of desert soils, favored calcification at a relatively shallow depth ("pedocals").

The Desert Project research showed that this explanation in most circumstances could not be correct. Ruhe, Gile, and their colleagues observed an enormous mass of pedogenic carbonate in sequences of soils that were formed in gravelly arkosic deposits dominated by silica-rich but calcium-poor minerals. Mass balance studies showed that chemical weathering of tens of meters of parent material would be required to produce this carbonate, yet observations could not provide evidence for this magnitude of weathering. Moreover, the Desert Project team observed that relatively large amounts of carbonate had accumulated in soils (stage I) that were formed in parent materials no older than late Holocene. Studies of modern dust samples collected using dust traps showed that modern dust contained both the kinds and amounts of materials required to form pedogenic carbonate, as well as to form the silicate clay in the overlying Bt horizons in middle Holocene soils. Although other researchers, notably Israeli scientists (e.g., Yaalon and Ganor 1973), had recognized the potentially large influence of dust on the genesis of calcareous and/or clay-rich horizons of desert soils, the Desert Project, by linking the atmospheric with the soil data, provided the data to critically test and ultimately accept the hypothesis. Finally, investigations showed that both the Bt and Bk horizons formed rapidly, and, in places, the Bt horizons formed more quickly in desert than in humid environments (Birkeland 1999).

The popular Desert Project field trips conducted annually well into the 1980s helped convey key concepts of the research to a wide array of scientists, including many from outside the United States (Gile et al. 1981, viii; personal communication, J. Hawley to L. D. McFadden 1996). These interactions not only helped provide an international audience for the Desert Project, but they also provided an opportunity for feedback and critique from accomplished desert soil scientists and geomorphologists from, for example, Israel and Australia.

The Desert Project findings significantly increased understanding of soil-forming processes in deserts and provided the basis for development of conceptual models of Quaternary soil-landscape evolution in desert regions. These models reflect the influences of Quaternary climate changes on soil development and geomorphic processes (e.g.,
changes in regional base level) and other important geologic factors. Figures by Peterson (1981), one of the early researchers in the Desert Project, and Wells et al. (1985) provide visual summaries of many key aspects of these models. All of the above acted as catalysts in the development of subsequent, innovative research in geomorphology.

The studies of Michael Machette and his colleagues exemplify some of this research. Bachman and Machette (1977) and Machette (1985), for example, applied the morphological-stage approach in mapping, identification, and correlations of Cenozoic deposits in the southwestern United States. During this research, they encountered soils that exhibited carbonate morphology much more advanced than stage IV. Consequently they defined two additional stages of development (stages V and VI), showing that at least in some deserts the soil-landscape connection could be sustained for several million years.

Machette (1978; 1985) also developed a means to procure numerical age estimates from calcic soils based on the determination of the total accumulated mass of pedogenic carbonate and some assumed rate of calcareous dust input. These were used to determine the ages of alluvial deposits, including seismogenic deposits such as fault scarp colluvium, and to estimate fault recurrence intervals. The 1978 study is one of the first to demonstrate the critical importance of soils in paleoseismologic research (see also Machette 1988). Machette (1985) also developed a more advanced conceptual model for calcic soil formation that combined dust input and climate to predict how climate changes might effect the evolution of calcic soils in the Quaternary.

Other advances that strongly reflect the influences of the Desert Project research include the development of a soil profile index that could be used for noncalcic and calcic soils (Harden and Taylor 1983; McFadden et al. 1986), numerical models for the evolution of calcic soils (McFadden 1982; McFadden and Tinsley 1985; Marion et al. 1985; Mayer et al. 1988; McDonald et al. 1996; McFadden et al. 1998), a new model for the formation of desert pavements (Wells et al. 1985; Wells et al. 1995; McFadden et al. 1986; McFadden et al. 1987; McFadden et al. 1998), new applications of soil-stratigraphic studies in geoarchaeological research (e.g., Holliday 1994), derivation of climate proxy and paleoatmospheric data from stable isotopes in calcic soils (e.g., Cerling et al. 1989; Quade et al. 1989; Amundson et al. 1988; Wang et al. 1996), studies of modern rates, compositions, and origin of desert dust (Reheis and Kihl 1995; Reheis et al. 1995), and numerical dating of soil carbonates (Ku et al. 1979; Amundson et al. 1994; Wang et al. 1996).

Ironically, the success of the Desert Project has also indirectly caused a few problems. Many earth scientists, for example, have had an unfortunate tendency to rely too heavily on observed stages of carbonate accumulation for age estimates of Quaternary alluvial deposits. Many of these researchers apparently do not recognize that there are other means by which nonpedogenic features that resemble petrocalcic horizons can form in surficial deposits or in the shallow subsurface environments (Birkeland 1999). Nor do they seem to recognize that rates of pedogenic carbonate accumulation can vary widely in many landscapes and that the observed progression of morphological stages in southern New Mexico (see Figure 9.5) does not even occur in some regions (Machette 1985; McFadden 1981; McFadden 1988; McDonald and McFadden 1994; Holliday 1995, 94). They may also overlook the fact that, whereas knowledge of age control for Holocene deposits, and therefore rates of Holocene carbonate accumulation, is generally good, age data for Pleistocene deposits and calcic soils is sparse, as well as the fact that many important questions remain concerning the actual genetic processes (e.g., biogenic versus inorganic) of pedogenic carbonate accumulation (Monger et al. 1991; Monger and Adams 1996; Verrecchia et al. 1995). These problems are partly due to the typically sparse treatment of soil science in the curricula of most earth science departments (McFadden 1993) and to the fact that earth scientists using this strategy are understandably motivated by the need to answer geologic questions and not by a desire to understand the soils or soil-like features themselves.

Another problem associated with the carbonate stage concept is that some researchers have attempted to base models of the timing and nature of alluviation and their linkage to Quaternary climate changes in deserts on temporal constraints provided by carbonate stage data. However, in the Desert Project study area most of the older deposits have little or no numerical age control. Subsequent research forced major changes in the original age estimates for upper Pliocene to middle Pleistocene deposits in southern New Mexico. This is because soils and sediments of more than one age are within the general age range of some geomorphic surfaces (e.g., Gile 1987) and because of subsequent studies in tephrachronology and magnetostratigraphy (e.g., Mack et al. 1993b). For example, Gile (Gile 1987; Gile et al. 1995) reported much wider age ranges and older ages for the Jornada II surface (25,000 to
150,000 years) and the Lower La Mesa surface (500,000 to 900,000 years) versus the earlier estimates of 25,000 to 75,000 years and 500,000 years (Gile et al. 1981). These very broad age ranges preclude attempts to associate deposition of the alluvium with these surfaces with particular climate changes in the Quaternary.

The ongoing value of the Desert Project is marked in several other ways. The New Mexico Bureau of Mines and Mineral Resources recognized the significance of the research by sponsoring all Desert Project publications beginning in 1967. The study area became a part of their environmental geology program in 1977, when they also assumed sponsorship of all subsequent field trips (Gile et al. 1981, vii). More broadly, the Desert Project research is prominent in some of the most widely read volumes on soils, geomorphology, and Quaternary geology (Birkeland 1984; Bull 1991; Gerard 1992) and in the major geomorphology textbooks (e.g., Ritter et al. 1995; Easterbrook 1993).

This exposure ensures that new generations of students in geomorphology and other areas of the earth sciences will be introduced to the ideas of the Desert Project and made aware of its legacy. Some of these students will be inspired to seek out the original publications of the Desert Project and will see how detailed soil survey investigations provided the essential foundation for ideas that have so strongly influenced scientists who work in deserts.

**Coastal Plain Project**

Begun in 1960 with R. B. Daniels as project leader and the assistance of pedologists E. E. Gamble and W. D. Nettleton from the SCS Washington office, the “Coastal Plain Project” investigated deposits, landscapes, soils, and paleoenvironments of geomorphic surfaces, ranging in age from Pliocene to Holocene, along the Atlantic Coastal Plain Province of North Carolina. Among other contributions, this investigation produced one of the first comprehensive studies of Ultisol genesis. Systematic increases in mineral weathering, solum thickness, and gibbsite and plinthite content were demonstrated to be associated with increasing age of the geomorphic surface on which soils occurred (Daniels et al. 1970; Daniels et al. 1978; Daniels and Gamble 1978), although these relationships were not linear because of water-table regime complications. For example, they concluded that the thickness of the E horizon and the depth to the B horizon was related to the posi-

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...tion of the water table. This study also showed that soil variability decreased from young to old surfaces as a result of parent material uniformity and the convergence of soil profile characteristics over extended periods of weathering and soil development (Gamble et al. 1970). The “edge effect” concept was developed during investigation of soil variability within geomorphic surfaces on this project. This concept explains variations in soil color, E horizon thickness, and gibbsite and free iron oxide content with respect to water-table flux in different landscape positions (Daniels et al. 1967). These studies also found that the relationship between soil color, saturation, and oxidation state were very complex and not evident solely through interpretation of soil morphology (Daniels et al. 1973).

The Coastal Plain Project led to subsequent, more extensive studies of soil-geomorphology on the Atlantic Coastal Plain and neighboring areas. From 1979 to 1984, the SCS and the U.S. Geological Survey (USGS) conducted cooperative regional studies of the relations between soils and geology on the Piedmont and Coastal Plain Provinces of the middle Atlantic and southeastern states (Markewich et al. 1986; Markewich et al. 1987; Markewich et al. 1988; Markewich et al. 1989; see also Markewich and Pavich 1991; Markewich et al. 1990). The work showed that soils and other aspects of physical and chemical weathering could be used to estimate the ages of landscapes with a variety of siliceous parent materials spanning the past several million years. In particular, they provided substantial data on the evolution of Ultisols and Spodosols, on the impact of parent material and drainage on pedogenic processes, and on the soil characteristics best suited to estimating the ages of land surfaces in that environment. Closer to the setting of the Coastal Plain Project, Phillips et al. (1994) tested the “edge-effect model” by looking at local-scale variability in soils. The model successfully predicted some aspects of soil variability, but not all patterns could be accounted for by water-table position, drainage, or topography. Phillips et al. proposed that local soil variability may be linked to biological factors such as tree throw and faunal turba...
Soils associated with late Pleistocene and Holocene geomorphic surfaces in the valley (Balster and Parsons 1968; Parsons et al. 1970), although they did conduct some studies on such nearby areas as the adjacent mountains (Parsons 1978). These landscapes evolved through a complex series of events related to base-level changes controlled by the Columbia River, catastrophic floodwaters and sediment input from the Columbia River system, and sediment input from glaciers within the Willamette watershed (summarized by McDowell and Roberts 1987).

Of particular interest in the studies were investigations of soil variability as a function of lithologic and stratigraphic variability in parent materials. The buried soil-stratigraphic record exerted considerable influence on the geography and interpretation of surface soils. For example, relatively flat smooth surfaces were shown to have complex origins that included both erosion and deposition; below such surfaces, the lithologies vary significantly. Parsons and Balster (1967) established that discontinuous lenses of primary clay were often mistaken for argillc horizons, and they demonstrated that the complex evolution of some surfaces included pedogenesis and subsequent soil burial, with surface soils now welded to buried soils (Parsons et al. 1968).

The model of fluvial landscape evolution that resulted from the Oregon Project had a significant impact on soil survey in Oregon. In the decades since the end of the SCS project, the model has been used for mapping soils and describing their distribution along rivers (e.g., Gerig 1985) and on the Pacific Coast (e.g., Shipman 1997). Indeed, Parsons prepared the discussions of geomorphic surfaces and soil development for some soil surveys (e.g., Gerig 1985, 182–187), illustrating well the significant contributions of basic soil-geomorphic research in the preparation and publication of soil surveys.

CONCLUSIONS

The SCS/NRCS's soil survey was probably the single most important program influencing the direction of pedological research in the United States in the twentieth century. As such, the soil survey influenced soil-geomorphic research, though to a lesser degree. The soil survey provided most of the basic language of pedologic research used in soil geomorphology, in the form of horizon nomenclature, guidelines for soil profile descriptions, and a taxonomy for soil classification. Soil survey activities have also provided a wealth of data on soils, in the form of field and laboratory data, county soil surveys and maps, and statewide soil maps.

In terms of understanding fundamental aspects of soil-geomorphic relations, soil survey work has been less successful, however. Much soil survey work focused on mapping, describing, and classifying soils, and surveyors were discouraged from pursuing important geomorphic or other geologic and environmental relationships, despite the fact that soil factorial functions and an understanding of soil-forming processes had been shown to successfully predict soil patterns (Jenny 1944; Jenny 1946; Arnold 1994). Input by geomorphologists familiar with the region or a means of communicating the geomorphic and geologic information that the soil mappers acquire would significantly enhance the usefulness of soil surveys.

The biggest impact of soil survey activity on soil-geomorphology was through the SCS soil-geomorphology studies from the 1950s to the 1970s, an "extraordinary collaboration between academic pedologists and soil scientists of the National Cooperative Soil Survey" (Jacob and Nordt 1991, 1994). The Iowa Project and the New Mexico Desert Project were the most notable achievements, helping to formalize and provide direction for the new field of soil geomorphology and influencing the broader disciplines of geomorphology and Quaternary geology. Much of the success of these projects resulted from the teaming of pedologists and geomorphologists.

The significance of these studies has been formally recognized by the Quaternary Geology and Geomorphology Division of the Geological Society of America. Every year since 1958, the division has given the prestigious Kirk Bryan Award for an outstanding publication. Two publications that won the award, Ruhé's 1969 book Quaternary Landscapes in Iowa (1974 award) and Gile, Hawley, and Grossman's 1981 Guidebook to the Desert Project (1983 award), resulted directly from the SCS soil-geomorphology projects. Additionally, the soil-geomorphology projects heavily influenced other award-winning books by Birkeland (1984) (1988 award) and Holliday (1995) (1998 award). The success of the SCS soil-geomorphology projects and the subsequent joint SCS-USGS surveys on the Coastal Plain and Piedmont Provinces indicate that pedologists, geomorphologists, and Quaternary geologists would substantially benefit from future soil-geomorphology projects, perhaps as cooperative ventures among the NRCS, the USGS, state geological surveys, and academic departments of soil science, geology, and geography.
The story of the influence of the Soil Survey on soil geomorphology reflects a strong dichotomy between soil survey and soil geomorphology, one representing the fundamental descriptive level of soil mapping and classification, the other the large-scale, long-term, interdisciplinary research projects. We believe that for soil-geomorphology to continue to benefit from the Soil Survey, and vice versa, the integration of the two needs to fall more often in the middle ground, particularly at the level of teaching and training fundamental principles of pedology and geoscience in both soil science and geoscience departments, at both the undergraduate and graduate levels.

Moreover, soil survey and soil mapping should more actively incorporate geomorphology and geomorphologists in its work, as was the case years ago. Few earth scientists get to know a landscape as intimately as soil mappers; they should be encouraged and trained to make geomorphic observations and to link soils and soil-forming processes to the landscape and geomorphic processes. Closer ties between agronomy-trained pedologists and geoscience-trained soil-geomorphologists will further both disciplines. As our friend John Hawley once put it: “You can’t understand geomorphology without understanding soils, and you can’t understand soils without understanding geomorphology.”

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Soil Survey and Soil-Geomorphology


INTRODUCTION

Every day land managers make decisions, the success of which depends wholly or in part on the nature of soils. Understanding the capability, limitations, and potential uses of our soils is fundamental to effective decision making. Soil survey data are among the most important pieces of information used by government units, businesses, and individuals to make land-use decisions that range from development and taxation to farming and natural resource protection.

Interpretations of soil survey data are based on how soils respond for a specific use. Soil interpretations employ a set of rules or criteria based on basic measured soil properties, inferred properties, or classes of properties. Soil interpretations may be developed at different levels of generalization. Highly integrative generalizations may be constructed for management groups—groupings of soils that require similar kinds of practices to achieve acceptable performance for a soil use. Many of these broad national-level interpretive groups (e.g., highly erodible lands, hydric soils, prime farmland) find their way into national legislation. National-level generalizations, by their very scope, typically lack the sensitivity necessary to support highly localized decision making. Thus, interpretations useful at the local level generally require adjustment or development of interpretive criteria that reflect local or regional distinctions as well as user needs. Effectively using soil survey interpretations in decision making depends on understanding the level of generalization as well as other pertinent considerations (see Figure 10.1).