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A History of Soil Geomorphology in the United States

Vance T. Holliday

Introduction

Soil geomorphology has a long and rich history in the United States and has had a significant impact on soil-geomorphic research worldwide. It has been particularly important in unraveling the ages and evolution of landscapes. The history of soil geomorphology is very poorly documented, however. What little is written is confined to very specific components of the story (e.g., Birkeland, 1989; Olson, 1989, 1997; Effland and Effland, 1992; Johnson and Hole, 1994; Holliday et al., 2002) or is tangential to it (e.g., Tandarich and Sprecher, 1994; Tandarich, 1998a,b; Bockheim et al., 2005). This is probably because: 1) the history of this subdiscipline is very diverse, with roots in Quaternary geology, pedology, and physical geography; none of which are well-documented; and 2) because soil geomorphology was not formally recognized as a distinct subdiscipline until late in the 20th century.

Outlining the history of soil geomorphology is important precisely because of its interdisciplinary roots and outlook. Although pedology has its intellectual roots in geology (Tandarich et al., 1988; Tandarich, 1998a,b), most pedologic training and research in both academic and governmental settings in the U.S. has tended to focus on soil description and classification, mapping, contemporary land use, soil quality, and plant productivity, and not on reconstructing the past (Daniels, 1988; McFadden and Kneupfer, 1990; Daniels and Hammer, 1992; Swanson, 1993; Tandarich and Sprecher, 1994; Bronger and Catt, 1998; McFadden and McDonald, 1998; Holliday et al., 2002). While important in characterizing soils, describing their spatial distribution, and understanding their potential for supporting crops, these subfields tell us little about how soils (and associated landscapes and environments)

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evolved and why soils are where they are on the landscape. Such characteristics of soils are crucial in their conservation. Moreover, soil geomorphology is an important tool for reconstructing the past. Soil genesis is dependent on a variety of environmental factors. Chemical, physical, and biological characteristics of soils uniquely reflect the integration of these factors. Soils, therefore, under the right circumstances, can help us understand these environmental factors in the past and how they interacted (e.g., Gerrard, 1992; Birkeland, 1999).

Research focusing on the relationship of soils and landscapes has rarely been a priority in either pedology or geomorphology, however. This situation largely evolved from the intellectual and physical separation of soil science from geoscience. Soil science became grounded in agricultural colleges, often on campuses physically separated from those with major research programs in geology and geography. This division mirrored the situation in the Federal government, where soil science research was a component of the U.S. Department of Agriculture (USDA) and generally not part of the U.S. Geological Survey (USGS) in the Department of Interior. Thus, the possibilities for “cross fertilization” and training among researchers, faculty, and students was and continues to be minimized. A goal of this chapter is to not only outline these unfortunate trends, but to highlight individuals, institutions, and programs that pursued and promoted research cooperation that became soil geomorphology.

This chapter is a first approximation of the development of soil geomorphology in the U.S. It follows several threads that evolved out of soil science and geology in the 19th century and went on to include physical geography in the years preceding WWII. The post-war explosion in scientific research in the U.S. is mirrored in the several lines of research, focused in Quaternary geology, pedology, and physical geography in both academic and governmental settings that led to the field of soil geomorphology as it stood at the end of the 20th century. The chapter is divided into five time blocks, based on general, convenient (though not altogether arbitrary) groupings of significant events in the history of the discipline: 19th century to the 1930s; 1930s to 1941; the war years; 1945 to 1974, and 1974 to 2004. Several individuals not from the U.S. and not working in the U.S. are mentioned in the discussion because their research and writing significantly influenced soil geomorphology in the U.S.

For this paper a broad view of what constitutes soil geomorphology is taken. At its most fundamental level, soil geomorphology is the study of genetic relationships between soils and landscapes (e.g., Ruhe, 1956a, 1965a; McFadden and Knuepfer, 1990; Daniels and Hammer, 1992; Gerrard, 1992, 1993). The focus is on pedogenic processes and geomorphic processes, and sometimes a strong component of hydrology, to understand the distribution of soils in the present (contemporary soil geography) and in the past. In a much
broader sense, however, soil geomorphology includes the investigation of soils as a means of studying and reconstructing the past, with a particular focus on soils as age indicators and soils as clues to past environments (especially vegetation and climate). These aspects of soil geomorphology evolved through both the “state factor approach” and through soil stratigraphy.

**19th Century to the 1930s**

There are two key threads in the early development of soil geomorphology. Both began in the 19th century, but include very different perspectives on soils. One thread is in pedology in Europe, studying soils at the surface. The other thread is in Quaternary geology in North America, looking at soils buried beneath the surface.

**Russian Roots**

An important step in the development of pedology and soil geomorphology was also one of the first steps in formulation of the “state factor concept” of soil genesis. This approach to soil genesis began with Russian scientists in the 1870s through 1890s, most notably V. V. Dokuchaev, but also N. M. Shibertsev and K. D. Glinka (Johnson and Hole, 1994; Tandarich and Sprecher, 1994; Tandarich, 1998a; Eutuhov, this volume). A noteworthy aspect of the five-factor approach as originally devised by Dokuchaev was its grounding in geology (Tandarich and Sprecher, 1994). Dokuchaev (1883/1967) outlined a framework for studying soils from a “geologic and geographic perspective.” His writing anticipated aspects of soil geomorphology a century later. For example, in his book on the Russian Chernozem (1883, translated in 1967) a chapter on the age of chernozems (pp. 373–386) includes discussion of the age of burial mounds and ancient fortifications as a means of dating underlying soils and soils on the artificial features. This approach to dating soils and estimating rates of pedogenesis continues to be important in soil geomorphology (e.g., Bettis, 1988; Alexandrovskiy, 2000).

The five-factor paradigm for soil genesis took root in the U.S. early in the 20th century, most widely promoted by C.F. Marbut, Chief of the Soil Survey Division in the Bureau of Soils (USDA), but also endorsed and espoused by E.W. Hilgard (1892) and G.N. Coffey (1909a,b; 1912) (see also Amundson, this volume). These soil scientists viewed the factors driving soil genesis in different ways, however, and the original Russian concepts evolved significantly as they were passed along. Coffey (1912) strongly emphasized the importance of climate in soil formation, but still recognized the importance of parent material. Hilgard expressly recognized the importance of late Quaternary geology in “agricultural survey” (soil
survey) (cited in Amundson and Yaalon, 1995) and, indeed, lobbied to have a division of agricultural geology (as soil science was then known) established in the USGS. After that effort failed, Hilgard worked with J. W. Powell, the eminent geologist who directed the USGS, to have that agency transferred to the USDA (Amundson and Yaalon, 1995). That attempt also failed, resulting in the institutional separation of pedology from geology.

Succeeding pedologists clearly tried to distance pedology from its geologic roots, although research demonstrating the significance of geology, especially geomorphology, to soils continued in the USDA. For example, E.E. Free (1911), with the Bureau of Soils, first demonstrated the significance of dust inputs in soil genesis. Glinka (1914) and Marbut apparently embraced the basic concept of the soil-forming factors, but most of Marbut’s lectures and writings, and those of his successor C.E. Kellogg, focused on the morphology and classification of soils. Marbut thus further distanced pedology from geology.

Even though the five factors of soil genesis became a leading conceptual framework in pedology, especially in the USDA, they almost disappeared from field work in the U.S. As the soil surveys developed through the 20th century, genetic and factorial relationships among series as well as geologic and other “physiographic” aspects, were expressly de-emphasized (Simonson, 1987, 1997a). Some pedologists apparently were eager to distance pedology from its geological roots (Wilding, 1994). Marbut (1928) himself indicated that soil characteristics and geologic characteristics should be considered completely independent of one another.

Midwestern Soil Stratigraphy

Another starting point for what is now soil geomorphology can be found in the early work on glacial stratigraphy in the Midwestern U.S. (Totten and White, 1985). Some of the earliest attempts at stratigraphic subdivision and correlation of glacial drift include reference to “buried forests” and buried plant remains (e.g., Whittlesey, 1848, 1866; Newberry, 1862; Worthen, 1868; Orton, 1870), although the full significance of these zones as indicators of past landscapes apparently went unrecognized. That quickly changed, however. Worthen (1870, 1873), Orton (1873), and Winchell (1873), among others, all recognized and described buried forest beds or peats, and believed that they represented interglacial intervals, and thus evidence of multiple glaciation. Newberry (1878, p. 38) later agreed that a buried forest bed represented an interglacial period and also “an interval of mild climate in the ice period,” an early allusion to the environmental significance of associated buried soils.

The most influential and widely known early work on soil stratigraphy in Midwestern glacial studies is the monumental body of research by T.C. Chamberlin and Frank Leverett. Chamberlin is best known for his field studies that resulted in
Table 1. Origin of glacial and interglacial stage names in North America
(from Totten and White, 1985, Table 1)

<table>
<thead>
<tr>
<th>Glacial</th>
<th>Interglacial</th>
<th>First reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wisconsin</td>
<td>Sangamonian</td>
<td>Chamberlin, 1894, 1895</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leverett, 1898a</td>
</tr>
<tr>
<td>Illinois</td>
<td>Yarmouthian</td>
<td>Leverett, 1899</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leverett, 1898b</td>
</tr>
<tr>
<td>Kansas</td>
<td>Aftonian</td>
<td>Chamberlin, 1894, 1895</td>
</tr>
<tr>
<td>Nebraskan</td>
<td></td>
<td>Chamberlin, 1894</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shimek, 1909</td>
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</table>

naming some of the classic interglacial stage names (Table 1). Less well known, however, is his training in soil science (or “agricultural geology”) (Tandarich et al., 1988; Tandarich, 1998a), and his use of degree of weathering of till to differentiate younger (Wisconsin) drift inside the classic Wisconsin moraine from older drift outside the moraine (Chamberlin, 1878), presaging similar soil-geomorphic work in the western U.S. almost a century later. Leverett’s work more directly related to soil stratigraphy. He recognized several buried soils and used them to establish several interglacial stages (Table 1). The Midwestern glacial and interglacial terminology quickly took hold and was used to identify glacial and interglacial stages. Thus, the Sangamon Interglacial was represented in the field by the Sangamon Soil, first named by Leverett (1898a) at its type section in central Illinois, developed in the Illinoian till sheet (Follmer, 1979). This soil was the first formally-named soil-stratigraphic unit, and is the best known and probably most intensively studied soil-stratigraphic unit in the world.

The Chamberlin-Leverett scheme, modified by Shimek (1909) (Table 1) became widely used in the early decades of the 20th century and helped focus geologic attention on the significance of buried soils in the glacial stratigraphic record. For example, poorly drained, gleyed deposits buried in till attracted attention and research, particularly the Sangamon Soil (Leighton and MacClintock, 1962; Follmer, 1979). This lead to identification of “gumbotil” (Kay, 1916), which was the poorly drained facies of the Sangamon Soil (though at the time, better-drained upland facies were not explicitly recognized). Subsequent research (Kay and Pearce, 1920) provided insights into the geochemical evolution of gumbotil that “was a major contribution toward understanding soil genesis” (Follmer, 1979, p. 82).

During the early work on the stratigraphy and character of the soils buried in Midwestern tills, little attention was paid to subtle variations in soil morphology
that we would now recognize as soil horizons (Follmer, 1979). In any case, most of the work tended to focus on gleayed, organic-rich “gumbo” soils. The field geologists who applied the soil-stratigraphic nomenclature typically knew little about soils or soil morphology (Follmer, 1979). This approach to soils began to change in 1923 when C.F. Marbut presented a series of lectures at the University of Illinois, making his case for the Russian approach to soil genesis and also presenting the A-B-C scheme of soil horizontation (Follmer, 1979). Soil scientists E. A. Norton and R. S. Smith (1928) were the first to describe the buried soils in terms of soil horizons, and geologists Leighton and MacClintock (1930) first recognized a relationship between well-drained and poorly-drained variants of the Sangamon Soil across a buried landscape, subsequently recognized as a buried catena (Follmer, 1979). By the 1930s, therefore, some geologists were beginning to apply the newly emerging concepts of pedology in unraveling the evolution of soils and landscapes.

1930s to 1941

In the 10 years or so before the U.S. became engaged in the Second World War, there were a series of developments in research and publication that had profound effects on the subareas within pedology, Quaternary geology, and physical geography that would emerge as soil geomorphology later in the century. In retrospect, that time, more broadly characterized in the history of the United States by economic turmoil (the Great Depression), environmental catastrophe (the Dust Bowl), and looming war, was something of a Golden Age in attempts at understanding the relationship of soils to landscapes, both modern and ancient. Indeed, some of these otherwise adverse conditions helped to drive what would become soil-geomorphic research. The research threads in pedology and Quaternary geology outlined above (promotion of the five-factor view of soil genesis and recognition of buried soils in the Midwest glacial sequence) continued, but several new research agendas and key players, and resulting publications, appeared on the scene.

USDA, The Soil Conservation Service and Soil Erosion Studies

In pedology, Marbut and then Kellog continued to promote the Russian approach to soil genesis both within the USDA and in other research and academic settings (Simonson, 1997b). In the USDA, the culmination of the Russian/Marbut influence can be seen in the official soil classification system published in 1938 (Baldwin et al., 1938). The classification was developed by Marbut in the years before his death in 1935 (Marbut, 1935; Kizer, 1985) and the importance of the factors can be seen at the higher levels of classification, with broad groupings based on
physiographic characteristics (e.g., “Tundra soils,” “Desert soils,” and “Prairie soils”) (Simonson, 1987). Further evidence of Marbut’s geologic view of soils can be seen in the emphasis on “mature soils” (or “zonal soils”). Notions of soil maturity and soil genesis undoubtedly stemmed from the concepts of landscape evolution espoused by one of Marbut’s professors, the eminent geomorphologist W.M. Davis (Cline, 1961; Johnson, 1985).

Another important event in the institutional study of soils in the 1930s was the establishment of the Soil Conservation Service (SCS) in the USDA. The roots of the SCS were in the Soil Erosion Service (SES), established in 1933 within the Department of the Interior (Effland and Effland, 1992). In 1935, due to severe wind erosion on the Great Plains, the SES moved to the USDA and became the SCS.

Within the SCS, a new approach to soils research, with significant geomorphic implications, was launched, driven by the advent of the New Deal and the severe environmental impact of the 1930s Dust Bowl. The following summary of the SCS soil erosion studies is from Effland and Effland (1992). In 1933 the “Science Advisory Board” (established during the New Deal) identified “land use” as an important problem that could be addressed by Federally-funded research. The Board contacted Carl Sauer (University of California-Berkeley), one of the leading geographers of his day, and he agreed with their assessment. He proposed developing a science of “surface and soil” and suggested that pedologists, geologists, and climatologists work together to study landscapes. Of particular interest at this time was soil erosion.

While these events were transpiring, the SCS established a Division of Climate and Physiographic Studies and hired climatologist C. Warren Thornthwaite, also an eminent researcher (with a PhD under Sauer), as chief of the Division. Thornthwaite took the recommendations of the Science Advisory Board, and he and Sauer established a series of soil erosion research projects at sites around the U.S. They made plans for research on the relationships of “surface and soil,” but most of the field scientists hired were geologists and geographers because few pedologists of the time were trained in erosion studies. The projects produced good data on erosion, but were ultimately limited by staff sizes, funding, and base-line data on soils and geology. This project, however, laid the groundwork for a remarkable series of soil-geomorphic studies several decades later. The work also brought geographers into the soil-geomorphic picture.

Hans Jenny and The Factors

The factorial paradigm of soil development culminated with publication of Hans Jenny’s Factors of Soil Formation (1941). Jenny (BioBox 1) prepared and published the book shortly after joining the University of California-Berkeley
(following in the footsteps of Hilgard). Much of his thinking evolved while at the University of Missouri, however, including his “rediscovery” of the soil-forming factors of Hilgard and the Russian school (Jenny, 1980, xi). Jenny presented the most comprehensive, detailed, and integrated statement up to that time on the

**BioBox 1 Hans Jenny, photographer unknown**

HANS JENNY  
b. 1899 in Zürich, Switzerland  
d. 1992 in Oakland, California, USA  

B.S. in Agriculture (1923) and Ph.D. in Agricultural Chemistry (1927), both from the Swiss Federal Technical Institute, Zürich. His teaching career began in Soil Science at the University of Missouri, Columbia in 1928. He moved to the Department of Plant Nutrition at the University of California, Berkeley, in 1936, then transferred to the newly created Department of Soils (1940) where he remained until he retired in 1967. Jenny’s initial interests were in soil chemistry and fertility, but exposure to soil mapping and classification in Missouri, and soil tours across the central and eastern U.S. sparked an interest in the factors responsible for pedogenesis. His focus was first on the factors of time and climate, but eventually grew into a desire to develop a “logical theory of soil-forming factors.” The result was *Factors of Soil Formation* (1941). His subsequent research and writing was diverse, including more on the factors (and an updated version of his book in 1980), and on soil chemistry and fertility, but also broader issues of ecology and conservation.

Amundson, 1994; Jenny, 1980, vii–xiii
influence of the soil forming factors (climate, organisms, relief, parent material, and time; the "clorpt factors"). The immediate impact of this volume was muted by the U.S. entry into Second World War (Arnold, 1994), but it went on to become one of the most influential books in pedology, and had a profound effect on soil geomorphology. Johnson and Hole (1994, p. 113) provide a succinct summary of the attractiveness of Jenny's approach: "... Jenny's distinctive contribution was to theoretically and methodologically showcase the formational-factorial approach by: using clear and simple language, using many excellent illustrations, bringing together under one cover numerous examples of soil forming situations, and calling attention to potential quantitative applications in pedology" (italics in original). Certainly the two most influential components of Jenny's thinking are formally outlining the "clorpt" formula and proposing a means of "solving" the formula by defining climofunctions, biofunctions, topofunctions, lithofunctions, and chronofunctions. The latter was an aspect of the factorial approach that was a significant step beyond the Russian/Marbut view of the factors.

In and of itself, however, Factors is not a volume on soil geomorphology nor is it a means to reconstructing the past. Jenny's training was in Agricultural Chemistry and his interest in writing his book was focused on systematizing soil data in ways other than classification (Jenny, 1941, xi) which by the 1930s was dominating much soil science research (p. xi). He wanted to organize soils data by means of "laws and theories" and "assemble soil data into a comprehensive scheme based on numerical relationships" (p. xi). The ultimate goal of the book was to "assist in the understanding of soil differentiations and... help to explain the geographical distribution of soil types" (p. xi). Jenny did not apply the factors as a means of reconstructing the past, and Factors was not intended as a textbook on soil geomorphology (though it inspired such work, discussed below). It was designed to "formulate a conceptual scheme" or "logical theory of soil-forming factors" (Jenny, 1980, xi). Applying the factorial approach to reconstructing the past had to wait for several more decades.

James Thorp

In the same year that Factors was published, James Thorp published a paper on the significance of the environment on soil formation (Thorp, 1941). Thorp (BioBox 2) was the leading figure within USDA, promoting continued attention to the geologic aspects of soils and to the importance of soils in understanding the past. Thorp had been a member of the Bureau of Soils under Marbut and, following Marbut's death, had gone on to further Marbut's views on soil genesis (and was a co-author of the 1938 classification). He also had training in and a continuing interest in geology (as did most soil scientists of the day) (Thorp, 1985), and this clearly comes through in the 1941 paper. Further, Thorp spent three years
(1933–1936) studying soils in China (Tandarich et al., 1985; Thorp, 1936, 1985) and became interested in the buried soils that are so prominent in the massive loess deposits (Thorp, 1935). His 1935 paper includes a review of the Russian approach to soil genesis, discussion of basic soil forming processes (e.g., laterization), and the role of soils in interpretations of Quaternary stratigraphy. This work was one of the first attempts to link the five factors, soil forming processes, buried soils, and reconstructions of past landscapes.

**Midwestern Soil Stratigraphy**

In Quaternary geology, soil stratigraphy continued to be applied for correlation and environmental reconstruction (see references in Scholtes et al., 1951; Thorp et al., 1951; Simonson, 1954). Thorp’s 1935 paper on his work in China (and published in China), was, as noted earlier, a landmark in this regard, but is little-known. Among those investigating buried soils, perhaps the best-known practitioner in the Midwest at the time was Morris M. Leighton of the Illinois Geological Survey. He was interested in using soils to determine the relative ages of glacial deposits (Ray, 1974). Leighton was strongly influenced by the Russian/Marbut approach to soils (indeed, he apparently spent time in the field with Glinka, according to Ray, 1974, p. 136), and attended lectures by Marbut at the University of Illinois in 1923.
(Leighton and MacClintock, 1930, 30). Leighton also apparently worked closely with soil scientists at the University of Illinois (Tandarich et al., 2002). The result was the promotion of the "weathering profile concept" (e.g., Leighton and MacClintock, 1930), which was essentially the geologic counterpart of the soil profile in pedology (Leighton, 1958). Tandarich et al. (2002) see this dichotomy in the geologic vs pedologic views of profiles as an important and unfortunate step in the distancing of pedology from its geologic roots (noted further below). Leighton (1934) also used relative degree of soil profile development to estimate the ages of Indian mounds in Illinois, an early application of soil development as an age indicator and one of the first applications of soil geomorphology in archaeological research in North America. A 1937 paper further carried the "weathering profile" concept to archaeological stratigraphy.

Kirk Bryan

Kirk Bryan is best known for his work on arid-land geomorphology and on archaeological sites (e.g., Haynes, 1990), but also published several influential papers dealing with soils and their significance in reconstructing the past (see BioBox 3). This research evolved from Bryan's geological and archaeological investigations in the Big Bend and Davis Mountains regions of far western Texas and in the Sandia Mountains of central New Mexico in the 1930s (Albritton and Bryan, 1939; Bryan, 1941; Bryan and Albritton, 1943). Bryan's work with his graduate student Claude Albritton in western Texas had the most far-reaching impact on soil stratigraphy. They were clearly influenced by the Russian view of soil genesis and by Jenny's then new volume (Bryan and Albritton, 1943, pp. 470–471), and also by a manuscript review from Thorp (Bryan and Albritton, 1943, p. 473). They formulated the concepts of monogenetic vs polygenetic soils and composite soils. As Johnson and Hole (1994, p. 115) note, "Their paper had a tremendous impact on pedology and geomorphology. The concept of polygenesis in particular has had a dramatic and lasting affect on these fields." Their concept of monogenetic soils was also important because it complemented Jenny's (1941) notion of a soil chronosequence whereby a set of soils varies only as a function of time (i.e., climate and the rest of the clorpt variables, except time, remained constant) (Johnson and Hole, 1994, p. 115).

Bryan was also involved in archaeological research at Sandia Cave, New Mexico. Though the archaeological work was in a cave (Hibben, 1941), most of Bryan's interests seemed to be drawn to the soils on the slopes outside (Bryan, 1941). He attempted to estimate the age of some enigmatic deposits and artifacts in the cave by comparing weathering characteristics (secondary iron content) of the cave deposits. He concluded that iron in the cave sediment must have been deposited when waters moving from the surface soil and through the rock carried
more iron, i.e., the source of the iron was from pedalfer soils. The current soils contain pedogenic carbonate, indicating and environment in which iron is not very mobile, so Bryan surmised that the iron in the cave originated during a past, wetter climate. Further, he correlated the cave stratigraphy and inferences about soils with the loess-, till-, and soil stratigraphy of the Midwest to estimate the antiquity of the cave inhabitants. The specifics of his reasoning and conclusions clearly do not hold up today, but this study was a milestone in applying principals of pedology and weathering to issues of Quaternary climate and archaeology.

International Influence: Milne and the Catena Concept

Through the 1930s Geoffrey Milne (East African Agricultural Research Station) and fellow soil chemists were attempting to come to grips with complex soil associations during the mapping of soils in Uganda. In one of the earliest statements on what would become known as the “catena concept,” Milne (1932, p. 5) wrote:

“over large areas where local variation in topography were regularly repeated, a given colour on any soil map... would have to be interpreted as
indicating the occurrence of not a single soil but of a sequence of soils occurring generally over the area, to be worked out on the actual ground in each instance according to topography and other local influences.”

Milne’s first formal publication on the topic, where he coined the term “catena” (1935a) essentially followed this original concept (see Gennadiyev and Bockheim, this volume). In a subsequent paper for the Third International Congress of Soil Science, Milne (1935b) expanded on his original ideas by noting that catenary associations can be due to differences in drainage conditions combined with the effects of erosion and redeposition along a slope. In a later paper, Milne (1936) argued that if erosion (including anthropogenic erosion) and redeposition kept pace with pedogenesis, then those processes should be considered pedogenic processes.

Milne was not the first to realize the importance of the soil-topography relation (these were long employed in the U.S. soil survey; Bushnell, 1927). However, Milne’s unique contribution was linking catenary patterns to specific processes: differential drainage, solute leaching downslope, and erosion/deposition (Milne, 1935b). A significant aspect of Milne’s research was that it focused entirely on mapping soils. Milne was not a geomorphologist and apparently had no interest in the evolution of landscapes in a geologic sense. His concept of the catena was described in terms of contemporary landscapes and processes.

The concept of the catena quickly caught on among U.S. pedologists (e.g., Bushnell, 1942) and was incorporated in the 1938 soil classification (Baldwin et al., 1938, p. 989). But here the basic idea was changed, in spite of objections by pedologists working in the tropics (ap Griffith, 1952). The catena was defined as a drainage sequence on uniform parent material. This was apparently done to aid classification of soil series into “geographic groups,” i.e., to classify different series by slope and varying drainage conditions, but otherwise formed in similar parent material (Thorpe, 1941, p. 42). The notion of uniform parent material was never considered by Milne, and his key concept dealing with transport/depositional processes was eliminated. Thus, the catena concept entered U.S. pedology in a form significantly altered from that originally proposed.

The War Years

Scientific research generally came to a halt during the Second World War. One significant exception deemed important to the war effort was joining geology and soil studies to create the Military Geology Unit (MGU) in the U.S. Geological Survey. Their mission was to provide geologic and other environmental data to answer military questions (e.g., evaluating, mapping, and illustrating landscapes to provide
indications of basic terrain characteristics, relief, and hydrology; suitability of areas for trafficability and construction, and availability of construction materials; and water supply). The individuals in the MGU had a dramatic influence on post-war soil geomorphology. During the years of the MGU (1942–1945), which operated under contract to the U.S. Army Corps of Engineers, 88 geologists, 11 soil scientists, and 15 other specialists were brought together to produce detailed strategic planning studies (USGS and USACE, 1945; Hunt, 1950; Terman, 1998). The leadership included Charles B. Hunt, who was first Assistant Chief and later Chief. As described below, he and several others in the MGU went on to become key players in combining soil studies with research on Quaternary geology and geomorphology within the U.S. Geological Survey (Table 2). Hunt (1972, v) clearly states that his interest in surface deposits and soils was stimulated in part by his participation in the MGU and “the opportunity to work with teams of soil scientists, plant geographers, hydrologists, and engineers, as well as geologists.” Others in the USGS, including Gerald M. Richmond (GMR to VTH, Feb 14, 1992, April 2, 1992) and Roger Morrison (RM to VTH, Jan 24, 1992) echoed those sentiments. James Thorp was also in the MGU, and his interests and background in both geology and soils provided additional stimulus for developing an appreciation of soils among the geologists (GMR to VTH, Feb 14, 1992, April 2, 1992). Hans Jenny also apparently had some connection to the MGU because both Richmond and Morrison first met him through the MGU, but no published information on the MGU or on Jenny note the nature of this relationship.

Table 2. A selection of geomorphologists and pedologists (and institutional affiliations) in the Military Geology Unit of the USGS, 1942–1945

<table>
<thead>
<tr>
<th>Geologists</th>
<th>SMU</th>
<th>Moss, John</th>
<th>Harvard (student)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albritton, Claude C., Jr</td>
<td>Wesleyan U</td>
<td>Ray, Louis L., Jr</td>
<td>Michigan State</td>
</tr>
<tr>
<td>Denny, Charles S.</td>
<td>Hofstra College</td>
<td>Richmond, Gerald M.</td>
<td>Corps of Engineers</td>
</tr>
<tr>
<td>Hack, John T.</td>
<td>USGS</td>
<td>Smith, H.T.U.</td>
<td>U of Kansas</td>
</tr>
<tr>
<td>Hunt, Charles B.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morrison, Roger B.</td>
<td>USGS</td>
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<td></td>
</tr>
</tbody>
</table>

Pedologists

| Baldwin, Mark               | USDA           | Sokoloff, Vladimir P. | UCLA             |
| Cady, John G.               | U of Idaho     | Thorp, James          | USDA              |

1 From USGS and USACE (1945) and Terman (1998, table 1). According to G. Richmond (GMR to VTH, Feb 14, 1992, April 2, 1992) and R. Morrison (personal comm., 2003), Hans Jenny was part of the MGU, but histories of the unit do not mention this. He may have had an informal, unofficial or temporary attachment.

2 Roy Simonson was “loaned” to the MGU for one year (Simonson, 1987, p. 1).
As indicated earlier and also discussed below, pedology and geology diverged in orientation and outlook through the 20th century. Relatively few individuals in either field were interested in research that combined the two field fields. Pedologists in particular became more focused on mapping and description, as well as other more agricultural applications. The MGU literally put geologists, including geomorphologists and Quaternary stratigraphers, together with pedologists. Their duties and goals clearly were not focused on soil geomorphology, but their daily close contact fostered an appreciation for shared interests in soils, landscapes, and environments both past and present that flowered in the post-war years and decades.

1945–1974

The rapid expansion and pace of scientific research in the U.S. following the Second World War is mirrored in the many developments in pedology, geomorphology, and Quaternary geology that grew into the field of soil geomorphology. As in the above discussion, these developments can be seen institutionally as well as in the activities of a few key individuals.

Institutional and Academic Pedology

Pedology in the USDA and in academic settings seems to have followed two very different paths in research agendas in the decades following the end of the war. Much of the USDA effort was on expansion of the soil survey program, which further distanced pedology from geology, but also included starting a separate research program in soil geomorphology that put pedologists and geologists together. The efforts of the soil survey program were most visible in the production of the Soil Survey Manual (1951) and in the development of a new system of soil classification, which became Soil Taxonomy (Simonson, 1987). Both of these efforts resulted in standardized, systematic, unambiguous nomenclature for describing and classifying soils. Because of the size and scope of the soil survey program, adoption of the description nomenclature and the new classification system quickly spread to academic soil science and, therefore, became the lingua franca of pedologists in the U.S. This standardized nomenclature for field descriptions was commonly applied in soil-geomorphic studies, sometimes with “unofficial” modifications to suit particular situations (Holliday et al., 2002; Holliday, 2004). Modifications to Soil Taxonomy to accommodate thick sequences of buried soils were proposed, including some from the USDA (e.g., Thorp, 1949; Ruhe and Daniels, 1958), but were never adopted. The Soil Survey Manual also re-emphasized the concept of the catena as a set of “strongly-contrasting soil series” along a slope, developed in similar parent material (Soil Survey Staff, 1951, p. 160);
different from the original concept and devoid of any notion of the significance of ero-
sion or deposition. Indeed, by this time, several pedologists equated the catena with a
toposequence (Bushnell, 1942; Jenny, 1946). In any case, because of the influence
of the manual, the dramatically altered concept of the catena among U.S. pedologists
became more entrenched (e.g., Buol et al., 1997, pp. 154–155).

A few pedologists in both governmental and academic settings continued to
press for better integration of geologic and pedologic concepts, in sometimes elo-
quent essays. James Thorp continued his work along these lines. For example, he
presented an exposition on the relationship of Pleistocene geology to soil science,
reflecting his years of interest and work on the topic (Thorp, 1949). The paper out-
lines the importance of Pleistocene geology to mapping and understanding soils,
and the importance of understanding soils for reconstructing Pleistocene land-
scapes. Thorp makes a forceful argument for cooperation between geologists and
soil scientists, reflecting, in part, his association with geologists in the MGU. In this
paper, Thorp also introduced the term “paleosol” to the English-language litera-
ture, equating it with “buried soil” (Johnson and Hole, 1994, 117). Later, Thorp
et al. (1951) presented a state-of-the-art inventory of Quaternary soil stratigraphy
of the central U.S. that still remains a standard reference. Other important contribu-
tions to soils and geomorphology include a monumental map compilation of
eolian deposits in the U.S. and Canada (Thorp and Smith, 1952) and one of the
first attempts at summarizing pedogenesis through the Quaternary (Thorp, 1965).

C.C. Nikiforoff, a Russian pedologist who worked for USDA, also published a
series of papers that, like Thorp’s, strongly espoused a reintegration of geology
with pedology. In particular, he urged development of the nascent field of paleo-
pedology (Nikiforoff, 1943). This paper was followed by one emphasizing that an
important implication of the factorial paradigm is that soils evolve, both down-
ward and upward, depending on the erosional/depositional setting (i.e., the land-
scape) (Nikiforoff, 1949).

Roy Simonson, a pedologist who spent most of his career with USDA and event-
ually became Director of Soil Classification and Correlation in the SCS, also
made several significant contributions to pedology that had ramifications in soil
g geomorphology. Trained in soil science, Simonson maintained an active interest in
buried soils (Simonson, 1941, 1954) and dealt with issues of polygenesis in buried
soils in till (Simonson, 1941). His most far-reaching contribution to soil geomor-
phology, however, was his “generalized theory” or “multiple process model” of soil
formation (Simonson, 1959, 1978). Simonson described soil genesis more broadly
than it was usually portrayed, as a set of individual processes such as podzolization
or calcification. He grouped the wide array of known soil-forming processes into
the now familiar four categories of additions, removals, translocations, and trans-
formations, arguing that soil formation results from the interaction of processes
within and among these broad sets of processes. This approach was not unique nor necessarily original, but was well explained in a highly visible soil science journal, and was widely accepted (e.g., Buol et al., 1973, 1980, 1989, 1997). His groupings provided an excellent complement to Jenny's factors; the factors are external or environmental controls that drive the internal pedogenic processes. This has been an important concept, particularly in teaching (e.g., Buol et al., 1973, 1997).

Marlin G. Cline, soil scientist at Cornell University, also presented a strong argument for maintaining links between pedology and geology, especially geomorphology. In a presentation designed to highlight the role of pedology as a component of soil science (in honor of the 25th anniversary of the Soil Science Society of America), Cline (1961, p. 443) succinctly argued that pedology "... must incorporate the basic concepts of geology; rocks and minerals and their transformations are keystones of our concepts; and geomorphology is the foundation of our interpretations of past events." Cline (1961, p. 444) goes on to argue that two of the three most important concepts in pedology to emerge in the previous 25 years were the importance of geomorphology and the importance of time (the third important concept being better understanding of the processes of soil formation).

The words and examples of Thorp, Cline, and a few others attempting to maintain links between pedology and geomorphology were largely unheeded, however. With development and publication of the revolutionary new system of soil classification, Soil Taxonomy (Soil Survey Staff, 1960, 1975, 1999), much of the emphasis in both governmental and academic pedology shifted to description and classification, and understanding site-specific (and profile specific) soil-forming processes, as well as mapping. This trend further separated a significant amount of soils research from geologic or geomorphologic research.

The USDA Soil-Geomorphology Projects

One significant exception to the trend within governmental soil science away from research on soil-landscape relations was the USDA soil geomorphology program of the 1950s–1970s. In this venture, the Soil Survey program of the SCS supported the most intensive and extensive systematic investigations of soil geomorphology attempted in North America. The following discussion is based on the history of the soil geomorphology projects prepared by Effland and Effland (1992, n.d.; see also Holliday et al., 2002). The projects evolved from the USDA soil erosion studies of the 1930s. The USDA was reorganized in 1952, resulting in placement of a "more research-oriented staff" in the soil survey program (Effland and Effland, 1992, p. 203). In 1952 and 1953, Charles D. Kellogg, head of the Soil Survey program, and Guy D. Smith, chief of Soil Survey Investigation, "... 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). In 1953, Robert V. Ruhe (BioBox 4, a geologist with interests and training in pedology, 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. The individual field studies were carried out by pedologists and geomorphologists working together.

BioBox 4 Robert Ruhe, photograph by P.W. Birkeland

ROBERT V. RUHE
b. 1918 in Chicago Heights, Illinois, USA
d. 1993 in Bloomington, Indiana, USA

BA Carleton College, MA Iowa State University, PhD, University of Iowa. He worked for the U.S. State Department in the Belgian Congo, 1951–1952, then 1953–1970 the USDA Soil Conservation Service, directing the soil-geomorphology projects 1953–1970, and spent the remainder of his career at Indiana University in Bloomington as Professor of Geology and Director of the Indiana University Water Resources Institute until retirement in 1985. Ruhe’s research career began in the Belgian Congo, but became firmly established with the USDA soil-geomorphology projects. He set up and directed the Iowa Project and then initiated the Desert Project before returning to Iowa. After leaving USDA, his work focused on soils and loess in the Midcontinental US.

Wright, 1995
Seven USDA soil geomorphology projects were authorized. The study areas were selected to represent a wide range of climatic and topographic features. Four of the planned seven projects were completed: 1) the humid, glaciated landscape of southwestern Iowa; 2) the arid and semiarid basin-and-range country of south-central New Mexico; 3) the humid Coastal Plain of North Carolina; and 4) the humid, maritime Pacific coast environment of western Oregon (Table 3). Two of the other three projects were partially completed (Table 3). Most of these investigations were in cooperation with local universities, agricultural experiment stations, and state geological surveys. They were landmark studies of the relationship of soils, geology, and landscapes and demonstrated the benefits of detailed soil geomorphology studies for interpreting landscape history and facilitating soil survey. The research had a variety of impacts on the evolution of soil geomorphology as a subdiscipline, at specific, local scales as well as more broadly in understanding and conceptualizing regional soil-landscape relations. Some of the studies became the standard for academic research in North America and the world, though they appear to have had minimal impact in the Soil Survey.

The Iowa Project and the New Mexico “Desert Project” were two of the most influential soil-geomorphic studies in the history of the subdiscipline. The

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<tr>
<th>Project</th>
<th>Principal Investigators</th>
<th>References</th>
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<tr>
<td>USDA Oregon Project</td>
<td>C.A. Balster, R.B. Parsons</td>
<td>Balster &amp; Parsons, 1968; Parsons, 1978; Parsons et al., 1968, 1970; Parsons &amp; Balster, 1967</td>
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<tr>
<td>USDA Hawaii</td>
<td>R.V. Ruhe</td>
<td>Ruhe, 1964b, 1965; Ruhe et al., 1965a,b,c</td>
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<tr>
<td>USDA Southern Plains</td>
<td>L.H. Gile, J.W. Hawley</td>
<td>Gile, 1979, 1985</td>
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impacts of these investigations are more fully enumerated by Holliday et al. (2002), but several examples provide illustrations. The Iowa Project was the first of the studies to get under way and therefore had some of the broadest impact. This was the first large-scale, long-term research that explicitly linked pedology, geomorphology, and Quaternary stratigraphy. As a result of the early stages of the work, Ruhe (1960) argued that because weathering takes place from the land surface downward, the soils and the landscape elements on which they occur are intimately linked, thus laying the conceptual groundwork for modern soil geomorphology. Another important concept introduced during the Iowa Project was the “hillslope profile,” a commonly used system describing the components of a slope profile, which include summit, shoulder, backslope, footslope, and toeslope (Ruhe, 1960). Ruhe and co-workers also related the Holocene history of erosion and deposition to slope evolution and basin infilling and to vegetation and inferred climatic changes, thus establishing linkages among vegetation cover, soil erosion, and sedimentation. These studies strongly influenced Holocene landscape evolution concepts in recently glaciated humid to subhumid continental regions (Gerrard, 1992).

The Desert Project was arguably the most influential study of arid-land soils in the history of pedology and soil geomorphology. The results of the research are prominent in some of the most widely read volumes on soils, geomorphology, and Quaternary geology (Birkeland, 1984, 1999; Bull, 1991; Gerrard, 1992) and in the major geomorphology textbooks (e.g., Ritter et al., 1995; Easterbrook, 1993). One especially significant study was on sequences of carbonate accumulation in desert soils by Gil et al. (1966), which first presented the now classic “stage” concept for carbonate accumulation in desert soils and their dependence on time. Recognition of this time dependency provided a powerful means to estimate the age of alluvial fan and terrace deposits throughout desert regions (e.g., Machette, 1985) because they seldom contain materials suitable for the numerical dating techniques available in the 1960s to 1980s. In the year preceding publication of this important paper, the Desert Project team introduced the K horizon as a new master horizon (Gile et al., 1965), a massive zone of carbonate accumulation that had a profound influence on subsequent soil development and landscape evolution. Though never adopted by the USDA, the concept of the K horizon and the morphologic stages of carbonate accumulation horizon were quickly adopted by many Earth scientists working in deserts, especially North Americans.

Another very significant result of Desert Project research was demonstrating the importance of dust and other external additions to soils in arid region soil genesis. 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 (see also Free, 1911, noted above). The
Desert Project, by linking the atmospheric with the soil data, provided the data to critically test and ultimately prove the hypothesis.

The Coastal Plain and Oregon projects were somewhat more limited in scope, but both were important contributions to broader themes in soil geomorphology. The Coastal Plain project produced one of the first comprehensive studies of Ultisol genesis (Daniels et al., 1970, 1978; Daniels and Gamble, 1978). This project also showed that soil variability decreased from young to old surfaces due to 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 an investigation of soil variability within geomorphic surfaces in the project area. 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). Of particular interest in the Oregon Project studies were investigations of soil variability as a function the buried soil-stratigraphic record, which exerted considerable influence on the geography and interpretation of surface soils (Parsons and Balster, 1967; Parsons et al., 1968).

Robert V. Ruhe

The USDA soil geomorphology projects provided an important venue for Robert Ruhe (BioBox 4) to develop many basic concepts of soil geomorphology that go beyond any one of the regional studies, and established Ruhe as one of the key figures in the development of modern soil geomorphology. Ruhe pioneered the integration of process-oriented quantitative geomorphology and hydrology with modern pedology (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, 1956b) and was heavily influenced by the pedimentation (slope back wearing) concepts of Lester King (1949, 1950, 1953) and especially the catena concept of Milne (1935a,b).

The papers by Ruhe (1956a) and Ruhe and Scholtes (1956), resulting from the Iowa Project, were two of the first papers in what we now recognize as soil geomorphology, documenting (rather than simply asserting or casually noting) the effects of parent material, landscape position, and landscape age on soil geography, and also using both surface and buried soils to reconstruct the evolution of the landscape. Ruhe’s chapter on “Quaternary Paleopedology” (Ruhe, 1965a) became one of the more influential papers on the topic, detailing his “tripartite” perspective on types of “paleosols” (buried, exhumed, and relict), although his definitions of the terms were somewhat at odds with the priority of their usage (Johnson and Hole, 1994, p. 118). Finally, Ruhe (1974) introduced the term “soil geomorphology,” though without explicitly defining it. In that paper he also
describes the “soil geomorphic unit” which is the repetitive occurrence of a soil-hillslope system that “illustrates the fit of specific soils with specific properties to the erosional and depositional parts of the hillslope” (Ruhe, 1974, pp. 493–494). He effectively reintroduced the catena concept as originally defined by Milne, though without citing him.

Several methodological approaches, seen as routine today, also emerged from the soil geomorphology projects and reflected Ruhe’s influence. One was the application of radiocarbon dating to determine the ages of landscapes and soils, particularly in Iowa and New Mexico. This use of radiocarbon dating was the first on such a large and regional scale, coming within a decade or so after the invention of the technique. The other methodological advance (summarized by Olsen, 1997) was in the use of widespread coring and trenching to work out stratigraphic and landscape relationships. This again reflected the post-war advances in technological (and financial) support available for such large-scale efforts.

U.S. Geological Survey

In the years following WWII, research on what would now be recognized as soil geomorphology also became an important part of Quaternary studies in the USGS. This was a direct outgrowth of the close collaboration between geologists and pedologists in the MGU during the war, and is best seen in the work of Charles B. Hunt, Gerald M. Richmond, and Roger Morrison. Hunt, who became Chief of the MGU, is emphatic on this point in the preface to his book *Geology of Soils* (Hunt, 1972, v). After the Second World War, Hunt stayed with the USGS for a time, then went on to The Johns Hopkins University and New Mexico State University, and ended his career back in the USGS. He published several stratigraphic studies that incorporated soils, including alluvial stratigraphy along the South Platte River (Hunt and Sokoloff, 1950; Hunt, 1954) and shoreline stratigraphy in the Bonneville Basin (Hunt and Sokoloff, 1950). Hunt’s work with soils in these settings inspired the research of co-workers Gerald Richmond in the La Sal Mountains and Roger Morrison in the Bonneville Basin (see below) and led to the classic soil-geomorphic work of Glen Scott (1963) in the Kassler Quadrangle of the South Platte, one of the first applications of surface soils both for correlation of terraces and for relative age estimates. Work on the coastal plain of Florida (Hunt and Hunt, 1957) incorporated a catenary approach (though not described as such) that also had archaeological implications (Holliday, 2004). His final publication dealing with soils was *Geology of Soils* (Hunt, 1972), the first English-language book that explicitly linked soils and geology in an integrated manner.
Gerald Richmond (BioBox 5) was also clearly influenced by his work in the MGU and association with C.B. Hunt. His initial exposure to soils came from Kirk Bryan (apparently before WWII), but the MGU provided a longer and more continuous apprenticeship. James Thorp was especially prominent in this role during and after the war (GMR to VTH, Feb 14, 1992). This association can be most prominently seen in Richmond’s (1962) study of glacial stratigraphy in the La Sal

**BioBox 5 Gerald Richmond, photographer unknown**

GERALD M. RICHMOND  
b. 1914 in Providence, Rhode Island, USA  
d. 2001 in Denver, Colorado, USA  
AB in biology and psychology, Brown University (1936), MA in geology, Harvard University (1936), and PhD. in geology, University of Colorado (1954). He joined the USGS in 1941. He stayed with the survey for his entire career, over 50 years, including work for the MGU (1943–1945) where his appreciation for and interest in soils began. Most of his work focused on Quaternary geology, particularly the glacial history of the Rocky Mountains and other parts of the mountain west. He was also a key figure in the 1965 INQUA Congress in Boulder, CO, where much U.S. soil-geomorphic and soil-stratigraphic work was showcased to the international Quaternary community.

Letters to VTH, February 14, 1992; April 2, 1992
Mountains, Utah. Soils were the most important tool for correlating deposits locally and regionally. Richmond took concepts from Thorp’s Midwestern soils studies and applied them to the mountains. More importantly, changes in soil morphology with altitude (soil facies) were recognized; probably a first in this sort of geologic mapping. This work showed a direct influence of Thorp, based on his work in Wyoming before WWII (Thorp, 1930). Field consultations with Hunt also benefitted Richmond’s soils applications in the La Sals (GMR to VTH, Feb 14, 1992). The La Sal work was the basis for his PhD dissertation in geology at the University of Colorado (the first in Quaternary geology in that department). Richmond’s influence extended beyond field work. He was a leader in incorporating soils as stratigraphic units in the Code of Stratigraphic Nomenclature (Richmond and Frye, 1957).

Roger Morrison’s work (BioBox 6) with soils began largely after WWII, when he worked in the Lahontan Basin of Nevada for the USGS (RM to VTH, Jan 24, 1992). Though exposed to the geologic significance of soils via the MGU, most of his initial soils training was largely in the field from USGS (and former MGU) colleagues Charles Hunt and Gerald Richmond. This background was important in Morrison’s research on the history of Pleistocene Lakes Lahontan and Bonneville (Morrison, 1964, 1965). Soils were an important part of the stratigraphic sequence he recognized and also were an important tool in mapping the surficial geology, which set the standard for others to follow (P. W. Birkeland, pers. communication, 2003). He came to recognize buried soils as important components of the stratigraphic record. His interest in soils resulted in a PhD dissertation (from the University of Nevada-Reno; also the first in Quaternary geology there) were he presented his views on Quaternary soil stratigraphy, subsequently published (1967) and revised (1978). This was perhaps the first systematic review of soils as stratigraphic units. Morrison’s dissertation and the 1967 paper are where the Geosol concept first appeared, later to be adopted (with some modification) as the official pedostratigraphic unit in the North American Code of Stratigraphic Nomenclature (NACOSN, 1983).

Midwestern Soil Science

Important soil-stratigraphic and related soil-geomorphic research continued in the stratified glacial and eolian deosits in the Midwest throughout the post-war years. Beyond the work of the USDA and R.V. Ruhe in Iowa, much of this research was in state geological surveys. M.M. Leighton, as Director of the Illinois Geological Survey, continued his work on the Quaternary evolution of Illinois and neighboring areas through the rest of his career (e.g., Leighton and Willman, 1950; Leighton, 1960, 1965; Leighton and MacClintock, 1962).
BioBox 6 Roger Morrison, photography by P.W. Birkeland

ROGER MORRISON
b. 1914 in Madison, Wisconsin, USA

A.B. in Geology (1933), M.A. in Economic Geology (1934), both from Cornell University. Morrison began working for the USGS in 1942, and served with the MGU until 1947, largely working on water supply (ground and surface water). In 1947 he moved out of Military Geology and into the General Geology Branch where he started working on the history of the Lahontan Basin. This is where his work on soils began, with encouragement from Charles B. Hunt and Gerald M. Richmond, and was followed by similar work in the Bonneville Basin. He received a PhD from the Mackay School of Mines at the University of Nevada-Reno. Much of his later work was for the EROS program of the USGS and focused on geomorphic mapping in the southwestern U.S. He retired from USGS in 1976.

Letter to VTH, January 24, 1992; personal communication, 2003
Another important figure was John C. Frye. He began his career in Kansas, working for the Kansas Geologic Survey from the war years to 1954. His work on Pleistocene stratigraphy and geomorphology included the use of soils for correlation and environmental reconstruction (e.g., Frye, 1949, 1951; Frye and Leonard, 1951, 1952; Frye et al., 1948). He then moved to the Illinois Geological Survey, succeeding Leighton as Director. Frye continued his own and Leighton’s work with soils as key stratigraphic markers (Frye and Leonard, 1955a; Richmond and Frye, 1957), furthered studies of the “gumbotil dilemma” that reformulated concepts of the Sangamon Soil (Follmer, 1979; Frye et al., 1960; Frye and Willman, 1963, 1970), and pioneered the use of petrography and mineralogy to study Cenozoic soils (Frye and Leonard, 1955b, 1957a,b, 1967; Frye et al., 1963, 1966). Frye also collaborated with Roger Morrison to propose long distance correlations, based in large measure on soils, of Quaternary stratigraphy between the Midwest, southern Great Plains, Wasatch Range, Bonneville Basin, and Lahontan Basin (Morrison and Frye, 1965).

In Wisconsin, soil mapping and subsequent research by Francis Hole were significant steps in understanding soil-landscape relationships. Soil survey in Wisconsin was part of the Wisconsin Geological and Natural History Survey, beginning in 1909 (Hole, 1962). Hole was a product of this unusual collaboration of soil science and geology. He was trained in geology, like so many pre-War pedologists, but went to work for the University of Wisconsin-Madison as a soil scientist. He spent much of his career in the decades after the war teaching in the Department of Soil Science and mapping soils in Wisconsin for the Geological and Natural History Survey. This work honed his insights on soil-landscape and soil-environment relations. In 1967 he gained a joint-appointment between the Department of Soil Science and the Department of Geography at the University of Wisconsin. He further developed his teaching and writing on soils within a geographic approach. His principal contributions in soil geomorphology were his views on soils as dynamic entities; he was an early proponent of the concept of “pedoturbation,” emphasizing the often subtle and microscopic, but nevertheless important movements within soils due to a wide range of processes during pedogenesis (Hole, 1961, 1981). His thoughts on the “vibrant” nature of soils are perhaps best captured in his last scientific publication, detailing “terra vibrata,” which he defined as the dynamics of soil landscapes (Hole, 1988). Hole and O. W. Bidwell (Bidwell and Hole, 1965) also anticipated the late 20th century interest and concern about human impacts on soils (e.g., Amundson and Jenny, 1991). Francis Hole left a significant teaching legacy for pedologists and soil geomorphologists as co-author of Soil Genesis and Classification (Buol et al., 1973, 1980, 1989, 1997), the most widely used and disseminated pedology text in the U.S. and perhaps the world.
Kirk Bryan Legacy

Kirk Bryan continued his work on geomorphology, soils, and archaeology in the years immediately after WWII. In soils, he published a short piece on “cryopedology” (permafrost soils) (Bryan, 1949) and a paper on the relationship of buried soils to climate change (Bryan, 1948). The latter remains almost wholly unknown because it was published in Spanish. Bryan died in the field in 1951, ending a remarkable career. He also guided a group of graduate students who exerted significant influences in geomorphology, Quaternary geology, and paleoecology (Haynes, 1990). Oddly, though none of these students continued Bryan’s interests in soils, the geomorphic significance of buried soils was recognized and incorporated into their geologic interpretations (e.g., Hopkins and Giddings, 1953; Judson, 1953; Leopold and Miller, 1954). His principal intellectual descendant in this regard is geoarchaeologist C. Vance Haynes, Jr., who further developed Bryan’s late Quaternary “alluvial chronology” by, among other things, utilizing buried soils as stratigraphic markers and as indicators of geomorphic stability (Haynes, 1968). More broadly, the work of Bryan, particularly the paper by Bryan and Albritton (1943), had long lasting results in geomorphology. “Polygenesis soon became the theoretical core of the geomorphic concept of ‘polygenetic landscapes’” (Johnson and Hole, 1994, p. 115).

INQUA 1965

In the years from 1965 to 1974, there were a series of events that culminated in the appearance of modern (late 20th/early 21st century) soil geomorphology. These events are built around several key publications and individuals. In 1965 the International Union for Quaternary Research (INQUA) held its VIIth Congress in Boulder, CO. Gerald Richmond was a key player in getting the meetings to Boulder and was the Secretary General of the Congress. Soils in geologic contexts were an important component of the themes, papers, and field trips of the Congress and in subsequent INQUA publications. In many ways the Congress and papers represent the initial integration of decades of interests in Quaternary soil stratigraphy among many geologists, the influence of the MGU, and the data emerging from the USDA soil geomorphology projects. For example, in the monumental review volume for the Congress, *The Quaternary of the United States* (Wright and Frey, 1965), soils are prominent components of the stratigraphic summaries that make up close to half of the book. The impact of the soil geomorphology projects can be seen in several chapters (Kottlowski et al., 1965; Wright and Ruhe, 1965) and, in particular, in Robert Ruhe’s “Quaternary Paleopedology” (Ruhe, 1965a), noted above.
Beyond that center-piece volume for the Congress, several other books evolved from the conference that featured soil stratigraphy and soil geomorphology, largely through Roger Morrison's efforts. Most notable among these books is *Quaternary Soils* (Morrison and Wright, 1967), the first edited volume to focus exclusively on the significance of soils in Quaternary research, and *Means of Correlation of Quaternary Successions* (Morrison and Wright, 1968), which includes discussion of soils as important correlation tools. *Quaternary Soils* is also the venue for Morrison's views on Quaternary soil stratigraphy, from his PhD dissertation (Morrison, 1967).

**International Influence: Butler K-Cycles; Yaalon and Paleopedology**

Several post-war developments in pedology outside of the U.S. had significant influences on pedology and soil geomorphology in the states. In the 1950s B. E. Butler in Australia developed the K-cycle concept. A key tenet in soil geomorphology (and soil stratigraphy in particular) is the relationship between soils and landscape stability. Soils in the stratigraphic record are uniquely suited to identifying phases of stability vs phases of instability (Gerrard, 1993). Put simply, soils form on stable landscapes, i.e., landscapes with no or little erosion or aggradation. There are exceptions to this concept (e.g., slowly aggrading floodplains or eolian landscapes or regions of continuous, intense weathering, e.g., tropical settings), but the basic idea has proven useful in the interpretation of buried soils. This view of soils and landscapes as “periodic phenomena” was formalized by Butler (1959, 1982) in his “K-cycle” concept (the K referring to the Greek *khrōnōs* for time). This approach to soils evolved from the initial stages of soil-stratigraphic and soil-geomorphic research in Australia in the 1950s “when pedology was concerned mainly with soil classification and mapping” (Walker, 1989, 589). Recognition of a complex Quaternary stratigraphic and geomorphic record by Walker (who would work with Ruhe on the Iowa Project; Table 3) and other Australian geoscientists led to recognition of cycles of stability and instability on the landscape (e.g., Tonkin and Basher, 1990).

Each K-cycle includes an unstable phase of erosion and deposition, followed by a stable phase with concomitant pedogenesis. A clear implication of this formalized approach to describing the events represented by buried soils is that they represent a sequence of landscapes, and recurrent cycles of landscape stability and instability. Butler (1959, 1982) also emphasizes the lateral variability of soils on both modern and buried soils and thus, without saying so, describes catenas and paleocatenas. Though not particularly well known by its name in the U.S., the K-cycle concept has been widely applied (e.g., in the USDA projects) and has proven useful for understanding the relationship between pedogenesis and other earth surface
processes (Brewer, 1972; Huggett, 1975; Catt, 1986, p. 166; Gerrard, 1992, pp. 216–220). The K-cycle concept is also important because it emphasizes the relationship of stratigraphy to landscapes, and also emphasizes soils, buried and unburied, as three- and four-dimensional entities.

On the other side of the globe, in 1971, Dan Yaalon edited and published a series of papers on “the origin, nature and dating of paleosols” in the volume *Paleopedology* (Yaalon, 1971a). Yaalon is an Israeli pedologist who worked on issues of soil-landscape and soil-stratigraphic relationships (e.g., Yaalon, 1967; Dan et al., 1968). The book was the result of the “Symposium on the Age of Parent Materials and Soils” held in Amsterdam in 1970 and co-sponsored by INQUA and the International Society of Soil Science. The symposium brought together “pedologists, geomorphologists, sedimentologists, stratigraphers, radiocarbon chemists, micromorphologists and clay mineralogists interested in paleosols” (Yaalon, 1971a, x). This was probably the first international gathering of such a diverse group of scientists in a symposium devoted exclusively to the topic of paleopedology. The volume was also the first attempt to systematically deal with the stratigraphic, paleoenvironmental, and geochronologic aspects of buried soils.

There were several influential papers in the volume. Yaalon (1971b) presented a summary discussion and table indicating relative rates of development of various pedogenic features, and the direct relationship between these rates and the persistence of the features in buried soils (i.e., features that take longer to form, tend to persist longer in the geologic record). This became a standard guide in the study of rates of soil formation and buried soils (e.g., Birkeland, 1999, table 1.5). Most significant, however, are the papers that deal with the issue of radiocarbon dating of soils; the first collection of papers on this topic. The papers by Geyh et al. (1971), Polach and Costin (1971), and Scharpenseel (1971), for example, became classic overviews of the problems and potentials of dating soil organic matter and, in particular, the issues of “mean residence time” and the mobility of humic and fulvic acids.

**University of California, Berkeley**

Following the Second World War, Hans Jenny continued his work on the soil-forming factors (Jenny, 1946, 1958, 1961; Jenny et al., 1968) as well as many other topics (Amundson, 1994). This work culminated in what was essentially an update of *Factors* (Jenny, 1980), but with more quantitative data. Quantification of the state-factor equation was a continuing interest of Jenny and his students. One of these, R. J. Arkley, eventually joined the Soil and Plant Nutrition faculty at Berkeley. Arkley was a pedologist but used geomorphic and Quaternary stratigraphic relationships to map soils in California (e.g., Arkley, 1964). He also
published a pioneering study in the quantification of soil formation and using soils data to get at past environment and to explain the distribution of soil. Arkley (1963) compared depth to the top of the calcic horizon to climate in a transect across the Sierra Nevada. Depths that seem discordant with present climate could be due to past climate. Arkley (1967) also looked at small scale patterns of soil distribution and showed that they could be linked to water-balance climatic parameters, based on soil-moisture storage capacity and mean annual temperature. These studies were several decades ahead of research on modeling climate and calcic horizon development, discussed below.

Another development in soil geomorphology at Berkeley was a decision to hire a geologist in Soils and Plant nutrition, a rare if not unique step for a soil science program. That hire (in 1962) was Peter W. Birkeland (BioBox 7), a Quaternary geologist and geomorphologist interested in using soils to work out Quaternary stratigraphic relationships in the Sierra Nevada. He credits Jenny and Arkley with his formal training in soils. This combined with working and teaching alongside them led Birkeland to systematically combine soils and geomorphology in both teaching and research (Birkeland, 1989). He also came to recognize the importance of soil stratigraphy when he continued his Quaternary stratigraphic work in the Sierra. Tracing units down the Truckee River he came in contact with Roger Morrison and his work in the Lahontan Basin (Birkeland, 1989, 2001). An immediate result of these collaborations was using soils for mapping Quaternary geology. For example, Birkeland worked with geologist R. J. Janda, and, using the careful geomorphically-informed soil mapping by colleague R. J. Arkley, prepared detailed maps of Quaternary geology in the San Joaquin Valley of California (Birkeland, 1974, fig. 2–3, 1999, fig. 2–3).

Peter W. Birkeland

In 1974, Peter W. Birkeland (BioBox 7) published Pedology, Weathering and Geomorphological Research, which, along with later editions, influenced much late 20th century soil geomorphology in the U.S. In 1967 Birkeland left Berkeley and moved to the University of Colorado where Richmond's work in the Rocky Mountains made a strong impression (Birkeland, 1989; pers. communication, 2003). In a later edition of his book (Birkeland, 1999), he specifically recognizes Richmond, Morrison, Jenny, Frye, and Ruhe for their influence on him and on soil geomorphology.

In his book, Birkeland took Jenny's "clorpt paradigm" for describing and quantifying the impacts of the five factors on the genesis and distribution of soils and recast it to establish a research paradigm for using soils to help reconstruct the past. A significant advantage of Birkeland's approach is the availability of a wide
BioBox 7 Peter Birkeland, photograph by V.T. Holliday

PETER W. BIRKELAND
b. 1934 in Seattle, Washington, USA

B.A. in Geology, University of Washington (1958); PhD in Geology, Stanford University (1962). At the invitation of Hans Jenny, he joined the Department of Soils and Plant Nutrition at the University of California-Berkeley as a geomorphologist in 1962, then moved onto Geological Sciences at the University of Colorado-Boulder in 1967. He retired in 1997. Birkeland was a Quaternary geologist who initially became interested in soils as a means of dating moraines in the mountains of the western U.S. Under the influence and tutelage of Hans Jenny, Roger Morrison, Gerald Richmond, Robert Ruhe, and Dwight Crandell (USGS) Birkeland recast the clorpt formula to study the past. He further combined the factorial approach with stratigraphic and geomorphic approaches to pedology evolved from the MGU (via Richmond and Morrison) and the USDA soil-geomorphology projects (particularly the Iowa and Desert projects). His own field work was in the glaciated terrain of the western U.S., largely in the Rockies and Sierra Nevada, but by the late 1970s he started working internationally, including field research in New Zealand, the Peruvian Andes, Israel, and Baffin Island. Most of this work focused on soil chronosequences and topo-chronosequences.

Birkeland, 1989, 2001; Hawley, 1989
variety of analytical methods, especially numerical dating techniques, to truly establish quantitative soil-forming functions. The “clorpt equation” combined with Birkeland’s quantitative approach provides a powerful means of establishing research questions regarding soil-landscape relationships. Pedology, Weathering and Geomorphological Research (Birkeland, 1974) and subsequent editions titled Soils and Geomorphology (Birkeland, 1984, 1999) became the standard textbook for soil geomorphology. As described by John Hawley (1989) (geomorphologist on the Desert Project), Birkeland’s book is “... by far the best and most comprehensive presentation of soil-geomorphic relations from a broad-based geological perspective.”

1974–2004

The last quarter of the 20th century saw soil geomorphology fully formed, insofar as we see it in the early years of the 21st century. In the same year that Birkeland published the first edition of his influential book, Ruhe (1974) coined the term “soil geomorphology” (ironically, also about the time the USDA closed the soil geomorphology projects). The importance of using soils to understand the evolution of landscapes and other aspects of the geologic past are well illustrated by use of the term “soil geomorphology.” In addition to subsequent editions of Birkeland’s volume, the term is applied to other author-written, systematic treatments (Daniels and Hammer, 1992; Gerrard, 1992), and several edited volumes (Richards et al., 1985; Knuepfer and McFadden, 1990). Through these publications as well as many others, most of the historical threads outlined above can be seen.

Birkeland’s approach to soil geomorphology broadened somewhat in subsequent editions of his book (1984, 1999). The catena concept and the effects of erosion and deposition across soil landscapes in different climatic regimes were added, including a full chapter in the 3rd edition (Birkeland, 1999). He and his students also began investigating topo-chronosequences, where soils within a catena are compared to those related to older deposits of a chronosequence (e.g., across moraines) (Table 4). This approach provided additional insight into soil variability within chronosequences and identified settings where age-related pedologic features might be well expressed or poorly expressed.

Birkeland’s influence can be seen in a variety of studies, both by direct academic descendants and by indirect intellectual descendants (e.g., Table 4). In particular, the study of chronosequences (Table 4) and the identification of paleoclimatic indicators in soils has been widely embraced. “There is no doubt that soil chronosequences are immensely powerful tools for probing the rate and direction of soil
Table 4. Examples of chronosequence and topo-chronosequence studies

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil variables</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Oregon</td>
<td>overall profile morphology, Fe &amp; Al, podzolization, clay illuviation</td>
<td>Langley-Turnbaugh &amp; Bockheim, 1997</td>
</tr>
<tr>
<td>Metolius River, OR</td>
<td>alteration &amp; translocation of Fe, Al, &amp; P</td>
<td>Scott, 1977</td>
</tr>
<tr>
<td>Rock Creek Basin, MT</td>
<td>argillic &amp; calcic horizon formation</td>
<td>Reheis(^2), 1987c</td>
</tr>
<tr>
<td>Rocky Mountain, CO,</td>
<td>cambic &amp; argillic horizon formation; overall profile morphology &amp; thickness;</td>
<td>Shroba(^2) &amp; Birkeland, 1983</td>
</tr>
<tr>
<td>Sierra Nevada, CA</td>
<td>rubification; alteration &amp; neoformation of clay minerals</td>
<td></td>
</tr>
<tr>
<td>South Platte River, CO</td>
<td>argillic &amp; calcic horizon formation; overall profile morphology &amp; thickness</td>
<td>Machette(^2), 1975;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Holliday(^2), 1987;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>McFaul et al., 1994</td>
</tr>
<tr>
<td>Mojave Desert, CA &amp; AZ</td>
<td>cambic, argillic &amp; calcic horizon formation</td>
<td>Shlemon(^2), 1978;</td>
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<td></td>
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<td>Bischoff et al., 1981;</td>
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<td></td>
<td></td>
<td>Shlemon &amp; Budinger, 1990</td>
</tr>
<tr>
<td>Eastern Mojave Desert, CA</td>
<td>argillic &amp; calcic horizon formation; overall profile morphology; rubification; alteration or translocation of Fe</td>
<td></td>
</tr>
<tr>
<td>Ventura Basin, CA</td>
<td>argillic horizon formation; overall profile morphology &amp; thickness; rubification</td>
<td>Rockwell et al., 1985</td>
</tr>
<tr>
<td>Transverse Ranges, CA</td>
<td>alteration of Fe &amp; clay minerals</td>
<td>McFadden &amp; Hendricks, 1985</td>
</tr>
<tr>
<td>Transverse Ranges, CA</td>
<td>argillic horizon formation; rubification; overall profile morphology; alteration or translocation of Fe</td>
<td>McFadden &amp; Weldon, 1987</td>
</tr>
<tr>
<td>Sacramento Valley, CA</td>
<td>cambic &amp; argillic horizon formation; overall profile thickness &amp; morphology; rubification</td>
<td>Busacca, 1987</td>
</tr>
<tr>
<td>Silver Lake Playa, CA</td>
<td>calcic horizon formation; overall profile morphology; rubification</td>
<td>Reheis(^1) et al., 1989</td>
</tr>
<tr>
<td>San Clemente Is, CA</td>
<td>argillic horizon, rubification, Vertisols</td>
<td>Muhs, 1982</td>
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(Continued)
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<thead>
<tr>
<th>Location</th>
<th>Soil variables</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Mesa, AZ</td>
<td>cambic, argillic, natric &amp; calcic horizon formation, argillic horizon thickness; overall profile morphology &amp; thickness; rubification</td>
<td>Karlstrom, 1988</td>
</tr>
<tr>
<td>Lubbock Lake site, TX</td>
<td>cambic, argillic &amp; calcic horizon formation; rubification</td>
<td>Holliday(^2), 1985, 1988</td>
</tr>
<tr>
<td>Ridge &amp; Valley area, PA</td>
<td>argillic &amp; cambic horizon &amp; fragipan formation; overall profile morphology; neoformation of clay minerals</td>
<td>Bilzi &amp; Ciolkosz, 1977a</td>
</tr>
<tr>
<td>Susquehanna River, NY</td>
<td>cambic horizon formation; overall profile morphology; rubification</td>
<td>Scully &amp; Arnold, 1981</td>
</tr>
<tr>
<td>Susquehanna River, PA</td>
<td>clay illuviation and argillic horizon thickness; overall profile morphology and thickness; rubification; alteration or translocation of Fe</td>
<td>Engel et al., 1996</td>
</tr>
<tr>
<td>Des Moines River, IA</td>
<td>cambic &amp; argillic horizon formation; rubification; over profile morphology</td>
<td>Bettis, 1992</td>
</tr>
<tr>
<td>Northern Michigan</td>
<td>Overall profile morphology; podzolization</td>
<td>Barrett &amp; Schaetzl, 1992</td>
</tr>
<tr>
<td>Blue Ridge Mtns, GA</td>
<td>clay illuviation &amp; argillic horizon thickness; overall profile morphology &amp; thickness; rubification; alteration or translocation of Fe</td>
<td>Leigh, 1996; Leigh &amp; Cable, 1997</td>
</tr>
<tr>
<td>Southeast U.S.</td>
<td>argillic horizon formation; alteration and translocation of Fe</td>
<td>Markewich &amp; Pavich, 1991</td>
</tr>
<tr>
<td>Cordillera Blanca, Peru</td>
<td>overall profile morphology &amp; thickness; rubification</td>
<td>Rodbell(^2), 1993</td>
</tr>
</tbody>
</table>

**Topo-chronosequences**

<table>
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<th>Location</th>
<th>Soil variables</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmon River Mtns, ID</td>
<td>clay illuviation &amp; argillic horizon thickness; overall profile morphology &amp; thickness; rubification; alteration or translocation of Fe</td>
<td>Berry(^2), 1987; Birkeland et al., 1991</td>
</tr>
</tbody>
</table>
Table 4. Examples of chronosequence and topo-chronosequence studies—Cont’d

<table>
<thead>
<tr>
<th>Location</th>
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<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind River Mtns, WY</td>
<td>clay illuviation &amp; argillic horizon thickness; overall profile morphology &amp; thickness; rubification; alteration or translocation of Fe</td>
<td>Swanson, 1985; Birkeland et al., 1991; Dahms, 1994</td>
</tr>
<tr>
<td>Whiskey Basin, WY</td>
<td>clay illuviation &amp; argillic horizon thickness; overall profile morphology &amp; thickness; rubification</td>
<td>Applegarth &amp; Dahms, 2001</td>
</tr>
<tr>
<td>Eastern Sierra, Nevada, CA</td>
<td>clay illuviation &amp; argillic horizon thickness; overall profile morphology &amp; thickness; rubification; alteration or translocation of Fe</td>
<td>Birkeland &amp; Burke, 1988; Berry, 1994</td>
</tr>
<tr>
<td>Southern Israel</td>
<td>gypsum, other salts &amp; argillic horizon formation; overall profile morphology</td>
<td>Birkeland &amp; Gerson, 1991</td>
</tr>
<tr>
<td>South Island, New Zealand</td>
<td>overall profile morphology &amp; thickness; rubification; leaching; alteration or translocation of Fe</td>
<td>Birkeland, 1994</td>
</tr>
<tr>
<td>Peruvian Andes</td>
<td>clay illuviation &amp; argillic horizon thickness; overall profile morphology &amp; thickness; rubification; alteration or translocation of Fe</td>
<td>Miller &amp; Birkeland, 1992</td>
</tr>
</tbody>
</table>

1 Rate of argillic horizon formation can include data on rates of clay illuviation; Fe alteration can refer to Fe oxidation or alteration of Fe oxides.
2 Student of P.W. Birkeland.

Evolution . . . Well dated chronosequences are therefore a boon to pedologists. They are also invaluable to geomorphologists, for, once a soil chronosequence is established, it may be used to investigate other landscape processes” (Huggett, 1998, p. 159). Willem Vreeken (1975b), a student of Ruhe’s, also defined subcategories of chronosequences (noted below). Birkeland furthered his influence on the practice of soil geomorphology through his own research. For example, the Utah Geological and Mineral Survey brought him and two former students, to train their geologic mappers and produce a manual on applying the five-factor approach in Quaternary geology and the mapping of Quaternary units (Birkeland, Machette, and Haller, 1991).
The importance of chronosequences was recognized by geomorphologists in the USGS who sponsored a series of soil geomorphology investigations in the eastern and western U.S. (Table 5). Developed by Dennis E. Marchand and continued by Jennifer W. Harden, Michael N. Machette, Helene Markewich, and Milan Pavich, the work was aimed at understanding age relationships between soils, landscapes, and various weathering criteria (i.e., the work focused on soil chronosequences). The field work was supported by an array of physical, chemical, and mineralogical data. The studies in the east were cooperative projects of the USGS and the USDA, thus representing a melding of sorts of several historic predecessors.

Evolving out of both the Jenny/Birkeland factorial approach to soil geomorphology and quantitative geomorphology were attempts at modeling soil forming processes. Much of this work has focused on modeling carbonate accumulation (e.g., McFadden and Tinsley, 1985; Mayer et al., 1988; McFadden et al., 1991, 1998), following in the footsteps of Arkley (1963), but also includes more general attempts at modeling pedogenesis (Chadwick et al., 1990). A very different approach to quantifying soil geomorphic studies was taken by Jennifer Harden, a USGS geologist who studied with Arkley and Jenny at Berkeley. She developed a “semi-quantitative” assessment of soil profile morphology as a means of objectively comparing soil profile development (Harden, 1982), following the work of Bilzi and Ciolkosz (1977b). The “profile development index” (or more informally the

<table>
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<tr>
<th>Project</th>
<th>Setting</th>
<th>References</th>
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<tbody>
<tr>
<td>USGS Western U.S.</td>
<td>Merced River, CA</td>
<td>Harden, 1987</td>
</tr>
<tr>
<td>1978–1983</td>
<td>Ventura River &amp; Ventura Coast, CA</td>
<td>Harden et al., 1986</td>
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<td></td>
<td>Kane fans, Cottonwood Creek, WY</td>
<td>Reheis, 1987a</td>
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<td></td>
<td>Rock Creek, MT</td>
<td>Reheis, 1987b</td>
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<td>Alpine soils, Front Range, CO</td>
<td>Birkeland et al., 1987</td>
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<td></td>
<td>Cowlitz River, WA</td>
<td>Dethier, 1988</td>
</tr>
<tr>
<td>USGS/USDA Eastern U.S.</td>
<td>Coastal Plain, MD, VA</td>
<td>Markewich et al., 1987</td>
</tr>
<tr>
<td>1979–1984</td>
<td>Coastal Plain, SC</td>
<td>Markewich et al., 1986</td>
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<tr>
<td></td>
<td>Uphapee Creek &amp; Tallapoosa River, AL</td>
<td>Markewich et al., 1988</td>
</tr>
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<td></td>
<td>Guide to soil &amp; weathering profile data, Coastal Plain</td>
<td>Markewich et al., 1989</td>
</tr>
</tbody>
</table>
“Harden index”) has proven useful in soil development studies in a wide variety of settings (Harden and Taylor, 1983; Busacca, 1987; Reheis et al., 1989; Birkeland, Berry, and Swanson, 1991; Vidic and Lobnik, 1997) but it is not necessarily universally applicable (Birkeland, 1999, 293). In a related development, Schaetzl and Mokma (1988) developed the “POD index” for semi-quantitative evaluation of podzolization.

The five-factor approach advocated by Birkeland has been criticized by some workers (see summaries in Birkeland, 1999, pp. 144–145; Johnson and Watson-Stegner, 1987; and Gerrard, 1992, 3–7). Ruhe (1975b, p. 177) viewed Birkeland’s factorial approach as simply “compartamentalization... useful for instruction” but otherwise “disappointing.” Daniels and Hammer (1992, pp. 195–202) explicitly and strongly criticize the use of soils as age indicators. They correctly note the many variables that can complicate the use of soils to date landscapes, but nowhere do they explicitly deal with the many successful chronosequence studies that illustrate the rate-dependent nature of a wide array of pedologic features (e.g., Table 4 and references in Huggett, 1998, and in chapters 8 and 9 of Birkeland, 1999).

Paton et al. (1995) attempted to overturn what they see as the “clorpt paradigm.” In their “new global view” of soils, they essentially reject the idea that the distribution of soil zones is determined by the five factors, particularly climate and vegetation, and the corollary concept that the factors drive soil-forming processes vertically down through the soil resulting in A-B-C profiles. Paton and his coauthors propose to replace the clorpt concept with one emphasizing surficial and biological processes (such as bioturbation) acting upon a weathered and mobile mantle of sediment. Their model appears to be most effective in explaining the spatial pattern of soils on tropical landscapes (Schaetzl, 2000, pp. 772–773). The “new global view” has come under heavy criticism, however (e.g., Catt, 1996). In particular, Beatty (2000), Courchene (2000), Johnson (2000), and Schaetzl (2000) forcefully argue that the traditional “clorpt, A-B-C” model does successfully account for the genesis and distribution of soils on younger landscapes in the middle latitudes. Johnson (2000, p. 780) is probably correct in his view that the old clorpt, A-B-C model “formulated for soils in the plainlands of European Russia and North America, conceptually promotes an atypical (but not aberrant) style of pedogenesis relative to most of the nonglaciated and loess-free rest of the world, an atypical style that has been applied, unfortunately, as the world standard.” Most soil-geomorphologic research, however, has been carried out in the Quaternary glacial, alluvial, eolian, and desert regions of the middle latitudes, where the traditional model works, and generally works well.

Certainly the five factors do not deal with soils and pedogenic process, but with external factors that affect the soil. In Quaternary research, however, the external factors often are the object of concern, and soils can be a means of reconstructing
them; the soils are environmental proxies. The five-factor approach cannot describe landscapes, however, and soils are selected on a landscape for their ability to solve the equation. The five-factor approach also tends to treat the factors individually as independent variables, although they often act together, such as climate and biota. This point was raised by Jenny in his original study as well as in his own revision in 1980. Indeed, in the final version of his book, Birkeland (1999) combined discussion of climate and vegetation because they are in many ways inseparable. The time factor is the only truly independent variable, but the passage of time in and of itself does not form a soil; it simply allows significant time for the other factors and processes to operate.

For the most part the general validity of the state factor approach has been upheld (e.g., Yaalon, 1975; Bockheim, 1980; Huggett, 1998), especially in soil-geomorphic research in the middle latitudes, where, historically most pedologic and Quaternary geologic work has been conducted. The application of the factorial equation has been especially useful in chronosequence studies on moraines and alluvial terraces, and in assessing the influence of parent materials on soils (i.e., in lithosequences) (e.g., Tables 4, 5). As an example of the significance and impact of chronosequence research, the topic has generated its own body of theoretical literature (Schaetzl et al., 1994; Rabenhorst, 1997; Huggett, 1998).

Ruhe did not leave a legacy in the form of a book focusing on soil geomorphology, and he produced a relatively small number of graduate students because much of his career was with USDA, but his influence is evident. His approach of combining pedology, geomorphology, and hydrology, as well as soil stratigraphy, evolving from his Iowa project, had a lasting influence on geologists and pedologists in the Midwestern U.S. (Olson, 1989, 1987). Ruhe’s student Raymond Daniels also went on to co-author a volume on Soil Geomorphology (Daniels and Hammer, 1992). It presents an approach very much in the Ruhe tradition that applies process pedology and geomorphology with hydrology to interpret past soil-forming environments. As indicated above, their approach contrasts strongly with Birkeland’s. Ironically, nowhere do they use the term “catena” (a criticism of Birkeland’s first edition in Ruhe’s 1975 review), though they describe a variety of catenary settings and soil associations. Other students worked with Ruhe or continued his work on topics such as landscape evolution in Iowa (Vreeken, 1975a), “welded soils” (Ruhe and Olson, 1980; Olson and Nettleton, 1998) and the Sangamon Soil (Ruhe et al., 1974), and mapping soils to better understand landscape evolution (Brevik and Fenton, 1999). Several of his students melded Ruhe’s approach to soil geomorphology, using stratigraphy and hydrology, with the clorpt factorial approach, including chronosequences (Vreeken, 1975b; Hall, 1999; Hall and Anderson, 2000).

Although Kirk Bryan left no academic legacy insofar as his students of geomorphology interested in soils are concerned, his name is now attached to
several soils-related studies. In 1958, as a result of an “outpouring of affection and funds ... upon his untimely death” (Sharp, 1993, P. 190) the Quaternary Geology and Geomorphology Division of the Geological Society of America established the annual Kirk Bryan Award for an outstanding publication. As of 2004, five of the awards went to research directly or indirectly relating to soil geomorphology. The first was Richmond’s 1962 study of the La Sal Mountains (1965 award), which relied on soils. Two of the awards were for research that resulted directly from the USDA soil geomorphology projects: Ruhe’s 1969 book *Quaternary Landscapes in Iowa* (1974 award), and Gile, Hawley, and Grossman’s 1981 *Guidebook to the Desert Project* (1983 award). The other two awards, for Birkeland (1984) (1988 award) and Holliday (1995) (1998 award), were heavily influenced by the other awardees.

Other trends in research related to soil geomorphology noted above continued through the last quarter of the 20th century. The Midwestern tradition of research on genesis of soil-stratigraphic units to understand the evolution of glacial and eolian landscapes continued (e.g., Norton et al., 1988; Jacobs and Knox, 1994; Leigh and Knox, 1994; Jacobs et al., 1997; Jacobs, 1998) and was also applied to alluvial systems (e.g., Bettis, 1992; Mandel, 1994). A key player has been Leon Follmer of the Illinois Geological Survey, following in the footsteps of Leighton and Frye (Follmer, 1978, 1979, 1982, 1983; Follmer et al., 1998). Studies in the tradition of the USDA soil geomorphology projects, using soils to reconstruct landscape evolution, have also continued (e.g., Busacca, 1989; Holliday, 1990; McDonald and Busacca, 1990, 1992; Snyder and Bryant, 1992; McFadden and McAuliffe, 1997; Schaetzl et al., 2000; Birkeland et al., 2003; Gaylord et al., 2003), though typically at significantly reduced scales of time and funding. One particular line of research inspired by the Desert Project is in the importance of dust infiltration as a factor in pedogenesis (e.g., McFadden et al., 1986, 1987, 1998; Litaor, 1987; Dahms, 1993; Reheis et al., 1995).

Some pedologists have maintained an interest in soil-geomorphic relations, even though research in pedology through the last quarter of the 20th century tended to focus on description and classification. In particular, pedologists from UC Berkeley have followed the path of Jenny and Arkley regarding processes of soil genesis, landscape relationships, and the state factors (e.g., Amundson et al., 1989; Harden, 1990; Amundson and Jenny, 1991). Soil-geomorphic research by other pedologists in the U.S. include work on rates of development and other factor-related studies (e.g., Bockheim, 1979, 1982, 1990; Foss and Segovia, 1984; Eash and Sandor, 1995; Langley-Turnbaugh and Bockheim, 1997), landscape evolution (e.g., Ciolcosz et al., 1990), including work in Uganda at Milne’s “type area” for the catena (Brown et al., 2004), and studies of buried soils (e.g., Busacca, 1989; Carter et al., 1990; Busacca and Cremaschi, 1998; Ward and Carter, 1998).
As soil geomorphology became established as a subdiscipline in its own right, it became applied in allied disciplines. A particularly important area of research is in using soil-stratigraphy, chronosequences, and other age relationships to determine the timing and recurrence rates of faults (e.g., Machette, 1978, 1988; Douglas, 1980; Harden and Matti, 1989; Berry, 1990; McCalpin and Berry, 1996; Keller et al., 1998). In archaeological research, soils were recognized as important stratigraphic and environmental indicators by such pioneers in soil geomorphology as Leighton (1937) and Bryan (1941). But not until the 1970s, probably due to Ruhe's work in the Midwest and the first edition of Birkeland's book, did soils research become an important component of geoarchaeological research, including work by pedologists (e.g., Foss, 1977; Foss et al., 1995; Cremeens, 1995; Cremeens and Hart, 1995; Morris, 2002) as well as geoscientists (e.g., Holliday, 1989, 1994, 2004; Reider, 1990; Bettis, 1992; Mandel, 1994, 1995; Bettis and Hajic, 1995; Mandel and Bettis, 2001).

The most significant conceptual advances in soil geomorphology since 1974 resulted from Francis Hole's work, especially on the dynamic nature of soils (e.g., Hole, 1981), and are seen most prominently in the work of geographers influenced by Hole's teaching and writing. For example, Curtis J. Sorensen (University of Kansas), who took courses from Hole at the University of Wisconsin, and his students (including Randall Schaetzl, who also took courses from Hole) produced an impressive body of literature dealing with soils as clues to climate change and landscape evolution (e.g., Sorensen, 1977; Barrett and Schaetzl, 1992; Dahms, 1994, 2002; Mandel, 1994; Schaetzl et al., 2000) and applying the factorial approach to understanding the distribution of soils (Schaetzl and Isard, 1996). The intellectual thread of Hole's views on soil dynamism can be seen in the work of Donald L. Johnson and his students at the University of Illinois. Johnson and Donna Watson-Stegner (1987) formulated the “Soil Evolution Model,” which incorporates aspects of several other models of pedogenesis, including Simonson's and Jenny's approaches, the thermodynamics and energy-transfer concepts of Nikiforoff (1959) and Runge (1973), the notion of soil evolution espoused by Nikiforoff (1949), and the concept of landscape evolution (though not expressly the idea of K-cycles) (see also Johnson et al., 1987, 1990). The authors recognize that soil formation is not a linear, unidirectional, process. Soils do not simply exhibit more horizons and get thicker over time, for example. They are affected by processes (external and internal) that promote or inhibit horizonation (or both), or promote or inhibit profile thickening (or both). At any given site or in any given region a subset of these “progressive” and “regressive” processes will operate and the resulting soil usually reflects the dominance of one group of processes over the other. The dominance of one group could shift to the other group over time as either internal or external processes or factors change. Such changes could include shifts in climate, vegetation, animal communities, human activity or geologic events and processes.
The soil evolution model in its holistic view of soil formation is the most sophisticated of the several models that have been proposed (and as a result, Johnson was awarded the 1990 G.K. Gilbert Award of the Association of American Geographers). It also provides considerable explanatory power in discussing soils once they have been studied. The model does not provide the \textit{a priori} means of investigating soil development that the Jenny factorial approach holds, but it is a useful conceptual approach that links the factors to the soil itself.

Perhaps a fitting culmination of the research and influence of Hole, Johnson, and Sorenson, and the work of many others linking pedology and geomorphology is publication of the volume \textit{Soils: Genesis and Geomorphology} by R. Schaeztl (a student of Hole, Johnson, and Sorenson) and S. Anderson (2005). The authors produced the most comprehensive English-language volume integrating traditional pedology with soil geography and soil geomorphology. The book treats soils and landscapes as dynamic components of one another, evolving together through space and time. Publication of this volume is a fitting and encouraging end-point to this history.

\section*{Summary and Conclusions}

Soil geomorphology in the U.S. has disparate roots in pedology, Quaternary geology, and physical geography going back to the late 19\textsuperscript{th} century. Several historical threads leading to modern soil geomorphology can be traced through the early 20\textsuperscript{th} century, but what most of us would recognize as soil geomorphology did not appear until after the Second World War. The beginnings, however, were in Russian pedology, with its emphasis on the landscape and the factors of soil formation, and in American Quaternary stratigraphy, with a focus on past environments and the Pleistocene time scale. These emphases remain important components of soil geomorphology today. One aspect of the field focuses on the relationships between soils and landscapes, emphasizing pedogenic processes, geomorphic processes, and hydrology to understand the distribution of soils in the present and in the past. This approach evolved more directly from pedology and process geomorphology as well as geography, largely under the influence of R.V. Ruhe and F. D. Hole. Institutionally, this approach derived from traditional soil mapping and from the USDA-sponsored soil geomorphology projects of the 1950s to 1970s. Soil stratigraphy, particularly Midwestern Quaternary stratigraphy, also played a role in this work.

A significant amount of soil-geomorphic research and writing also focuses on soils as a means of studying and reconstructing the past, with a particular focus on soils as age indicators and soils as clues to past environments (especially vegetation and climate). These aspects of soil geomorphology evolved more directly from study of the relationship between soils and the soil-forming factors that began with the
Russians, was most famously espoused by H. Jenny, and then refocused on the past by P. W. Birkeland. Institutionally, this research approach also evolved from some of the USDA soil geomorphology projects, but also from the U.S. Geological Survey, beginning with the Military Geology Unit in Second World War and continuing with a variety of Quaternary geologic studies, largely in the western U.S., first by C. B. Hunt, R. Morrison, and G. R. Richmond, and later by workers encouraged by D. E. Marchand and J. Harden.

A result of the evolution of soil geomorphology in the U.S. is a geographic distinction between what can be over simplified as soil geomorphology in the Midwest and soil geomorphology in the mountain and desert West. The Midwestern approach, following Ruhe and his many predecessors, emphasizes hillslopes, hydrology, and stratigraphy. Much of the Midwestern landscape today is undergoing erosion, which is superimposed on till and loess sheets with multiple buried soils (forming the “time-transgressive chronosequences without historical overlap” of Vreeken, 1975b) traceable over vast (multi-state) regions. Given the humid climate, overland and subsurface flow of water are also ubiquitous processes. The emphasis on soil geography as a component of soil geomorphology in the Midwest also is related to the close cooperation among pedologists and Quaternary geologists and geomorphologists probably due to the long tradition of Quaternary geology in the region and because of the agricultural significance of the regional soils. The tradition of field conferences that bring Quaternary geoscientists and pedologists together, such as the Friends of the Pleistocene, is also an old one in the Midwest, and likely contributed to the cross-fertilization between geologists, geographers, and pedologists.

In the West, soil geomorphology includes soil stratigraphy, but buried soils are restricted to specific settings such as paleo-lake basins or alluvial valleys. More commonly, soil geomorphic work has focused on chronosequences and topo-chronosequences on moraines, alluvial terraces, and paleo-lake shorelines (Table 4). These Quaternary landform assemblages are ubiquitous throughout the western U.S., and their associated chronosequences (the “post-incisive” variety of Vreeken, 1975b) provide a unique opportunity to study rates of soil development in a variety of settings and to use soils to correlate landforms. Soil geography has rarely been emphasized, probably because there were fewer instances of pedologists working with Quaternary geologists in the west. This situation, in turn, is likely due to the much more limited nature of farmable land in the west.

Since the very beginnings of research into the geologic aspects of soil genesis and the development of the field of pedology, pedologists have increasingly distanced themselves from geologists and geology. To a large extent this was an institutional accident resulting from the evolution of schools of agriculture separate from schools of natural science, the housing of soil science in those agricultural colleges, and most
government-funded soil science research coming from the USDA. The emergence of soil geomorphology after Second World War represents, in many ways, the most substantive re-integration of pedology and geology. This was due in large measure to the USDA soil geomorphology projects. Since they ended, however, there have been few comparable investigations based in soil science beyond the exceptions noted above. Otherwise, most substantive soil-geomorphic research has been based in the USGS (e.g., Table 5) and in departments of geology and geography. The broader implications of this history in soil science are unclear, but certainly the decline in hirings of pedologists in soil science departments and in pedologic research into the relationship of soils to contemporary and past landscapes and environments is an unsettling trend. More positive developments can be seen in the soil-oriented research of geologists and geographers, represented by the books from Birkeland (1999) and Schaetzl and Anderson (2005). Ultimately, however, maintaining soil-geomorphic research in soil science as well as geology and geography is the healthiest direction.

Notes

2. Because soil geomorphology is a young field with roots in several disciplines, few will agree on the relative importance of specific individuals, events, and agencies in its evolution. Our individual views on these matters are strongly colored by our training and our research and (in some cases) academic experience. In my own case, I was trained in pedology at Texas Tech University under B.L. Allen, and received a PhD in Geosciences at the University of Colorado under Peter Birkeland. I then spent a total of 17 years teaching Geography and Geology at the University of Wisconsin-Madison. This experience exposed me to two very different but widely applied approaches to soil geomorphology and soil stratigraphy (the western Morrison/Richmond/Birkeland tradition and the midwestern Ruhe/Hole tradition). This paper resulted from my curiosity about the origins of these approaches. My years in the Midwest also alerted to me to the broader issues of soil geomorphology coming out of physical geography and pedology.

3. The discussion and comments on the catena concept throughout this paper is based on conversations with, and unpublished papers from, David Brown (2004), now at Montana State University.

Acknowledgments

My thanks to Benno Warkentin and Dan Yaalon for organizing and shepherding this volume. My interest in this subject began when I was on the Geography
faculty at the University of Wisconsin-Madison following my graduate training and research in soils. As I became exposed to Midwestern soil-stratigraphy and soil-geomorphology I quickly recognized the very different approaches to the topics there vs what I was exposed to in my training “out west.” So I casually and unsystematically began talking with and corresponding with others interested in the history of science and those who made the history. Among the former was John Tandarich, who has become the leading historian of pedology in the U.S. In the latter category, Roger Morrison and the late Gerry Richmond kindly answered my many questions and shared their professional development with me. Richmond alerted me to the very important role of the MGU. Francis Hole also enthusiastically talked about his many years of soil mapping in Wisconsin and the evolution of his thinking about soils. John Hawley and B.L. Allen shared their recollections of the Desert Project and the other USDA soil-geomorphology projects. David Brown was the source of my information on the history of the catena concept, when he was a graduate student in Soil Science at Wisconsin. David also helped me crystallize my thinking on many aspects of the history of pedology and soil-geomorphology via long, enjoyable conversations. As the manuscript came together a number of colleagues provided comments on various drafts and I thank them. Pete Birkeland read three drafts (!), Erik Brevik, Jeff Homburg, Bill Farrand, Tom Fenton, and Alan Busacca all read through it once. Erik also alerted me to the work of E.E. Free and G.N. Coffey.

Finally, an anonymous reviewer prodded me to look further into the prominent role of U.C. Berkeley in this story. This paper is dedicated to Roger Morrison, Gerry Richmond, Lee Gile, John Hawley, and all of the men and women of the MGU, USGS, and USDA who worked hard to maintain the link between pedology and geomorphology.

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