SOIL GEOMORPHOLOGY OF THE COPPER RIVER BASIN, ALASKA, USA

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INTRODUCTION

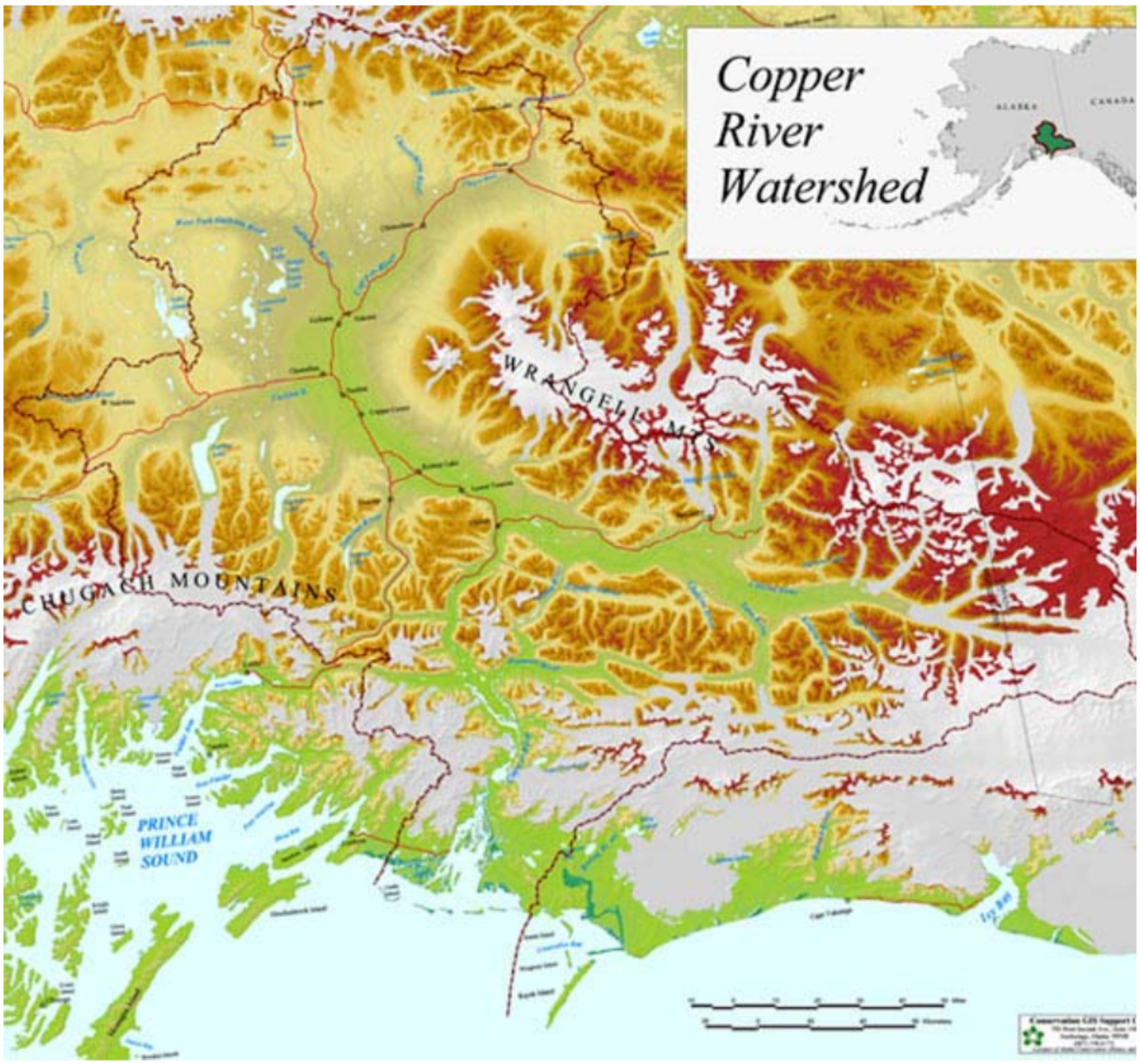
Soils in the Copper River basin in southeast (SE) Alaska reflect the unique combination of landscape forming processes that occur in high latitude areas. Connections between landscape position and soil type and/or development rate can be understood using methods developed by soil geomorphologists. Soil geomorphology is a good way of investigating watershed and local soil processes at a given point on the landscape (Daniels & Hammer 1992, Gerrard 1992). There are several distinct landscapes that occur in the Copper River basin, and each landscape tends to promote certain types of soil development (Richardson & Vepraskas 2001). Variations in soil type and local processes can have profound impacts on vegetation communities, and ultimately, the animal species that populate Alaskan ecosystems.

The Copper River basin is a varied and rugged landscape, which includes the Chugach and Wrangell mountain ranges and a significant delta grading into the Gulf of Alaska (Figure 1). Glaciation is the most significant geomorphic element in the Copper River basin. Late Pleistocene and early Holocene glaciations resulted in ice covering the entire basin at some point in the last 45,000 years (Clark and Kautz 1998). Presently, glaciers cover approximately 18% of the basin [refer to (Bowersox 2002) in this volume for more detail].

Repeated glaciations resulted in the obliteration of previous soil development, and set the stage for the recent era of soil development. Therefore, soil development in the Copper River basin is a geologically young phenomenon and is generally controlled by landscape position (Clark and Kautz 1998). Soil development in SE Alaska is a function of not only landscape position, but macro- and microtopography, hydrology, age, vegetation development, disturbance pattern, and freeze-thaw processes (Van Cleve et al 1993). No discussion of soil process in Alaska is complete without focusing on the role of freezing and thawing in soil development. These processes are discussed briefly in this paper, and are treated more thoroughly, along with other periglacial processes, elsewhere in this volume (Rains 2002).

The major landforms in the Copper River basin are glacial, lacustrine, or fluvial in nature. Post-glacial soil development processes can be used to understand the fine scale context for the soil types present in the basin today. By understanding both the form and the process, predictions can be made regarding the type of soil based on landscape position. Further, the interplay between soil development and the terrestrial ecology of the region can be explored.

Figure 1. Copper River Watershed



SOIL GEOMORPHOLOGY OVERVIEW

Geomorphology and Pedology

Soil geomorphology is a discipline that is well suited to interdisciplinary watershed science. In the past, soil science has been approached in two general ways. The first way is more geologically oriented and focuses on recording sedimentary deposits. The second way (pedology) is focused more on *in situ* soil development of the chemical and physical aspects of a soil profile. Soil geomorphology is an attempt to meld the two approaches to inform the researcher about fine scale geomorphic aspects of the landscape (Gerrard 1992, Daniels and Hammer 1992). Soil geomorphology records the apparent depositional history at a location, and also takes into account the post-depositional development processes in the interpretation of past and present hydrologic, chemical, and ecological processes at the site.

Soil Taxonomy

Soil Scientists with the Natural Resources Conservation Service (NRCS) have devised and refined a detailed Soil Taxonomy (USDA Soil Survey Staff 1998) over the past 25 years. This taxonomy includes terms that can be applied in the field to classify different soil types (Richardson and Vepraskas 2001). These terms will be used sparingly in this paper to allow the focus to remain on watershed scale processes.

The descriptive terms focus on the origin and subsequent modification of materials in the soil profile. A generalized soil profile may include an upper section that is derived from aeolian (wind) processes, and a lower section that is composed of the decomposition products from the underlying bedrock. Further, the generalized profile may include some movement downward (illuviation) of organic materials or other elements that can undergo chemical transformations in the soil profile.

Tables 1 and 2 list the descriptive terms used by the NRCS for master horizons. The master horizon designations can be further modified by subscripts (e.g. Oi = fibric organic layer). A list of the subscripts likely to be used in Copper River soils is also included in Appendix A. The NRCS has recently published a Soil Survey of Copper River Area (Clark and Kautz 1998). This volume is a valuable source of information, and provides example soil profiles for each soil series. The survey does not cover the entire basin, but the area investigated included most of the major landforms found in the lower portion of the watershed.

Horizon	Characteristics
O	Organic horizon, Usually at soil surface, dominated by organic material
A	Topsoil, Darkest mineral layer, accumulation of humified organic matter mixed with mineral fraction
E	Mineral horizon where loss of silicate clay, iron, aluminum results in concentration of sand and silt particles of quarts or other resistant materials
B	Mineral horizon below an O, A, or E horizon where illuviation of silicate clay, Fe, Al or removal of carbonates has occurred, or where the soil horizon is conspicuously lower in value, higher in chroma, or redder in hue than other horizons.
C	Horizon is little affected by pedogenic processes, and does not show the characteristics of an O, A, E, or B horizon.
R	Hard bedrock

Table 1. Soil Master Horizon Descriptions (SSSA 1996)

Subscript	Definition
p	Plowed/anthropogenically modified
w	Development of color or structure in a horizon but with little or no apparent illuvial accumulation of materials
h	Illuvial accumulation of organic matter in the form of amorphous, dispersible organic matter-sesquioxide complexes.
s	Illuvial accumulation of sesquioxides and organic matter in the form of illuvial, amorphous, dispersible organic matter-sesquioxide complexes if both organic matter and sesquioxide components are significant and the value and chroma of the horizon are >3.
t	Accumulation of silicate clay that either has formed in the horizon and is subsequently translocated or has been moved into it by illuviation.
i	Fibric organic matter (little decomposition)
e	Hemic organic matter (some decomposition)
a	Sapric organic matter (highly decomposed)
b	Buried horizon
f	frozen ground
g	Strong gleying

Table 2. Partial List of Soil Horizon Subscripts and Descriptions (SSSA 1996)

LANDFORM -- SOILS RELATIONSHIPS

The landforms of the Copper River basin are predominantly related to glaciations that have occurred since the late Pleistocene. Therefore, all landforms in the basin started as glacial landforms, and their classification today depends on the degree to which lacustrine and fluvial processes have influenced the landscape since glaciation (Clark & Kautz 1998).

Glacial Landforms

Repeated glacial advances and retreats have resulted in a relatively young landscape in the Copper River Basin. The entire basin has been covered in ice at some point in the last 45,000 years; however, the lower elevations have been ice-free for at least the last 15,000 years (Clark and Kautz 1998). The main glacial landforms are till plains, outwash plains, drumlins, end moraines, and recessional moraines. These landforms often occur at higher elevations in the basin, where they have been less influenced by lacustrine and fluvial processes. Glacial landforms can result in nearly flat (outwash plains), undulating (till plains), convex (drumlins), and steep sided (moraines) surfaces (Clark and Kautz 1998) (Figure 2).

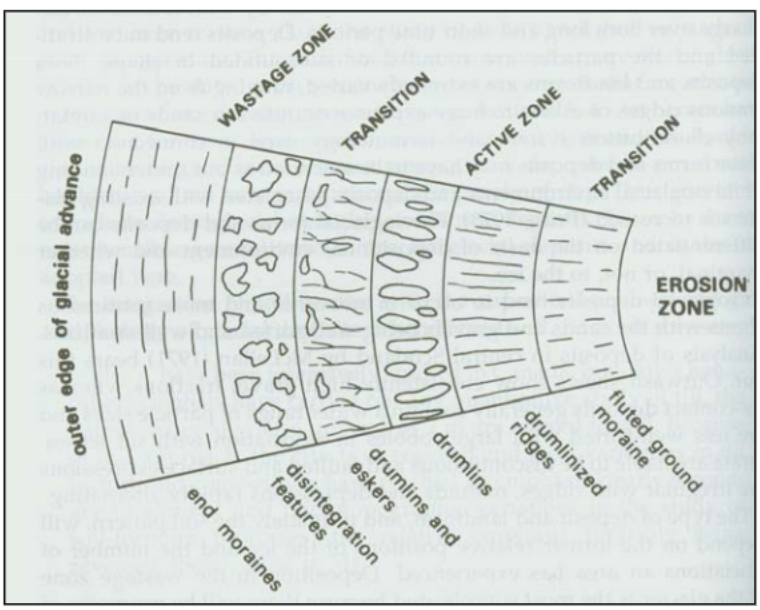


Figure 2. Conceptual spatial view of glacial landform succession. The erosion zone represents the glacier (Gerrard 1992).

During the most recent glaciation, an ice dam formed in the Chugach Mountains, which created a large proglacial lake (Clark and Kautz 1998). Deposition of fine aeolian and river sediment in the lake created vast, level expanses of loamy to clayey lacustrine sediments (Figure 3). Rivers have incised through the terraces since the ice dam melted and the area drained.

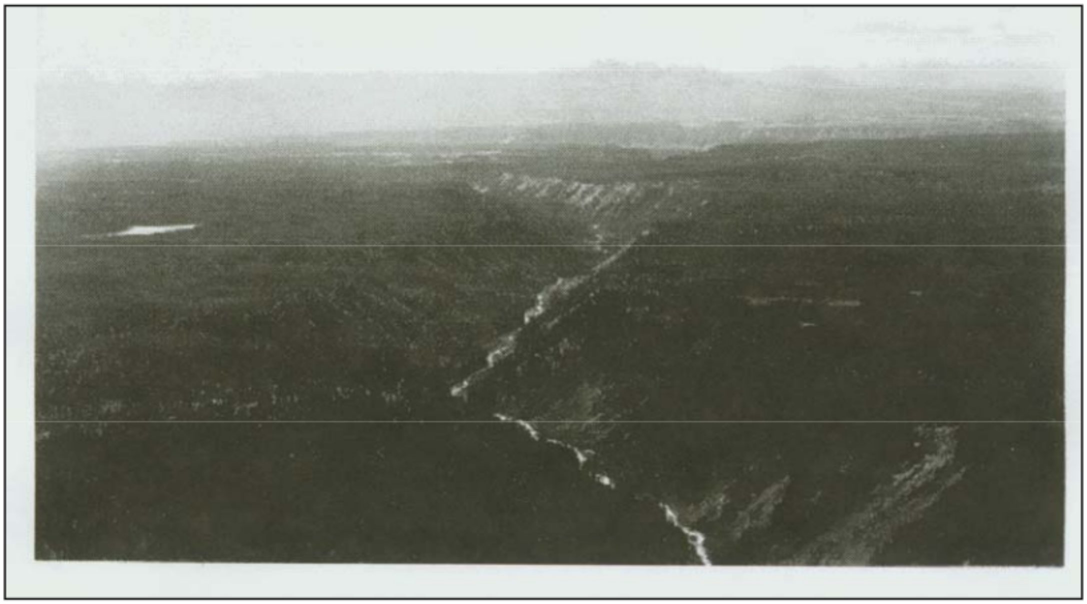


Figure 3. Broad Lacustrine Terrace with Incised Copper River (Clark & Kautz 1998).

Presently, there are numerous large and small lakes (muskegs) in the Copper River basin (Figure 4). These lakes are either associated with glacial retreat or are the result of freeze-thaw

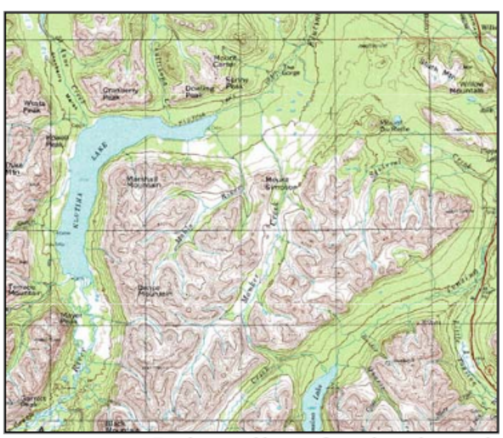


Figure 4. A section of the USGS Map Valdez showing Klutina Lake, formed behind the end moraine of a valley glacier

processes. Lakes allow for the deposition of fine aeolian materials, and are often associated with Cryofibrist soils with significant organic mat development (Clark & Kautz 1998).

Fluvial Landforms

Fluvial landforms are generally the youngest features of the landscape. Soils are usually less well developed in the alluvial valley because of the age of the surface, and because of periodic disturbance by inundation, erosion, and/or deposition.

Floodplains

Floodplains are the youngest features of the landscape and are at or near the lower flow elevation of the streams. Researchers have noted a successional pattern for floodplain soils that encompasses soil and vegetation community development [refer to (Trowbridge 2002) in this volume for more detail]. Bare alluvium in the inside of meander bends becomes the foundation for the development of riparian vegetation communities (Viereck et al 1993).

Stream Terraces

As the Copper River and its tributaries cut down through the glacial, lacustrine, and fluvial deposits, stream terraces were created that are now rarely flooded (Van Cleve et al 1993). Soil development on a stream terrace generally varies by landscape position, and by the disturbance regime for the terrace. Vegetation development also plays a role in soil development on stream terraces. More vegetation reduces flow velocities during floods, and promotes deposition of sediment on the floodplain. Sediment deposition provides new parent materials for soil development, and also acts to increase the elevation of the terrace, thereby decreasing the depth and duration of flooding (Van Cleve et al 1993).

Delta Lower Valley/Delta

On the coastal plain of the Copper River, a significant delta has formed as a result of fluvial, wave, and tide energies. The relatively low slope of the coastal plain encourages the deposition of fine grained sediments creating poorly drained silt/clay layers. Occasional higher flow events and meandering channels deposit layers of stratified silts and sands that interbed with the finer grained lenses. Further, organic soil development occurs in back swamp areas off the main channels (Clark and Kautz 1998).

POST GLACIAL SOIL PROCESSES IN THE COPPER RIVER BASIN

There are several general post-glacial soil processes that occur in the Copper River basin: (1) loess deposition, (2) organic matter accumulation, (3) *in situ* soil development, (4) permafrost, (5) fire, (6) fluvial deposition/erosion, and (7) colluvium processes. The extent to which each process is important in any specific location varies significantly as a function of the parent materials, micro- and macrotopography, vegetation, and hydrology. Each process is generally described below, and will be put into the context of the different landforms in the basin in the succeeding sections.

Loess deposition

As the glaciers receded, vast areas of bare soil were exposed, creating a source for aeolian transport and deposition. Therefore, most landforms in the basin are mantled with some loess materials. The amount of loess in a particular location varies with landscape position. Higher elevation and higher slope positions generally have less loess deposition than low slope depressional areas. The soil survey indicates that loess deposits are generally silt or finer (Clark and Kautz 1998). Since loess deposits are generally less well drained than other glacial sediments, the depth of loess materials can have significant impact on local scale shallow subsurface hydrology.

Organic Matter Accumulation

Vegetation development results in the accumulation of organic matter (OM) and in some cases a thick organic mat over the mineral soil surface (Figure 5).

Figure 5. Example of organic mat development in Alaskan soils. Photo courtesy Mark C. Rains.

Pioneer species invade bare soil that may be exposed after glaciers recede or rivers meander, and the detritus creates an organic layer (O layer – Table 1). The O layer generally provides a growing medium that allows secondary species to colonize that area. Further cycles of vegetation succession play an important role in the amount and type of OM and nutrients in the soil profile (D'Amore and Lynn 2002).

OM can insulate the mineral soil and promote the formation of permafrost. Permafrost underlies much of the Copper River basin, and has significant impacts on both soil and plant community development. Permafrost generally increases the amount of OM accumulation by perching water and saturating the upper soil layers. When the upper portion of the soil profile is saturated, decomposition rates decrease, which promotes the further development of the organic mat. OM accumulation can vary significantly throughout the Copper River basin. OM accumulation is generally a function of soil wetness, temperature, grain size, slope, and position. In general, a convex position at the top of a drumlin or moraine will have better drained soils, which will accumulate less OM than a depressional or flat position on the lacustrine terrace.

In situ **soil development**

In situ soil development in the Copper River basin generally consists of the illuviation of organic matter and hydrolysis of free iron (Fe) downward in the soil profile (Alexander and Burt 1993b). In situ soil processes can occur relatively quickly, on the order of tens or hundreds of years (Bormann et al 1995). Illuviation of OM is generally a function of the amount of water moving through the profile, redox conditions, and the amount of OM in the profile. Therefore, there is a distinct difference in soil development between better drained warmer soils and less well drained colder soils in the Copper River Basin.

In wetter, non-frozen portions of the soil profile, soil development generally consists of illuviation of organic material which creates an E horizon, and the loss of organic acids and free-Fe to form Bh and Bhs horizons in forested portions of the basin (Alexander and Burt 1996a). There are also processes related to the organic soil layers where decomposition will cause Oi and Oe layers to tend toward an Oa layer.

In drier, generally coarser grained areas (e.g., convex shoulder and slope landscape positions) soils are usually warmer and not as influenced by permafrost processes. In these soils the organic layer is usually thin (less than 5 cm), and B layer development is muted (e.g., Bw layer) (Clark and Kautz 1998) (Figure 6).

Figure 6. Example of warm, well-drained Alaskan soil with shallow bedrock. Photo courtesy Mark C. Rains.

Alexander and Burt (1996a &1996b) studied soil profile development at several sites exposed by the receding Mendenhall Glacier at the Juneau ice cap in southeast Alaska. Sites were chosen on glacial features of known ages from 10 years to greater than 240 years old to track the soil development with time and vegetation community development. None of the profiles had permafrost, and all were well, moderately, or excessively well drained. They proposed five stages of soil development in the area, presented here as Table 3.

Stage	Age (years)	Characteristics
1	10	Little soil development; dwarf fireweed invading bare soil
2	38	Rapid leaching and accumulation of organic matter in Oi, Oe, and A horizons; alder thicket develops
3	70	Loss of A horizon and development of E and incipient Bs horizon; spruce begin to replace alder
4	240	Development of a Bhs horizon with spodic properties; spruce forest dominates
5	>240	Development of a Bh horizon; spruce/hemlock forest

Table 3. Alexander and Burt's (1996a&b) Five Stages of Soil Development on Glacial Features in SE Alaska

The accuracy of the stages defined in Table 3 is constrained by the sample size and locations sampled by Alexander and Burt (1996a&b). However, the stages are useful as a conceptual model of soil development on warmer well-drained sites in SE Alaska.

Wet Permafrost

Perhaps the most important soil formation process in SE Alaska involves the freezing of water within or above the mineral surface (Swanson 1996) (Figure 7).

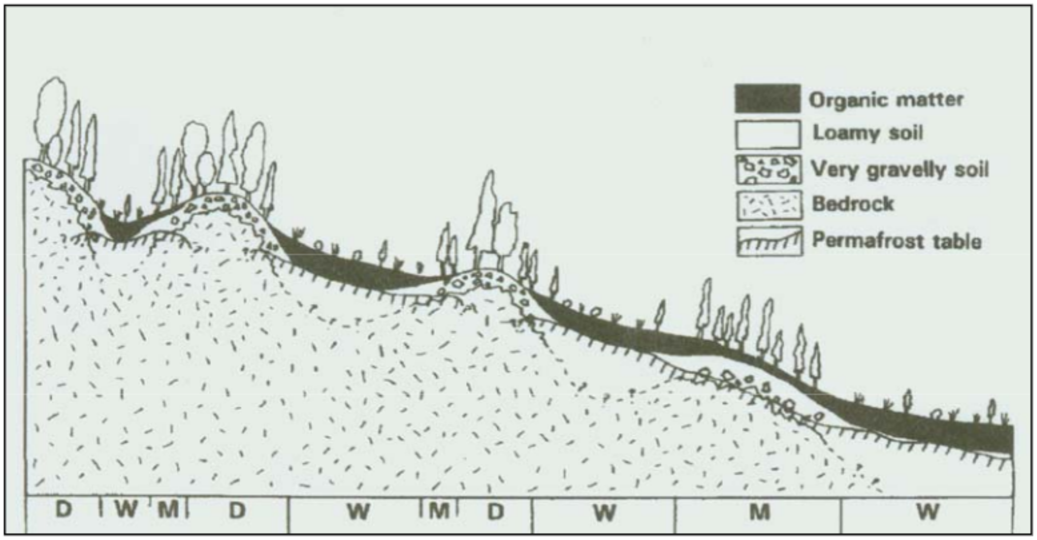


Figure 7. Schematic view of the landscape position, soil grain size, and permafrost interactions (Swanson 1996).

Freezing of shallow groundwater results in wet permafrost, which can pond water in the upper part of the soil profile, which will further influence soil development [refer to (Rains 2002) in this volume for more detail]. The presence of permafrost has also been shown to influence the nutrient dynamics of watersheds. In general, permafrost allows for more export of organic carbon from the soil to streams and lakes (MacLean et al 1999). Greater export occurs due to permafrost not allowing percolation into soils, and by the slowing of decomposition processes in the saturated upper portion of the soil profile.

Fire

The primary disturbance factor for soil in the Copper River basin is the fire regime (Swanson 1996b). Fire results in the clearing of vegetation, partial or entire removal of the organic mat, and thawing of permafrost. Changing these factors has profound effects on the characteristics of the soil profile. A wet-cold-frozen soil, with permafrost insulated by a thick organic mat can become a dry-warm soil type after a fire (Clark and Kautz 1998) (Figure 8).

Figure 8. The effects of fire on a soil profile. This profile was highly organic, with gleyed subsurface, indicating very wet conditions. After a fire, much of the organic mat was removed, the permafrost melted, and the soil now resembles the warmer drier soil shown in Figure 7. Photo courtesy Mark C. Rains.

Fluvial Disturbances

Fluvial disturbance to soil profile development can occur on many scales in the Copper River basin. During periods of rapid glacier retreat or ice dam breakouts, surface discharge of water can be large enough to form large glacio-fluvial outwash plains that can effectively wipe out all soil development on the valley floor [refer to (De Paoli 2002, Bowersox 2002) in this volume for more detail].

On the annual/decadal scale, fluvial processes such as meandering can erode portions of the floodplain and deposit sediment on the inside of meander bends. In the Copper River basin, river braids are prevalent and can result in semi-permanent islands where soil and vegetation can develop [see (Wooster 2002) in this volume for more details]. Overbank deposition of sediments can provide nutrients for vegetation communities, and can further elevate stream terraces above the active floodplain (Van Cleve et al 1993).

Colluvium/Hillslope Processes

The dominant hillslope processes that impact soil development in the Copper River basin are mass wasting events. Often, the melting of permafrost in a section of hillslope can weaken the area enough to be washed away during storm events (Swanson 1996a, Clark and Kautz 1998). The presence of permafrost allows for gelifluction terraces and other interesting surficial landforms. Essentially, the permafrost, combined with saturated conditions in the upper soil profile causes the upper part to slide downhill (Gerrard 1992). Often, anthropogenic disturbances can hasten hillslope processes. Land clearing for roads, logging, or agriculture can have the effect of destabilizing the soil surface, and promoting erosion from hillslopes to the alluvial valley (Clark & Kautz 1998).

SUMMARY

The landforms in the Copper River basin result in a complex array and distribution of soil types. Soil geomorphology is an effective way to investigate watershed level processes, as the existing soil profile tells the story of the processes occurring at that point on the landscape.

A general model of soil development in the Copper River basin focuses on two scenarios, one in a wetter colder soil, and the other in warmer drier situations. In colder wetter soils organic matter accumulation and local hydrologic conditions allow for the development of significant organic horizons. The organic mat allows for the development of permafrost in the soil profile, which further promotes accumulation of organic material. In drier warmer soils, soil development consists of illuvial processes that result in the formation of B layers.

The general model of soil development can be applied to glacial, lacustrine, and fluvial landforms in the Copper River basin. The relative importance of soil development processes will vary between landforms. Glacial landforms generally have greater topographic complexity, while lacustrine landforms are usually broad flat terraces. Stream terraces and floodplains are often disturbed by high flow events that can erode and deposit significant amounts of sediment.

Soil development in the Copper River basin has important implications for the terrestrial ecology of the watershed. Soil is the growing medium for vegetation that makes up the base of most terrestrial food webs. Vegetation community development has important feedback loops with soil development, as some vegetation successional stages are more effective at accumulating organic matter than others (Shaw et al 2001)(Figure 9).

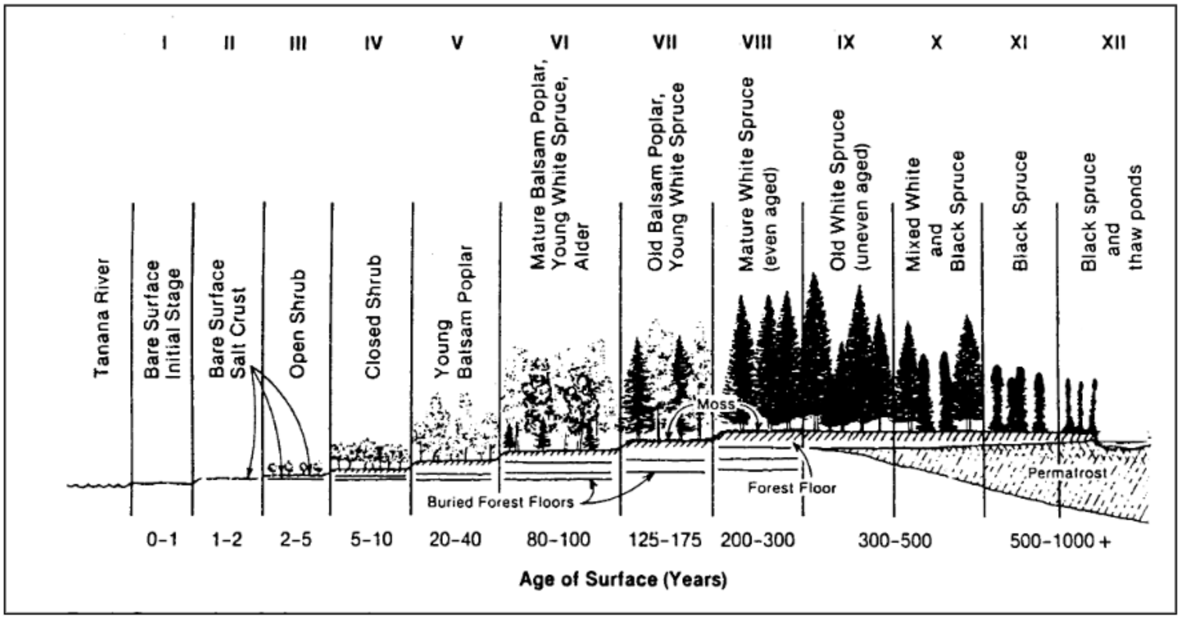


Figure 9. Schematic view of the interplay between soil and vegetation development on the Tanana River floodplain, Interior Alaska (Viereck et al 1993).

In conclusion, soil geomorphology is a good way to use information gained from a single point on the landscape (e.g., a soil pit) to learn about the geologic and ecological history of the location. The connections between soil development and vegetation community composition and extent are clear. Glacial processes and the cold climate determine the shape of the bare ground which provides the starting point for soil and vegetation development. Further, certain types of vegetation will not grow without suitable soil development, and it takes certain types of vegetation (e.g., deciduous species, mosses) to promote organic matter accumulation and associated pedologic features (Schimel et al 1998). The relative lack of nutrients in glacial soils limits the size and type of climax forest to black spruce (Hobbie et al 1998, Viereck et al 1993).

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