# SOILS RELATIVE TO GEOLOGY AND LANDFORMS IN WALNUT GULCH EXPERIMENTAL WATERSHED, ARIZONA, USA

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## ABSTRACT

Soils of the Walnut Gulch Experimental Watershed (WGEW), southeastern Arizona, are dominantly sand and gravel loams that vary from deep, relatively mature, and well drained soils on undissected pediment surfaces to thin, immature soils on surfaces exposed by recent stream incision, bedrock, and colluvium veneering plutonic, volcanic, and carbonate rocks. All soils are strongly reflective of a semiarid climate and the rocks upon which they have formed, but vary with in texture and composition with landform and the length of time that the surface has been exposed to biochemical weathering. Soil areal extent and physical properties for the WGEW are contained the Natural Resource Conservation Service products STATSGO, SSURGO, and a more detailed version of SSURGO conducted specifically for the WGEW. All three of these surveys are available at http://www.tucson.ars.ag.gov/dap/ .

## 1. INTRODUCTION

Soil, as a product of natural hydrologic and geomorphic processes, is a layered mass of minerals and, generally, organic matter and rock fragments that differs from the parent material (rocks) from which it is derived in terms of morphology, physical and chemical characteristics, and organisms and organic content. The layers, or horizons, that comprise a soil are of variable thickness (as also are soil bodies), are typically but not always unconsolidated, and differ from each other in terms of degree of alteration that has occurred during the weathering process of the underlying parent material **[***Joffe,* 1949**]**.

The Walnut Gulch Experimental Watershed (WGEW) in southeastern Arizona is part of the USDA Agricultural Research Service's Southwest Watershed Research Center, Tucson, AZ.  A major tributary of the upper San Pedro River, the 149-$km^2$ watershed is highly instrumented to help address the goal of relating rainfall, runoff, and sediment yield to land use through erosion modeling.  To meet this goal, basic knowledge of watershed characteristics, including soils and the factors by which they evolved, is essential.  The objective of this investigation is to interpret which variables most significantly influence soil types and distribution in the watershed, and to summarize soil characteristics relative to watershed conditions of climate, time, geology, landforms, and vegetation.  In the WGEW, and many areas of southeastern Arizona, geology is inferred to exert a major control on soil distribution, maturity, thickness, and permeability.  Most soils of the watershed are unconsolidated, but locally near-surface soil horizons may be moderately to well consolidated owing to the deposition of calcrete.

## 2. SOIL SURVEYS

The Natural Resource Conservation Service (NRCS) is the agency responsible for conducting and publishing soil surveys in the US.  The presentation of soils information has evolved from printed descriptions of pedons, tables of soil physical and chemical characteristics, and maps of soil series distributions to Internet based Geographical Information Systems (GIS) such as STATSGO and SSURGO.  The first soil survey of the WGEW was conducted by the NRCS in the late 1960s **[***Gelderman,* 1970**]** and contained pedon descriptions and locations of 21 soil map units.  Physical and chemical properties of the soil series of the map units became available in 1974 **[***USDA-SCS,* 1974**]**.  Currently three GIS soil surveys are available for the WGEW, STATSGO consisting of 3 soil map units, SSURGO consisting of 18 soil map units, and a more detailed survey **[***Breckenfeld,* 1994**]** based on the SSURGO data consisting of 25 soil map units.  The discussion below is based on the latter survey.

## 3. DETERMINANTS OF SOIL CHARACTERISTICS

Typically soils are regarded as products of geology and the weathering processes to which rock types are subjected.  The length of time that biochemical weathering and erosion act on a parent material is also a principal determinant of soil development and thus maturity. Because topography and biology, particularly vegetation and land use, affect erosion and related hydrologic and geomorphic processes and are interactive with and dependent on geology and climate, often they too are viewed as fundamental determinants of soil genesis. More specifically, the slopes and slope lengths of landforms that define the topography of a watershed are controls of weathering rates and erosion and sediment movement from hillsides to bottomlands, and from bottomlands of the watershed to downstream parts of the drainage network. Thus, soils of the WGEW vary with components of the small-scale landforms of the watershed and their geologic characteristics.

The detailed soil surveys of the WGEW **[***Gelderman*, 1970; *Breckenfeld*, 1994**]** have demonstrated that soil types are functions of local geomorphic features, and that many soils are immature owing to semiarid climate, slow biochemical weathering, and rampant post-settlement rill and gully erosion in fan deposits north and east of Tombstone **[***Graf,* 1983**]**. Where accelerated erosion of the last century has not stripped the upper horizons, soils tend to be thick, mature loams rich in sand and gravel and of high carbonate (calcrete) content. Virtually all of the soils reflect the underlying rocks from which they developed.

Climate - The WGEW has a warm, semiarid climate that results in relatively slow biochemical reduction of bedrock. Soils of Holocene age, therefore, are typically coarse, permeable, and poorly developed. Surfaces, such as those of fan terraces, that were first exposed to weathering processes prior to Holocene time when the climate may have been more moist than now, are deeper, more mature, and generally more argillaceous than the younger soils.

Time - The amount of time that a rock or deposit of rock fragments (such as fan deposits) is exposed to a set of climatic and biological conditions determines the texture, composition, and extent to which a soil develops on the rock or rock-deposit surface. In the WGEW, time has been inconsequential relative to soil-forming processes in areas of bare rock. In contrast, where surfaces of fan terraces remain and have been exposed to weathering processes throughout the late-Cenozoic and Quaternary periods, time has been sufficient to yield deep, argillic soils, even where climatic conditions have been generally arid to semiarid. Nowhere in the watershed has time been adequate, under prevailing climates, to yield clayey soils, rich in iron and aluminum oxides and hydroxides, that are indicative of long-term warm, moist conditions.

Geology - Basic controls of soil formation in the WGEW include a semiarid climate, an incomplete vegetation cover, and landform surfaces that been exposed too little time to permit weathering to deep, mature soils. Accordingly, soils of the watershed are mostly poorly developed and strongly indicative of the rock types from which they evolved.

A comparison of the soils map of the WGEW (fig. 1) with a map of the geology **[***Osterkamp*, this issue, fig. 1**]** suggests that areas of soil groups correlate well with bedrock outcroppings and colluvial veneers on bedrock, fan deposits, and alluvium. Specifically, areas of plutonic-rock exposures are underlain by shallow, quickly drained gravelly sand or clay loams, and hilly areas of volcanic rocks are capped by moderately deep, poorly permeable cobbly clay loams. Moderately permeable, shallow to very shallow cobbly loams are associated with limestone and dolomite of the Tombstone Hills. Soils on fan terraces of the Gleeson Road Conglomerate are typically very deep, poorly permeable gravelly sandy loams, whereas younger soils on steeper slopes of dissected beds of the Gleeson Road Conglomerate are deep, moderately permeable sandy loams and clay loams. Soils of mid- to late-Holocene alluvium are deep, well drained, and highly permeable sand loams **[***Breckenfeld*, 1994**]**.

Landforms - Landforms of the WGEW were categorized by **[***Breckenfeld*, 1994**]** as hills and mountains, fan terraces, alluvial fans, basin floors, and flood plains. These landforms are products of fluvial erosion, deposition, and related hillslope processes, and hence they and the soils that veneer them reflect late-Quaternary climate and climate variability. A unique suite of soil types is associated with each landform category.

Hills and mountains in the Basin and Range Physiographic Province of southeastern Arizona range from steep erosional features that supply sediment from bare rock surfaces to upland surfaces of low to moderate slope upon which erosion is less intense and generally thin argillic (enriched in silicate-clay) soils may accumulate on bedrock surfaces. Slope steepness is largely a function of the ability of a bedrock type to resist chemical weathering, and the intensity by which a hill or mountain has been affected by faulting and folding. Principal examples of this type of landform in the WGEW are small areas granitic and gneissic rocks of the Dragoon Mountains, rounded hills formed of the S O Volcanics in the southeastern part of the watershed, and surfaces underlain by mostly carbonate, volcanic, and igneous-intrusive rocks in the Tombstone Hills.

Fan terraces, as defined by **[***Breckenfeld*, 1994**]**, are remaining surfaces of alluvial fans that have had stream incision since the end of fan deposition. The remnant surfaces, therefore, overlie generally mature argillic soils and are interrupted by escarpments with thinner and less mature soils that slope down toward the channels that have dissected the fan deposits. In related discussions on the geology of the WGEW **[***Osterkamp and Miller,* this issue**]** and the geomorphology of the watershed **[***Osterkamp and Nichols*, this issue**]**, the fan deposits that are capped by fan terraces are uppermost beds of the Gleeson Road Conglomerate, and the large-scale surfaces that have been dissected are the Whetstone Pediment and the Tombstone Surface.

Mid-Holocene to recent accumulations of basin-fill, alluvial-fan, and flood-plain deposits described by **[***Breckenfeld*, 1994**]** in the WGEW are restricted to partially closed basins, locales adjoining upland bedrock surfaces, and terrace and inset sediment, sand and gravel bars, and stream gravel within fan incisions. These deposits, which are grouped as the Jones Ranch Alluvium and late-Holocene alluvium **[***Osterkamp and Miller*, this issue**]** originate from mountains, hills, and other up-slope sources, and generate permeable, very immature, sandy-loam soils that may be susceptible to covering or modification by subsequent episodes of channel erosion or sedimentation.

Vegetation - In the WGEW the distribution and density of plant species appear to be more dependent on moisture availability and slope conditions than they are on geology. Vegetation, therefore, is a control that, like soils, varies with climate, landform, and external stresses such as land use. Of the factors that control soil development, vegetation is likely the least correlated with soil distribution in much of semiarid southeastern Arizona.

**4. SUMMARY OF SOIL GROUPS**

Figure 1 is a soils-distribution map based on the soil map units defined by *Breckenfeld* **[**1994**]** and Table 1 is a list of the map units, areal extent, and textural class. To simplify the discussion that follows, the map units in Figure 1 were combined based on similar geologic parent material and/or geomorphic surfaces and are shown in Figure 2. The Baboquivari-Combate-Bodecker Group consists of permeable, immature soils formed on late-Holocene channel, flood-plain, and alluvial-terrace deposits in all parts of the watershed. Mature, poorly transmissive soils of the Forrest-Bonita Group are derived principally from early- to mid-Holocene cienega and inset deposits of the Jones Ranch Alluvium and weathered side-slope alluvium of recently dissected fan deposits. Large amounts of clay and silt result in the bottomland soils of the Forrest-Bonita Group being mostly clay and silt loams.

Deep sandy gravel loams of the Blacktail-Elgin-Stronghold-McAllister-Bernardino Group occur on beds of the Gleeson Road Conglomerate. The generally deep, mature soils of this group have developed slowly in areas of the upper, eastern part of the watershed where the Tombstone surface and Whetstone pediment (planation surfaces on the fan deposits) are incompletely dissected. In the lower, western part of the watershed soils that have formed on the erosion surfaces of Jones Ranch Alluvium and the Gleeson Road and Emerald Gulch Conglomerates are in the Luckyhills-McNeal Group. Because soils of the group also are derived largely from fanglomerate beds, and because the Tombstone surface and the Whetstone pediment are more dissected in the western half of the watershed than elsewhere, the soils of the Luckyhills-McNeal Group tend to be sandy and gravelly loams that are immature compared with soils where rilling and gully erosion have been less extensive.  An A horizon of these soils is typically absent, having been removed by late-Quaternary erosion **[***Breckenfeld,* 1994**]**.

Soils of the Sutherland-Mule-Tombstone Group have developed from weathering of clastic rocks of the Bisbee Group (fig. 1) and from conglomerate beds derived from it in areas adjacent to the Tombstone Hills and in upper parts of the watershed.  The Sutherland-Mule-Tombstone soils are very gravelly, mature loams that typically contain well developed pedogenic calcrete.

Soils that have developed directly on and beside exposures of volcanic rocks, igneous and carbonate rocks of the Tombstone Hills, and igneous and metamorphic rocks in the uppermost part of the watershed include, respectively, those of the Epitaph-Graham-Grizzle Group, the Mabray-Chiricahua-Rock-Schieffelin-Lampshire-Monterosa Group, and the Budlamp-Woodcutter Group.  The soils of these groups strongly reflect the rock types from which the soils formed; they have little organic matter and are almost everywhere less than 0.2 m in thickness **[***Breckenfeld,* 1994**]**.  Volcanic-terrain soils of the Epitaph-Graham-Grizzle Group, for example, are mostly thin, clay-rich loams containing abundant gravel and cobble clasts of basalt or andesite and tuff derived from the S O Volcanics.  Most soils of igneous and carbonate rocks in the Tombstone Hills, the Mabray-Chiricahua-Rock-Schieffelin-Lampshire-Monterosa Group, are very immature, shallow gravel and cobble loams; exceptions are clay and gravelly clay loams of the Chiricahua Series **[***Breckenfeld,* 1994**]**, which forms on the Bolsa Quartzite.  In headwater areas of the watershed are shallow clay-, sand-, and gravel-loam soils of the Budlamp-Woodcutter Group that occur above monzonite and gneissic granite.

## 5. DATA AVAILABILITY

The STATSGO, SSURGO, and Breckenfeld **[**1994**]** soils maps and associated soil physical properties data bases for the WGEW are available at http://www.tucson.ars.ag.gov/dap/

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Table 1. Map units, areal extent, and textural class of soils in the WGEW based on *Breckenfled* **[1994]**.

| Map unit | Area (ha) | Percent of total area | Textural Class |
|---|---|---|---|
| Baboquivari-Combate complex | 543 | 3.67 | sandy loam |
| Blacktail gravelly sandy loam | 245 | 1.66 | gravelly sandy loam |
| Budlamp-Woodcutter complex | 65 | 0.44 | very gravelly sandy loam |
| Chiricahua very gravelly clay loam | 147 | 0.99 | very gravelly sandy loam |
| Combate loamy sand | 106 | 0.72 | loamy sand |
| Elgin-Stronghold complex | 1504 | 10.16 | very gravelly fine sandy loam |
| Epitaph very cobbly clay loam | 242 | 1.63 | very cobbly clay loam |
| Forrest-Bonita complex | 140 | 0.95 | fine sandy loam |
| Graham cobbly clay loam | 284 | 1.92 | cobbly clay loam |
| Graham-Lampshire complex | 244 | 1.65 | very cobbly loam |
| Grizzle coarse sandy loam | 81 | 0.55 | coarse sandy loam |
| Lampshire-Rock outcrop complex | 385 | 2.60 | very cobbly loam |
| Luckyhills loamy sand | 68 | 0.46 | loamy sand |
| Luckyhills-McNeal complex | 4255 | 28.75 | very gravelly sandy loam |
| Mabray-Chiricahua-Rock outcrop complex | 495 | 3.35 | very cobbly loam |
| Mabray-Rock outcrop complex | 838 | 5.66 | extremely cobbly loam |
| McAllister-Stronghold complex | 1358 | 9.17 | gravelly fine sandy loam |
| Monterosa very gravelly fine sandy loam | 284 | 1.92 | very gravelly fine sandy loam |
| Riverwash-Bodecker complex | 171 | 1.15 | sand |
| Schiefflin very stony loamy sand | 393 | 2.66 | very stony loamy sand |
| Stronghold-Bernardino complex | 760 | 5.13 | very gravelly loam |
| Sutherland very gravelly fine sandy loam | 674 | 4.55 | very gravelly fine sandy loam |
| Sutherland-Mule complex | 182 | 1.23 | very gravelly fine sandy loam |
| Tombstone very gravelly fine sandy loam | 1275 | 8.62 | very gravelly fine sandy loam |
| Woodcutter gravelly sandy loam | 62 | 0.42 | gravelly sandy loam |

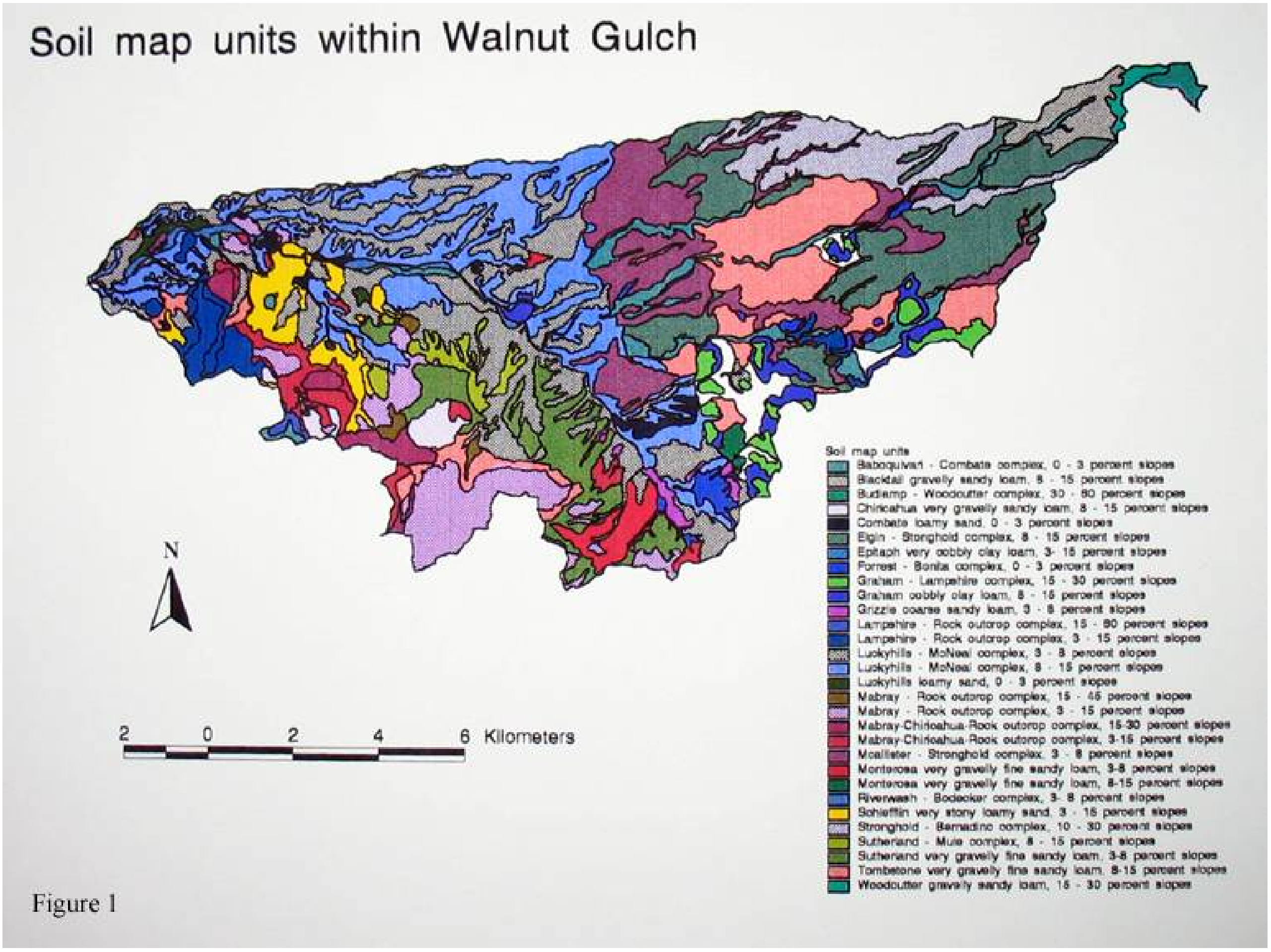


Figure 1. Soil Map Units for the WGEW based on *Breckenfeld* **[**1994**]**.

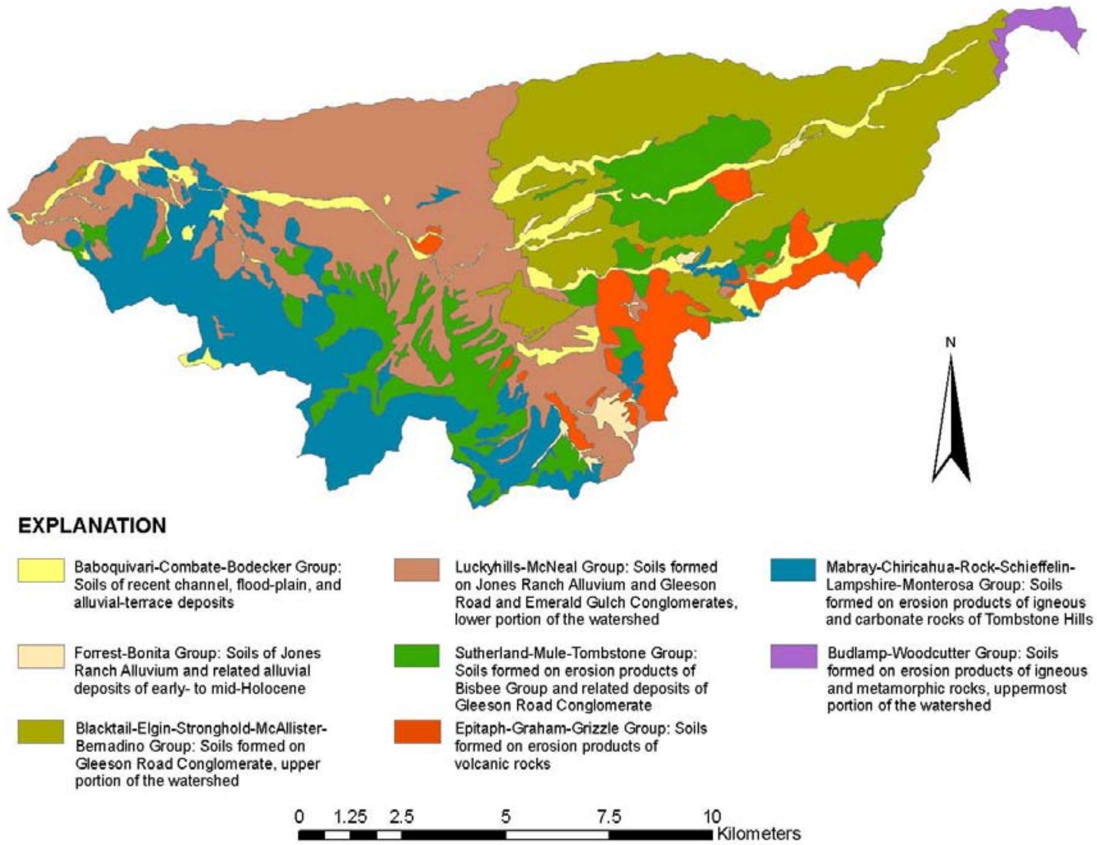


Figure 2. Simplified distribution of soil groups in the WGEW adapted from *Breckenfeld* **[**1994**]**.