Postdiluvial Soil Formation and the Question of Time
Part II—Time

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Abstract

Many believe that most soils require great periods of time to form. This argument has been used in an attempt to refute the Bible's claims for a global flood only a few thousand years ago. In addition to arguments based on formation of extant soils, many geologists or paleopedologists see evidence of multiple fossil soil horizons or paleosols in the geologic record. Few, if any, of these researchers have examined carefully the assumptions behind their arguments. As described in Part I of this paper, pedogenesis is a complex phenomenon affected by several environmental factors. In Part II of this paper, we describe predictions of traditional and diluvial approaches to natural history and compare these predictions with constraints resulting from analysis of soil-forming mechanism rates. The results indicate that data from soil science are not only compatible with a diluvial view of earth history, but are actually more easily accommodated by it than by the traditional view.

Pedogenesis

Pedogenesis is the development of soil from geologic parent material. As described in Part I of this paper, pedogenesis is a complex phenomenon. Adding to the complexities of soil science are differences over the definition of soil and a reliance, particularly in the past, on the following:

- genetic definitions (historical, not scientific),
- definitions of soil-forming factors that include time both implicitly and explicitly,
- zonal definitions that fail to recognize interaction of soil-forming processes and geologic, geomorphic, or hydrologic factors.

Assumptions about earth history and the rates of soil-forming processes greatly affect one's view of pedogenesis, both in perceived rates of formation and the relative importance of environmental factors.

As described in Part I of this paper (Klevberg and Bandy, 2003), five *soil forming factors* are commonly accepted among soil scientists: climatic, parent material, topographic, biotic, and time.[1] Having noted the confusion introduced by having time itself as a soil forming factor, we have presented the idea of five *environmental factors* that influence soil formation. These environmental factors are mathematically described as partial derivatives *with respect to time*. The combination of environmental factors determines the rates of change of the actual *soil-forming mechanisms*. These environmental factors and soil-forming mechanisms are summarized below.

Environmental factors:

- Climatic (C): $\partial^2S/\partial C\partial t$ = change in soil state over time due to climatic factor
- Parent Material (M): $\partial^2S/\partial M\partial t$ = change in soil state over time due to parent material factor
- Geomorphic (G): $\partial^2G/\partial B\partial t$ = change in soil state over time due to geomorphic factor
- Biotic (B): $\partial^2S/\partial B\partial t$ = change in soil state over time due to biotic factor
- Ground Water (W): $\partial^2S/\partial W\partial t$ = change in soil state over time due to ground water factor

The change in soil state caused by environmental factors is secondary via influence on soil-forming mechanisms.

Soil-forming mechanisms:

- Epigenesis (E): $\partial^2S/\partial E\partial Mt$ = change in soil state over time due to epigenesis
- Physical weathering (P): $\partial^2S/\partial P\partial t$ = change in soil state over time due to physical weathering

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[1] The first part of this series forms an essential foundation for this paper. Important terms that may be unfamiliar to some readers and were not included in the glossary of the first paper are included in a glossary near the end of this paper.

- Leaching (L): $\partial^2 S/\partial L \partial t$ = change in soil state over time due to leaching
- Organic matter (O): $\partial^2 S/\partial O \partial t$ = change in soil state over time due to organic matter

The change in soil state caused by soil-forming mechanisms is primary to pedogenesis.

Five soil orders often interpreted as requiring moderate to long periods of time to form are especially considered in this paper. Parts of the world where these orders are dominant are shown on Figure 1. The focus of this paper is rates of change in soil state due to soil-forming mechanisms for these soil orders and the influence of environmental factors on these rates based on disparate views of earth history.

Parametric Study of Pedogenic Processes

Because time is implicit in the common variables of pedogenesis, complexities abound in analyzing the parameters that influence the rates of soil formation. Because soil formation occurs in time, pedogenesis lies properly within the sphere of history, and science can deal with it only indirectly. Predictions of physical and chemical changes in soil formation are greatly influenced by the bias of observers based on their views of earth history. In general, these views can be categorized as but two: the establishment geologic paradigm (EGP), which generally holds to gradualism, naturalism, an ancient earth, and evolutionism; and the diluvial geologic paradigm (DGP), which holds to a relatively young earth, catastrophism, and biblical history. Variants that do not fit these stereotypes are relatively unimportant to the analysis of pedogenesis presented in this paper.

Soil History Predictions Based on View of Earth History

Because the EGP assumes the availability of long periods of time for soil formation, pedologists who subscribe to this view tend to assume that soil formation has been a slow, gradual process (Brady, 1974, p. 309; Harding, 2001; Natural Resource Conservation Service, 1997; Weaver, 1989, p. 106). Evolutionists will therefore tend to expect gradual or cyclic pedogenic processes. By contrast the DGP assumes a short time for earth history, the availability of vast amounts of energy within the year long global Flood cataclysm, and probable residual catastrophism. Diluvialists, while recognizing the influence of environmental factors on soil-forming mechanisms, place greater or lesser emphasis than their establishment counterparts on individual factors and assume that the rates at which environmental factors have operated may have varied greatly in the past. Rates and types of soil formation would thus have also var-

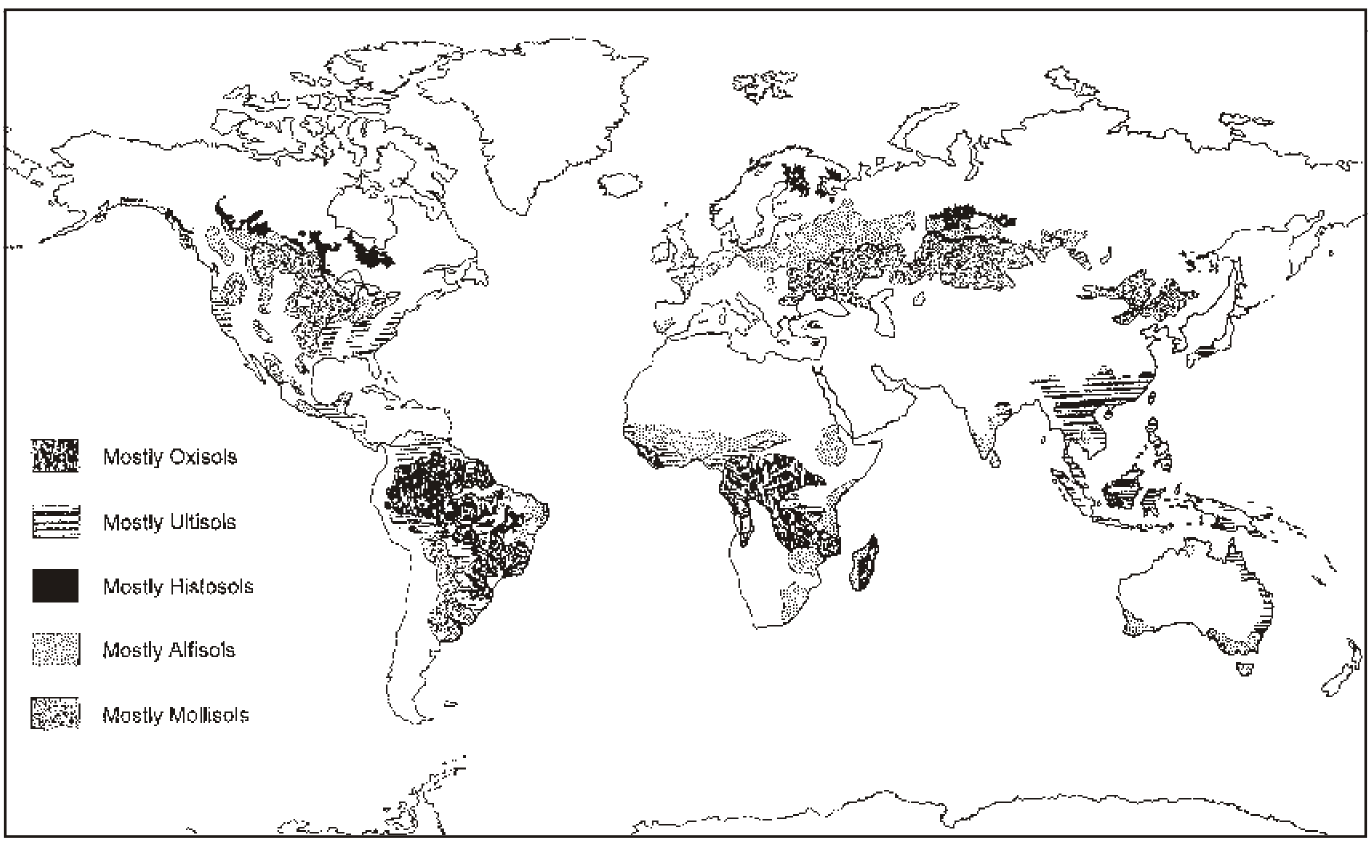

Figure 1. Dominant Soil Orders of the World (data from Brady, 1974, and U.S.D.A. files).

ied greatly in the past and may have been significantly different from the present. According to the DGP, many soils can be expected to have complex histories.

EGP Expectations

- Climate has exerted its influence on pedogenesis over vast periods of time, and climate change has tended to be gradual throughout earth history, allowing the soil to often reach or approach equilibrium with its environment (Brady, 1974, pp. 303,309; Selley, 1976, p. 55; Weaver, 1989, p. 106).
- Parent material, exerting the principal influence at the onset of pedogenesis, becomes relatively unimportant over vast periods of time and will, therefore, tend to be relatively unimportant for mature (near equilibrium) soils (Weaver, 1989, p. 106).
- Geomorphology and topography are constantly changing and exert, therefore, a constantly changing influence on pedogenesis (Brady, 1974, p. 309).[2]
- The biotic factor is strongly influenced by climate. Its influence, though sometimes slight, may result in a great cumulative effect over vast periods of time (Paton, Humphreys, and Mitchell, 1995, pp. 33–86).
- Ground water is a secondary variable largely determined by climate and topography (Jenny, 1941, p. 92).
- Epigenesis is largely determined by climate and topography (Weaver, 1989, pp. 107,143). With much time available, many soils can be assumed to be mature and specific clay minerals (physils) can be assumed to be products of epigenesis (Selley, 1976, p. 55).
- Much time favors translocation of physils and ions, resulting in formation of soil horizons, including argillic and cambic horizons (Blatt, Middleton, and Murray, 1972, p. 254).
- Highly leached soils, in both extent and magnitude, can be expected when vast amounts of time have been available for soil formation (Selley, 1976, p.55; Williams, 1969).
- While organic matter can rapidly reach equilibrium in soil, it can have a great effect on both leaching and the formation of horizons when great amounts of time are available (Selley, 1976, p.54).

DGP Expectations

- Climate has exerted its influence on pedogenesis over a relatively short period of postdiluvian time. Climate change has tended to be significant, possibly exponential, damped sinusoidal, or stochastic, and was likely warmer and wetter in early postdiluvian time than now (Oard, 1990).
- Parent material, exerting the principal influence at the onset of pedogenesis, is likely to be much more important than commonly perceived by EGP adherents, and may include stratification, oxidation, well developed weathering profiles, and initial physil content that can be falsely inferred as pedogenic.
- Geomorphology has probably changed little since the Deluge, and topography may also have remained constant in many places. Their effect, therefore, has been a relatively constant modifying influence on the climatic and other factors.
- The biotic factor is strongly influenced by climate. Organic matter could be expected on much of the ground surface or incorporated into sediments at the beginning of the postdiluvian period (Scheven, 1996). A warmer, wetter climate would have encouraged rapid growth of plants (Buol *et al*., 1990) and both microscopic (Brady, 1974, pp. 111–132) and macroscopic animals, expediting soil formation.
- Ground water could be expected to begin as a maximum, with saturated ground and a moist climate, approaching modern levels in response to climatic changes, topography and hydrogeologic (parent material) properties.
- Rates of epigenesis may have been greatly affected by significant climate change, atmospheric aerosols (Brady, 1974, p. 282; Oard, 1990), and carbon dioxide levels due to decaying organic matter (Paton, Humphreys, and Mitchell, 1995, p. 17).
- With relatively little time available, translocation of physils could be expected to be slight in some soils and a nonlinear (possibly exponentially decreasing) function with time.
- Highly leached soils, in both extent and magnitude, would only be expected to result from initially leached material (i.e. geological, not pedological, origin), accelerated weathering in an environment unlike the current environment, or more rapid actual rates of leaching than are commonly expected for the modern environment.
- Long periods of time for organic leaching and bioturbation would not be available. Thus, pedogenesis attributed to these processes by EGP adherents may be overstated, modern rates may be understated, or past rates may have been significantly higher during times of more favorable climate.

[2]Geomorphology (large-scale landforms) and topography (local scale) are constantly being eroded, slope angles becoming reduced, etc. These changes occur over time. Geomorphology, as practiced, is often focused on reconstructing natural history and relies heavily on stratigraphy (Daniels, Gamble, and Cady, 1971, p. 55). Stratigraphy, as practiced, is generally unscientific (Klevberg, 1999, 2000a, 2000b; Woodmorappe, 1999a).

Natural History Inferences and the Five Environmental Factors

As summarized in Table I, expectations of the behavior of the climatic environmental factor ($\partial^2S/\partial C\partial t$) differ markedly between the EGP and DGP. Based on a biblical view of earth history, climate would probably describe a roughly exponential curve from initial conditions at the end of the Deluge to current "equilibrium" conditions (recognizing normal climatic fluctuations). This can be expressed as $\partial C/\partial t \neq 0$ (i.e. climate change occurs) and $\partial^2C/\partial t^2 \neq 0$ (i.e. climate change is nonlinear). Initial climatic conditions (C_0) would be determined by long-term (equilibrium) factors in the antediluvian and diluvian periods, and initial geomorphology (G_0) and initial ocean temperature at the end of the Deluge. Equilibrium climate would be dependent on atmospheric conditions (greenhouse gases, volcanic aerosols, variations in insolation) and changes in terrestrial conditions (land surface coverage by vegetation, water or ice.) The rate of change of climate would therefore have been a function of initial conditions (including G_0) and equilibrium (long-term) conditions (including B). The DGP envisions relatively warm, moist conditions in early postdiluvian time (Oard, 1990), circumstances favorable to relatively high rates of epigenesis, physical weathering, and leaching.

As summarized in Table II, expectations of the importance of parent material to soil formation ($\partial^2S/\partial M\partial t$) and nature of the "initial" parent material (M_0) differ significantly between the EGP and DGP. According to the DGP, initial (t_0 = end of the Deluge) parent material (M_0) would plainly be a result of the Deluge. In addition to unweathered rock[3], one would expect weathered rock and unconsolidated sediments to have been common on the surface of the earth. It would, in fact, be expected that very little fresh bedrock would have been exposed by the final, waning currents of the Flood waters. Thus, M_0 may not be assumed to consist solely of homogeneous, unweathered rock. Graded sequences of unconsolidated sediments would be expected from waning flows of sediment laden currents. It may, therefore, be difficult in some cases to differentiate between horizons resulting from diluvial sedimentation processes and buried soil horizons or certain profiles which may have resulted from soil forming processes. Eluviation and illuviation would suggest soil forming processes (not unequivocally, cf. Birkeland, 1974, p.

[3]A small amount of this may have been antediluvian, in which case it would have been predominantly primordial based on the biblical historical record.

Table I. Comparison of Parameters: Climatic Environmental Factor.

Parameter	EGP	DGP
C	Very important to soil formation; largely dependent on G and various independent variables	Very important to soil formation; largely dependent on C_0, G and various independent variables
C_0	On average, similar to current	May have been significantly warmer at end of Deluge
$\partial C/\partial t$	Gradual oscillations over long periods of time	Rapid change (exponential) following Deluge ($\partial C/\partial t \neq 0$)
$\partial^2C/\partial t^2$	Value small or zero	Value may have been large following Deluge ($\partial^2C/\partial t^2 \neq 0$), decreasing with time
$\partial^2S/\partial C\partial t$	A generally linear (gradual) change (soil formation) over vast periods of time	A generally exponential decrease in change (rate of soil formation) since Deluge

Table II. Comparison of Parameters: Parent Material Environmental Factor.

Parameter	EGP	DGP
M	Very important to soil formation; a complex result of C, G and other variables	Very important to soil formation; primarily a result of M_0 modified by C, G, B, W and other variables
M_0	May be assumed as homogeneous and unweathered	May have been heterogeneous and contained weathered materials already at end of Deluge
$\partial M/\partial t$	Weathering occurs ($\partial M/\partial t \neq 0$) and is important process; it has proceeded over vast ages	Weathering occurs ($\partial M/\partial t \neq 0$) and is important process; it may occur or have occurred more rapidly than commonly believed
$\partial^2M/\partial t^2$	Value of $\partial^2M/\partial t^2$ small or zero	Value may have been large following Deluge ($\partial^2M/\partial t^2 \neq 0$), decreasing with time
$\partial^2S/\partial M\partial t$	A generally linear (gradual) change in soil state (i.e. soil formation) over vast periods of time	A generally exponential decrease in change (rate of soil formation) since Deluge (i.e. $\partial^2S/\partial M\partial t^2 < 0$)

111), though these rates could also be expected to have been higher in the past. Fresh volcanic ash would have been abundant immediately after the Deluge and for some time thereafter (Oard, 1990;Whitcomb and Morris, 1961) and may have been important in the formation of some soils (including entisols and especially andisols[4]). Both the EGP and DGP understand that the parent material factor is not static. If a traditional soil forming factor definition is used ($\partial S/\partial M$), both the EGP and DGP recognize that $\partial M/\partial t \neq 0$, i.e. weathering occurs. Some disagreement may exist on the value of $\partial M/\partial t$, especially if estimates are based on natural history assumptions ("dating" methods). With our preferred definition of parent material as an environmental factor, the DGP certainly recognizes that $\Delta M \neq 0$, i.e. transport into and out of the control volume occurs (including clays), and adherents of the EGP are increasingly recognizing this also (Chadwick *et al*., 1994, p. 94; Daniels, Gamble, and Cady, 1971, pp. 51–88; Lavkulich, 1969, p. 28; Nettleton, Price, and Bowman, 1990, p. 152; Paton, Humphreys, and Mitchell, 1995; Simonson, 1959; Weaver, 1989 p. 182; Valentine and Dalrymple, 1976). In the DGP, we would expect $\partial^2 M/\partial t^2 \neq 0$, i.e. sediment transport rates would not have been constant.

As shown in Table III, there exists a mixture of agreement and disagreement between the EGP and DGP on the likely role of the geomorphic factor in soil formation during earth history. Substantial agreement exists on the small scale of local topography; substantial disagreement exists on the large scale of geomorphology. Unlike the EGP, which envisions vast changes in landscapes over vast periods of time ($\Delta G >> G_0$), the DGP envisions only minor changes to the landscape during the comparitively brief span of postdiluvial time. The abative and dispersive phases of the Deluge (Walker, 1994) would have been primarily responsible for the present landscape. Geomorphic modification by wind, ice and water since the end of the Deluge would have been minor ($\Delta G << G_0$). Most soils can thus be expected to have formed in pretty much the same geomorphic environment as at present on the large scale, though significant changes may have occurred on the small scale. Topographic changes have been primarily a function of climate (C) and parent material (M), since the presence of plants, an important consideration in slope stabilization, would largely depend on climate and parent material. As a result, $\partial^2 G/\partial t^2 \neq 0$, i.e. rates of erosion, would have varied in the past, in agreement with the observation that the rate of lateral and vertical transport of earth materials is generally nonlinear. "Erosion rates are roughly proportional to slope; other conditions being equal, doubling the angle of slope increases the loss of sediment by about two and a half times. Doubling the length of slopes increases the loss about one and a half times" (Hunt, 1972, p. 51). Thus, other variables assumed constant, erosion rates can be expected to slow as slope angles decrease.

As summarized in Table IV, expectations of effects of the biotic factor over earth history differ between the EGP and DGP. In general, DGP expectations include much greater fluctuations in the magnitude of effects to soil formation in the past that envisioned by EGP adherents. At t_0, organic matter (O_0) can be expected to have been present in many locations as debris left by the Deluge (Genesis 8: 11, Holroyd, 1996; Oard, 1995a, 1995b; Sheven, 1996). The DGP envisions rapid colonization of the denuded earth by plants (Genesis 8:11). Successions would probably have occurred rapidly at first, especially with rapid climate change (i.e. $\partial B/\partial t \neq 0$), slowing in response to declining values of $\partial C/\partial t$ and $\partial M/\partial t$ (i.e. $\partial^2 B/\partial t^2 \neq 0$). Since fresh water is less dense than salt water, initial salt concentrations would not be expected to hinder plant growth in

[4]Rapid formation of entisols (soils lacking distinct horizons) and andisols (derived from volcanic material) is often accepted in the EGP; however, volcanic ash may have been important in the formation of other soils (Froede, 1995, 1996; Ping, 2000, pp. 1262–1263; Selley, 1976, p. 57; Weaver, 1989, p. 154; Williams *et al*., 1998).

Table III. Comparison of Parameters: Geomorphic Environmental Factor.

Parameter	EGP	DGP
G	Important to soil formation; primarily a function of C and M, secondarily B and W	Important to soil formation; primarily a function of C, M and G_0, secondarily B and W
G_0	May have been vastly different from present on both large and small scales	Geography at end of Deluge probably very similar to present
$\partial G/\partial t$	Great changes have occurred over vast periods of time ($\Delta G >> G_0$)	Large-scale geomorphology probably has changed very little in postdiluvian time ($\Delta G << G_0$ and $\partial G/\partial t$ is small), though significant local (small-scale) topographic changes may have occurred
$\partial^2 G/\partial t^2$	Value small or zero, especially as long-term average	Value decreasing following Deluge ($\partial^2 G/\partial t^2 < 0$), especially with revegetation
$\partial^2 S/\partial G \partial t$	A generally linear (gradual) change (soil formation) over vast periods of time	A generally static variable at large scale, episodic at small scale

most surficial diluvial deposits. In addition, abundant moisture would have facilitated leaching of the salts from the soils at a more rapid rate than at present. Meteoric water would have served to dilute salts. Treating residual organic matter as a component of M_0, it is evident that B is primarily a function of C (modified by G) and M, with W dominating only in particular environments.

Table V summarizes the different natural history expectations of the EGP and DGP relative to soil forming effects of ground water. Ground water can affect pedogenesis much more strongly than has typically been acknowledged in the past (Twidale, 1990). Weathering may be much more rapid than would be anticipated from climate alone (Birkeland, 1984, p. 307). "If appreciable water is available, not necessarily rainfall, and can move freely (relief, porosity, permeability) virtually any rock or aluminosilicate mineral will alter to kaolin-gibbsite-Fe oxides suite" (Weaver, 1989, p. 143). The EGP envisions gradual change as typical of most environments, so little change in ground water hydrology would be expected. The DGP envisions W_0 as a maximum at the end of the Deluge. The rate at which present ground water conditions would be reached would be dependent upon the hydrogeology of the site (M) and climate, along with the influence of plants. Locally, topography would exert a strong influence in driving W toward its equilibrium condition. Insofar as soil formation was a function of ground water, the rate of soil formation could be expected to follow this (generally) declining curve.

Natural History Inferences and the Four Soil-Forming Mechanisms

The changes that occur within the soil (i.e. the control volume) can be categorized as epigenesis, physical weathering, leaching, and the accumulation and effects of organic matter. As used here, $\partial^2S/\partial E/\partial t$ refers to the time derivative of change in soil state due to effects of epigenesis, i.e. mineral transformations due to chemical

Table IV. Comparison of Parameters: Biotic Environmental Factor.

Parameter	EGP	DGP
B	Important to soil formation, but a secondary variable, i.e. B is highly dependent on C and M, also dependent on G, locally W	Important to soil formation, but a secondary variable, i.e. B is highly dependent on C and M, also dependent on G, locally W
B_0	On average, similar to present	May have been significant amounts of organic matter incorporated into O_0 at end of Deluge
$\partial B/\partial t$	No significant global trend with time, but local changes over long periods could be great due to climate change, etc.	Rapid change (exponential) following Deluge ($\partial B/\partial t \neq 0$), especially revegetation; microbial activity probably optimized at end of Deluge
$\partial^2B/\partial t^2$	Value small or zero	Value may have been large following Deluge ($\partial^2B/\partial t^2>0$), decreasing with time ($\partial^2B/\partial t^2<0$)
$\partial^2S/\partial B\partial t$	A generally linear (gradual) change in soil state (i.e. soil formation) over vast periods of time	Soil formation likely to be a complex, stochastic response to biologic mechanism due to number of variables

Table V. Comparison of Parameters: Ground Water Environmental Factor.

Parameter	EGP	DGP
W	Locally important to soil formation, but a secondary variable, i.e. W is highly dependent on C, M, and G, less so on B	Locally important to soil formation, but a secondary variable, i.e. W is highly dependent on C, M, and G, less so on B
W_0	May have been less or more than at present due to changes in C and G over vast periods of time.	Expected to be a maximum in most cases immediately following Deluge
$\partial W/\partial t$	Gradual changes expected locally over long periods due to changes in C and G	In most cases, expected to fall relatively rapidly (rate dependent on M) following Deluge ($\partial W/\partial t<0$), driven toward equilibrium by C and G with lesser influence by B
$\partial^2W/\partial t^2$	Value small or zero	Value may have been large following Deluge ($\partial^2W/\partial t^2<0$), decreasing with time ($\partial^2W/\partial t^2\approx 0$)
$\partial^2S/\partial W\partial t$	Changes in water table likely to have been minor or gradual for most soils	Many soils may have experienced higher water table or soil moisture in past

weathering, including leaching and the effects of organic compounds. Table VI summarizes the differences between the EGP and DGP views of the epigenetic soil forming mechanism.

The EGP has the luxury of permitting either rapid or slow formation of minerals through alteration of parent material, but the uniformitarian bias generally prevents this in practice. “Clay-mineral formation and transformation in the soil is a slow process” (Birkeland, 1974, p. 247), a process often believed to require hundreds of thousands of years (Birkeland, 1984, p. 221). There is little incentive within the EGP to consider the possibility of relatively rapid epigenetic pathways, though some within the EGP are now beginning to recognize the possibility of specific physils or groups of physils in parent material rather than as solely the products of mineral transformation (Weaver, 1989, pp. 154–182).

Although much effort has been exerted in determining epigenetic pathways in response to climate, many physils identified in North American soils appear to be inherited from parent material unrelated to subjacent regolith (Hunt, 1972, p. 272). Weaver (1989, p.188) shows that EGP predictions do not match physil suites. “Again, the parent material helps determine the kind of clay that forms through availability and kind of bases” (Birkeland, 1974, p. 142). Nettleton, Price, and Bowman (1990,p. 152) found that “The clays[in Redlands and Witt aridisols] appear to be inherited from the parent material, or have accumulated from subsequent dust, because the primary sand and silt grains, except for biotite, are only slightly weathered.” Physil aggregates may be deposited in high energy environments where clay deposition would not normally be expected (Weaver, 1989, p. 116). Physils considered indicative of climate, e.g. montmorillonite, can form from a variety of parent materials (Weaver, 1989, p. 155) and can be found in various epimorphic combinations (Paton, Humphreys, and Mitchell, 1995, pp. 24–27).

Inferred rates of epigenesis are often decidedly biased by EGP presuppositions and “absolute dates” (Chadwick *et al.*, 1994; Colman and Dethier, 1986; Dahms *et al.*, 1997; Hall and Shroba, 1993; Leighton and MacClintock, 1962; Locke, 1986; Mahaney and Halvorson, 1986; Nahon, 1986; Taylor and Blum, 1995). EGP assumptions have long resulted in disparate, inconclusive, or incorrect estimates for epigenetic rates (Foss and Segovia, 1990; Grandstaff, 1986; Hall and Martin, 1986; Neall and Paintin, 1986), a fact even EGP adherents have recognized in some cases (Lowe, 1986; Paton, Humphreys, and Mitchell, 1995; White, Benson, and Lee, 1986) and that Jenny documented (1941, pp. 35–44) with rapid soil formation on Kamenetz Fortress in Ukraine (12 inches in 230 years), volcanic soils, sand dunes, and the work of Miss Shreckenthall on moraines in the Alps in the late 1800’s. Epigenesis is particularly rapid in tropical entisols, and carbonates may form rapidly enough to clog drain pipes (Hunt, 1972, pp. 45,46). Negligible varnish has formed at archaeological sites in the American Southwest since pueblos dated A.D. 1, yet it has been observed to have formed in railroad cuts and tunnels. The apparent necessary condition is the presence of water (Hunt, 1972, pp. 158–160). Thus, rates of epigenesis may be easily underestimated and requisite time for soil formation overestimated.

Evidence of significant epigenesis (physil development) in even the harsh environment of Antarctica has been observed on moraines believed to be only 17,000 to 21,000 years old according to the EGP (Ugolini, 1986). Much faster rates could obviously be anticipated for more temperate climates, especially where humid conditions exist. Lowe (1986, pp. 268–270) noted that the 10,000 to 15,000 years generally believed necessary for the transformation of volcanic glass and feldspar to halloysite via allophane was in significant conflict with the stratigraphy of New Zealand tephras. “This implies that tephra composition and site weathering conditions frequently may have been underestimated in favor of the *assumed* tephra age-based weathering sequence” (p. 270; emphasis ours). Halloysite (the end product of this sequence) has been observed to form in 300 to 4,000 years in the humid tropics (Lowe, 1986, p. 270). Depth of burial can significantly affect the rate of epigenesis (Lowe, 1986, p. 279). “The types and rates of formation and transformation of clay minerals derived from tephra deposits of acid to intermediate composition are determined chiefly by macro- and micro-environmental factors together with the mineralogical and physicochemical composition of the parent deposits. *The length of time of weathering in clay mineral genesis is indirect and subordinate in its effect, in that weathering rates, and weathering products and their alteration, are largely*

Table VI. Comparison of Parameters: Epigenetic Soil Forming Mechanism.

Parameter	EGP	DGP
Epigenetic Mechanism	$\partial^2 S/\partial E \partial t$	Generally assumed to occur gradually in response to climatic factor May have occurred rapidly in response to varying climate and other environmental factors
Initial Epigenetic State	E_0	Often assumed to be zero (i.e. stable physils derived from parent material by epigenesis) May be significant amount of inherited physils

dictated by other controls" (Lowe, 1986, p. 281; emphasis ours). Supposed intermediate species (e.g. allophane, imogolite) may persist, and supposed end products (e.g. halloysite, gibbsite) may form directly from tephra. These minerals can co-exist and often do (Lowe, 1986, p. 284)

Lowe's assertions are substantiated by the work of King (1986), who found little correlation between expected epigenetic products and a stratigraphic sequence of ash deposits in Canada. Surprisingly rapid epigenesis has been observed in ash from the 1980 eruption of Mount St. Helens (White, Benton, and Yee, 1986), with a rapidly declining rate of epigenesis attributed to a change from the initial domination of hydrochloric, nitric, and sulfuric acids to domination by the much weaker carbonic acid. Chloride and sulfate were leached within three months of ash deposition (White, Benton, and Yee, 1986, p. 372). While many EGP pedologists will agree that andisols can form rapidly, many of these epigenetic pathways are similar to those inferred for other soil orders.

"The rate of chemical weathering of geologic materials depends on the chemistry of weathering fluids and on the nature of reactions at mineral surfaces" (Colman and Dethier, 1986, p. 5). Growth of new mineral phases as epigenesis progresses in mineral crystal defects may enlarge these conduits, accelerating weathering, or occlude these passages, depending on the secondary mineral species (Eggleton, 1986). Weathering rinds with depth may result from variations in the rate of weathering, not the amount of time since deposition, since weathering in the shallow subsurface is generally greater than either surficial weathering or weathering at depth (Twidale, 1990, p. 36). Weathering rinds are probably more indicative of soil moisture than age (Twidale, 1990, p. 30). Oxisol formation appears to be greatly affected by lateral soil moisture movement, resulting in segregation of aluminum, magnesium, and iron, and possibly the formation of stone lines (Birkeland, 1974, pp. 193, 194). Organic matter and compounds can greatly accelerate chemical weathering in the solum (Birkeland, 1984, p. 75; Brady, 1974, p. 310; Paton, Humphreys, and Mitchell, 1995, p. 17; Ruhe, 1975, p. 27). The DGP envisions conditions generally more conducive to epigenesis during the early postdiluvian period than at present.

As used here, $\partial^2 S/\partial P \partial t$ refers to the time derivative of change in soil state due to effects of physical weathering, including both breakdown of individual rock and mineral grains, and translocation of soil particles (i.e. particle movement within the control volume). Table VII summarizes the differences between the EGP and DGP views of the physical weathering soil forming mechanism.

Mechanical breakdown of rocks can occur as a result of physical and thermal stresses. Although temperature fluctuations in themselves are probably a negligible factor (Birkeland, 1974, p. 59), ice lenses that form in soil attract water and grow, often inducing significant stresses (Hunt, 1972, p. 94). Salts, clays, and plants can also induce significant physical stresses (Birkeland, 1974, p. 59). As mineral grains are broken down, resultant fine particles can be transported into the subsoil as suspended or dissolved load as leaching occurs.

Evidence of physical weathering can be equivocal. Grus development to great depth has been observed in arid climates, indicating chemical weathering rather than physical weathering, contrary to common belief (Birkeland, 1974, pp. 73–75). This may also indicate a wetter climate in these regions in the past. Patterned ground may be formed by processes other than freeze-thaw (Ruhe, 1975, pp. 208, 209). Stone lines may be formed pedogenically (Paton, Humphreys, and Mitchell, 1995, p. 84–86) or by creep, but often rounded or exotic clasts are present that neither process explains, thus indicating an unconformity (Ruhe, 1975, pp. 127-129). Tephra accumulation over a'a (a very rough-textured lava common in Hawaii, where Chadwick *et al*. conducted their study) produces horizons free of rock fragments overlying the a'a (Chadwick *et al*., 1994, p. 98), a profile that could be misinterpreted as evidence of physical weathering. "Because cumulative soils have parent material continuously added to their surfaces, their features are partly sedimentologic and partly pedogenic. In a soil study, therefore, it is important that sedimentologic features are not ascribed to pedogenesis" (Birkeland, 1984, p. 185).

Table VII. Comparison of Parameters: Physical Weathering Soil Forming Mechanism.

Parameter		EGP	DGP
Physical Weathering Mechanism	$\partial^2 S/\partial P \partial t$	Rates of mechanical breakdown of particles and translocation in solum typically slow—similar to modern rates–and often assumed to be linear	Rates of mechanical breakdown of particles and translocation may be relatively rapid, may have varied in the past and may be more exponential than linear in response to build-up of resulting substances
Initial Physical Weathering	P_0	Often assumed to be virtually zero	May have been substantial at end of the Deluge

Formation of an argillic horizon by translocation of clay-size particles is one of the most important processes in soil profile development for many soils. It is not possible to distinguish between clay translocated via suspension (P) or solution (L), and establishing that translocation of clay-size particles has occurred in a soil profile can be very difficult (Birkeland, 1974, p. 111). Argillic horizons are sometimes observed where they would not be expected, e.g. in aridisols. "Prominent argillic horizons occur only in soils [Redlands and Witt aridisols] that formed primarily during the Pleistocene and hence are largely relict," yet many factors would tend to rapidly destroy these features, not preserve them (Gile and Grossman, 1968, pp. 14, 15). This suggests that they may be relatively young. "Expression of the argillic horizon is related to soil age but not as closely as the horizon of carbonate accumulation" (Gile and Grossman, 1968, p. 15)[5]. Weaver (1989, p. 115) states, "The time factor [re: clay translocation] has been difficult to quantify." Data are needed on clay translocation rates and the effects of aeolian clay and silt on B horizon development in texture-contrast soils (Boardman, 1985, p. 72). Sesquioxide concentrations sometimes exceed what may be expected from parent material, indicating transport, but sesquioxides, carbonates, electrolytes, and positively charged coloids also inhibit clay migration, and above approximately 20 to 40 percent clay content (depending on physil species), clay translocation may virtually cease (Birkeland, 1974, pp. 111–114; Blatt, Middleton, and Murray, 1972, p. 254). Thus, modern rates may differ substantially from rates in the past, often being much lower. Based on archaeological evidence, clay translocation in alfisols can readily occur in fewer than three thousand years, and lateral ground water movement may be important in translocation (Fisher, 1983).

As used here, $\partial^2 S/\partial L \partial t$ refers to the time derivative of change in soil state due to effects of leaching of ions from the solum by meteoric water. Table VIII summarizes the differences between the EGP and DGP views of the leaching soil forming mechanism.

Leaching is largely a function of climate, being dependent on the availability of excess moisture to provide free water for transport of ions from the solum (Locke, 1986). "The most active agency in soil-profile formation is percolating water" (Jenny, 1941, p. 47). White and Blum (1995) found that SiO_2 and Na weathering followed a linear function of precipitation and an Arrhenius temperature function (exponential). No climatic correlation was observed in leaching of K, Ca, or Mg. Grandstaff (1986) found an Arrhenius relation to temperature and proportionality to free ligand concentration for olivine weathering in Hawaiian beach sand. The importance of excess soil water has been established in modern environments. Chadwick *et al.* (1994, p. 102), in a Hawaiian study, noted, "Long term rates of desilication increase by nearly an order of magnitude as time-weighted median rainfall increases from 20 to 350 cm. Long term rates of base action leaching increase by about a factor of about 4 over the same rainfall gradient."

As pointed out by Chadwick *et al.* (1994 p. 94), "All regional and global estimates of chemical weathering are derived from dissolved load output from Earth's major river systems." Thus, common estimates for the rate of past soil formation are automatically uniformitarian, assuming current conditions as analogous to past conditions. Taylor and Blum (1995) derived silicate weathering rates by means of "known" ages, the result being 3.4 times faster than estimates based on stream flows. Yet present rates are considerably in excess of rates expected from the "known" ages of the moraines in their study, an observation that might be expected by diluvialists. Dahms *et al.* (1997) point out that Taylor and Blum erred to assume a closed system and that their reported precision in estimating weathering rates is impossible. Similar efforts based on "known ages" have been made by Hall and Martin (1986), Locke (1986), Mahaney and Halvorson (1986), and others. Since diluvialists would expect a higher temperature and precipitation regime immediately after the Deluge (Oard, 1990), significantly higher rates of leaching could be expected in many parts of the world, with the rates declining thereafter to modern values. Discrepancies between current rates of leaching and those anticipated based on EGP scenarios may be expected. "Texture influences the rate and depth of leaching, and this is related to many soil properties" (Birkeland, 1974, p. 142). Just translocation within the solum to form an argillic horizon ($\partial^2 S/\partial P \partial t$) could be expected to reduce soil permeability by a couple orders of

[5]Birkeland (1974, p. 170) notes that the modern $CaCO_3$ influx to aridisols similar to those studied by Gile and Grossman is too low to explain observed concentrations even with the ages ascribed to them by the EGP.

Table VIII. Comparison of Parameters: Leaching Soil Forming Mechanisms.

Parameter		EGP	DGP
Leaching Mechanism	$\partial^2 S/\partial L \partial t$	Rate largely determined by climate, often assumed similar to present	Rate largely determined by climate, which may have been somewhat warmer and much moister than present
Initial Leaching	L_0	Often assumed to be zero	May have been quite high at end of Deluge

Table IX. Comparison of Parameters: Organic Matter Soil Forming Mechanisms.

Parameter		EGP	DGP
Organic Matter Mechanism	$\partial^2 S/\partial O \partial t$	Rate largely determined by climate, often assumed similar to present or slightly more favorable for histosol formation during or after ice ages	Rate largely determined by climate, which may have been somewhat warmer and much moister than present, possibly cooler at end of postdiluvial ice age
Initial Organic Matter	O_0	Often assumed to be zero in parent material	May have been considerable at end of Deluge

magnitude, suggesting that leaching of the A horizon may have been less and of the B horizon more in the past for many ultisols and alfisols. For example, a poorly graded (well sorted) sand may have a permeability of 10^{-2} cm/sec, but if silt or clay particles occupy many of the pore spaces between sand grains, the permeability may be reduced to 10^{-4} cm/sec. Formation of laminae in petrocalcic horizons may have been slow *or rapid*—data are insufficient (Daniels, Gamble, and Cady, 1971, p. 75, emphasis ours). The natural history scenario of the DGP predicts that many soils would have experienced rapid initial leaching of already weathered parent material, with the rate of leaching declining in response to drier climates and, in some cases, decreasing permeability of the solum.

As used here, $\partial^2 S/\partial O \partial t$ refers to the time derivative of change in soil state due to effects of organic matter present in the soil. Table IX summarizes the differences between the EGP and DGP views of the organic matter soil forming mechanism.

"Organic matter probably reaches a steady state more rapidly than any other property of the soil," states Birkeland (1984, p. 203), "Nevertheless, these and other data suggest that the time to achieve steady state may range from as little as 200 years to perhaps 10,000 years." Organic matter as an argument for long times of formation hinges primarily on quantity, especially the amount of time required to form the extensive peat bogs in some parts of the world. Organic matter has been used in attempts to date deposits using radiocarbon (^{14}C) dating. Effects of organic matter on soil formation are also important, since organic matter can strongly influence the rate of formation of mineral soils.

The question of organic matter accumulation and time of formation may be illustrated by returning to our Leteensuo Peat Bog example (Klevberg and Bandy, 2003, p. 256). Assuming no initial organic matter ($O_0 = 0$) and an exponential decline in peat accretion from the initial maximum rate of Retallack (1990, p. 271) of 20 cm/year to 0.5 mm/year within the space of four millennia of postdiluvial time results in the following equation:

$$h = 200\, e^{-0.0015t} \qquad (1)$$

where *h* is net annual peat accumulation in millimeters and *t* is time in years since the Deluge.

Total peat accretion, *H,* can therefore be calculated for any time period to the present:

$$H = \int 200\, e^{-0.0015t}\, dt \qquad (2)$$

This scenario results in total peat accretion of 133 m in 4,000 years! This is greatly in excess of commonly observed histosol thicknesses, and at an average rate of accumulation *much less* than Retallack's "maximum conceivable rate." Using Equation (2), the time required to form the Leteensuo Peat Bog would have been approximately 2,300 years with an *initial* (maximum) rate of 15.5 mm/year, roughly 8% of Retallack's "maximum conceivable rate." Even assuming a constant rate of formation of 2.5 mm/year and no initial organic matter, the Leteensuo Peat Bog could have formed in 4,000 years. According to the DGP, O_0 was very likely nonzero. The rapidity with which histosols, can form, even in modern environments, is illustrated by a 175 mm thick histic epipedon constituting part of a mucky soil 735 mm thick (a nascent histosol) formed northwest of Augusta, Montana, in eighty years (Figures 2 and 3) since the commencement of irrigation. This is a good, though not ideal, site for histosol formation.

It may be argued that histosol formation is dependent on a narrow range of conditions which change over time, principally the position of the water table relative to the ground surface, and that average rates of net annual peat accumulation of much less than 1 mm/year are possible (Hunt, 1972, p. 161). However, this assertion devolves to a simple statement of the need for a site-specific hydrogeologic study, which in some cases may indicate that the water table probably rose concurrently with addition of organic matter (we here include the organic material as a "geologic material" for the study of ground water hydrology—obvious hydrogeologist bias!). That many peat deposits include allochthonous organic matter (i.e. $O_0 > 0$) is indicated by the presence of calcite and dolomite nodules in some deposits incompatible with modern swamp environments (Retallack, 1990, p. 411).

Radiocarbon dating has been attempted in many studies of organic-rich soils, but it is difficult at best due to the mobility of carbon (Weaver, 1989, p. 106) and mixing with "old" carbon in the many soils containing carbonates (Ruhe, 1975, p. 226). Attempts to constrain weathering

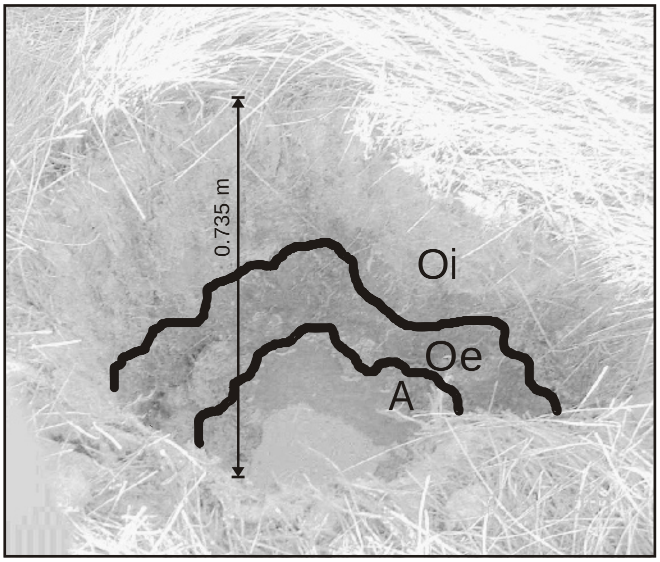

Figure 2. Test Pit in Wetland Near Augusta, Montana (nascent histosol).

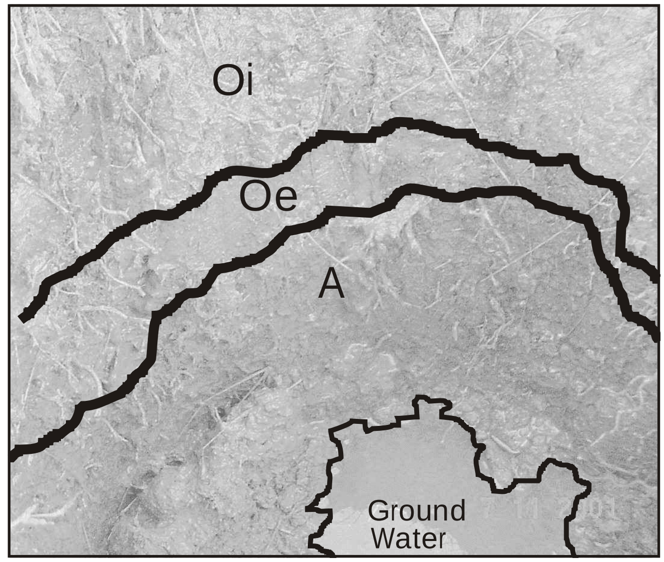

Figure 3. Recently Formed Histic Epipedon near Augusta, Montana.

rate estimates using radiocarbon dating can produce scattered data with no evident trend (Neall and Paintin, 1986). Fallacies inherent in the "dating" method itself have been documented elsewhere (Whitelaw, 1993; Woodmorappe, 1979; 1999b).

Some have argued that soils would have been sterile in early postdiluvian time (Harding, 2001), but this is most certainly not the case. Although some plants can tolerate soil lacking organic matter, humus development greatly increases the suitability of a soil to support plant life (Brady, 1974). Although much of the enormous antediluvian biomass no doubt ended up as coal, oil, natural gas, and carbononiferous and kerygenous matter (Woodmorappe, 1993), certainly some of this organic matter would have been incorporated into surficial sediments, often on top of them (Holroyd, 1996). At least in some locales, such organic material can be expected to have been abundant at the end of the Deluge. This would readily decay in the warm, humid conditions expected to prevail at that time, resulting in rapid formation of humus. Humus and other products of the decay of organic matter result in greatly accelerated epigenesis (Birkeland, 1984; Brady, 1974; Paton, Humphreys, and Mitchell, 1995).

Traditional Views in Light of Modern Data

Data obtained over a century of pedologic research have not substantiated the popular conceptions of the EGP. Instead, the complexity of pedogenesis has become more apparent, and attempts to infer times of formation for various soils based on "maturity" have been abandoned. More refined dating attempts have suffered from circular reasoning and the complex interdependence of assumptions undergirding so-called "independent" methods within the EGP (Klevberg, 2000b, p. 95; Thompson and Berglund, 1976). Since most questions in pedogenesis are historical, not scientific, conclusions must be based on historical records or natural history assumptions. In most cases, the assumed history of the DGP would enhance rates of soil-forming mechanisms, while many estimates based on EGP assumptions actually produce rates lower than those observed operating today. These differences are displayed in Table X.

Based solely on the assumed earth history of each geologic paradigm, very different expectations for rates of soil formation are generated. These are summarized below:

Climate: Climate change is now widely acknowledged (Birkeland, 1984; Hunt, 1972; Lavkulich, 1969.) Evidence for wetter climates in the past is common (Hunt, 1972, p. 158; Oard, 1990, p. 78).

Parent Material: Parent material has been recognized as responsible for some features formerly expected to be dominated by climate (Birkeland, 1984, pp. 177–189; Paton, Humphreys, and Mitchell, 1995), though what constitutes "parent material" remains a matter of debate. Diluvialists will recognize the likelihood of weathered, sometimes stratified, and often physil-rich parent material.

Geomorphology: Geomorphology and topography constitute a modifying factor. EGP advocates place a greater emphasis on geomorphic changes than do diluvialists.

Organisms: The ability of organisms to facilitate epigenesis has come to be recognized (Ruhe, 1975, p. 27), as has the significance of bioturbation (Paton, Humphreys, and Mitchell, 1995, pp. 33–78).

Ground Water: Ground water, in both the saturated and vadose zones, is now being recognized as far more important than many had previously believed (Twidale, 1990).

Table X. Comparison of Expected Rates of Soil Formation (DGP/EGP[1]).

Soil-Forming Mechanism[3]	Environmental Factors[2] C	M	G	B	W
E	+	+	NA	+	+
P	+	+	0	–	+
L	+	NA	0	+	+*
O	+	+*	NA	+/–	NA

[1]Qualitative comparison of DGP to EGP: + = soil formation due to indicated relationship more rapid in DGP scenario than EGP scenario; – = soil formation expected to be more extensive in EGP than DGP; 0 = degree of expected soil formation similar in DGP and EGP; NA = relationship between indicated factors not apparent or deemed minor.
[2]Environmental factors: C - climatic factor, M - parent material factor, G - geomorphic factor, B - biotic factor, W - ground water factor.
[3]Soil-forming mechanisms: E: epigenesis (mineral transformation), P: physical weathering, L: leaching, O: soil organic matter.
*Evaluation based on inferred initial conditions.

In general, the DGP envisions effects of environmental factors on pedogenesis resulting in significantly higher rates than the EGP, particularly in the past. These expectations are compatible with climatic and mineralogic data.

Epigenesis: Epigenetic pathways may be multiple and complex and represent thermodynamic systems (Lavkulich, 1969). EGP estimates based on "known" ages (including radiometric dates) are often lower than modern measured rates. Modern rates are often much less than rates expected by DGP adherents for past soil formation.

Physical Weathering: Some weathering processes thought to be physical may be chemical and more rapid than had been supposed. Observed relationships between clay particles and other soil substances indicates that translocation is a generally nonlinear and diminishing function with time. Translocation is known from archaeological evidence to occur within a few centuries or millennia.

Leaching: Many factors affect leaching rates. Measured rates of chemical weathering have exceeded rates expected based on EGP assumptions. Diluvialists not only expect past rates of leaching to have generally been higher than current values, but also expect initial parent material to have been weathered in many cases, making distinction between initial weathering profiles and subsequent leaching difficult in many soils.

Organic Matter: Rates of organic matter accumulation in modern environments can explain deep accumulations of peat within only a few thousand years, much less time than the EGP envisions since the last ice age. DGP adherents would expect some initial organic matter in many histosols, further reducing the time required for histosol formation. Radiocarbon "dating" is fraught with problems.

In general, the DGP envisions rates of soil-forming mechanisms declining from an initial maximum for many soils. These expectations are more compatible with observed rates than some EGP predictions, which are actually less than measured rates. Nonzero initial values, anticipated by the DGP, would further reduce the requisite time to reach the current state of soil development. *Some profiles probably could not have been preserved for the length of time envisioned by the EGP.*

Pedogenesis and the Question of Time

Much of the information presented above has been produced since we graduated from college. We shall now reevaluate arguments for long ages of soil formation that we formerly found quite convincing.

Oxisols

Oxisols are prominent for their lack of horizons and relative enrichment in aluminum and iron hydroxides. This can readily result from prolonged, intense leaching in a tropical climate, as is commonly asserted by EGP pedologists. Oxisols, particularly acrorthox, appear to provide strong evidence for an ancient earth. Many kaolinite and bauxite deposits are believed to be relict oxisols.

However, Boardman (1985, p. 71) points out problems in correlating soil redness with ambient temperatures. Estimates of acrorthox formation from both granitic and ultramafic rocks are less than 50 mm per thousand years (Nahon, 1986, p. 171). However, not only is this linear assumption suspect, but many of these soils are acknowledged to be relict (Nahon, 1986, pp. 184–186). Rates of formation are largely based on radiometric dating of associated volcanics (Nahon, 1986), an inference rife with faulty assumptions and readily discredited (Austin, 1992; 1994; 1996; Austin and Snelling, 1998; Woodmorappe, 1979; 1999a; 1999b). This is yet another example of the fact that *the past is the key to the present,* not vice versa.

Retallack (1990, p. 343) recognizes, "Alumina enrichment can be caused both by hydrothermal alteration and by weathering, so that care must be taken in interpreting aluminous rocks [bauxite] in highly deformed and very ancient terranes." Yet he (Retallack, 1990, p. 344) goes on to assert that kaolinite ". . . has persisted in these profiles despite subsequent diagenetic alteration, " an assertion clearly involving historic, nonscientific presuppositions. Selley (1976, p. 62) notes three sources of origin: 1) hydrothermal alteration of feldspars, 2) intense weathering of diverse rocks, and 3) transport and deposition.

Only 2) is a pedogenic process, and even it can be diagenetic rather than pedogenic, which may be indicated by the variability of residual kaolins (Selley, 1976, p. 62). That traditional explanations for oxisols fall short has been recognized for some time. “There are many unsolved problems concerning this soil type” (Blatt, Middelton, and Murray, 1972, p. 257).

Evidence *against* a pedologic origin of some alleged oxisols is very clear. Ganisters and tonsteins in Europe are probably intensely weathered volcanic ash beds rather than leached soil horizons (Selley, 1976, p. 76). Extensive bauxite deposits in Romania contain bones of dinosaurs and other fauna that are virtually impossible to explain pedogenically, and many deposits in North America run afoul of paleoclimatologic inferences (Oard, 1999). Some oxisols may be almost entirely geologic in origin, and others may be polygenetic. It is impossible to establish that any particular oxisol developed solely as the result of *in situ* weathering, but it is possible to demonstrate that at least some of these deposits did not. That many seem oblivious to geologic explanations for these deposits may stem from the pervasive tendency toward analytic specialization; pedologists will see pedologic explanations, sometimes where they do not exist.

Ultisols

Ultisols are typified by a deeply leached weathering profile and translocation of clays. Both the EGP and DGP recognize that ultisol formation is a nonlinear function with time (Birkeland, 1984, p. 225), but the natural history scenario envisioned by the DGP would result in a much less linear function. Diluvialists would expect rates of both leaching and translocation to have declined over time in response to soil profile development, as well as possible climate change. Present rates of these soil-forming mechanisms may, therefore, represent *minima* and not average values. To some degree, the response of leaching and translocation rates to soil profile development in ultisols can be evaluated by comparing them with alfisols, where formation within centuries or a few millennia has been observed. This not only suggests that formation of ultisols within a few thousand years is reasonable, but that the nonlinearity of leaching and translocation may call into question the possibility of traditional ages for many ultisols based on their current profile development. The importance of parent material in ultisol development may also have been underappreciated. “Although the native fertility disadvantage of the Ultisols may be attributed in part to the higher rainfall and temperatures [assumed in their global warming scenario], this is not a totally valid relationship; parent material is undoubtedly a very significant soil forming factor contributing to differences in native fertility between Mollisols and Ultisols” (Buol *et al*., 1990, p. 79). In the case considered by Buol *et al*., soil fertility and soil profile development are closely related.

Histosols

Histosols no longer appear a convincing argument for long periods of formation. The rapid formation of histic epipedons in recent times appears to indicate that *observed histosols permit too little time for the EGP*, suggesting that continental glaciation (generally believed to have occurred where the majority of histosols are found today) may have occurred more recently than can be accommodated within the EGP.

Alfisols

Alfisols, which exhibit less intensive leaching than ultisols, may be presumed to develop more rapidly than ultisols; however, differences in the climatic and parent material factors experienced by these soils may be more important than time in explaining these differences. Consider the Thoeny and Creed soils of northern Montana (U.S.D.A., 1986). The Thoeny series formed in “glacial till,” a diamict with a fine-grained matrix, in the time since the withdrawal of ice sheets from the area. The Creed series has formed in the same region and has thus experienced the same climatic influences, but it has formed in alluvium south of the ice limit. A typical pedon for both soils consists of A and E horizons to 6 inches (150 mm) with the base of the Bt horizon at 17 inches (430 mm) in the Thoeny and 16 inches (410 mm) in the Creed. According to the EGP, the Creed would be a much older soil and should be more highly developed, with a much deeper Bk horizon. It is apparent that the climatic influences have dramatically effected soil formation without being dramatically affected by time. It may be, too, that considerably less time has been available for pedogenesis than the EGP purports, with pedogenesis occurring relatively rapidly. Caution must be exercised in inferring times of development for alfisols. The ages assigned to the surfaces on which alfisols and ultisols are commonly found may relate to inferences based on the EGP. Investigation of the methods employed to “date” these surfaces is a worthy topic for further research but is beyond the scope of this paper.

Mollisols

Mollisols, though expected by diluvialists to form more rapidly than the EGP predicts, are not a matter of great controversy between the two paradigms. However, mollisols provide good examples of “average” soils that call into question the idea of slow pedogenesis. Consider the

Telstad (U.S.D.A., 1986) and Evanston soils of northern Montana (U.S.D.A., 1988, and unpublished data). Both are classified as fine-loamy, mixed, superactive, frigid, aridic argiustolls. The Telstad soil is formed in "glacial till," a diamict with a clay loam matrix, north of the Missouri River. The Evanston soil is formed in alluvium south of the Missouri River. (The Evanston series also occurs in alluvium which appears to be reworked till in various places north of the Missouri River; in these places, the Evanston is apparently *younger* than the Telstad, while south of the river it should be *older.) Both soils exhibit a mollic epipedon 4 to 6 inches (100 to 150 mm) deep over an argillic horizon. The uniformity and degree of profile development of mollisols on both terrain north of the Missouri River believed to have been glaciated and terrain south of the river believed to have escaped glaciation is similar. This could result from a great span of time since glaciation or from rapid soil profile development, but based on the Telstad and Evanston soils (as well as the Thoeny and Creed soils mentioned above), we favor the latter.*

Evaluating rates of pedogenesis

Complexities and limitations in evaluating rates of pedogenesis are many. "As more pedological research is carried out and more soils are observed and studied, the pedologist is recognizing that many of the soils occurring on the present landscape are polygenetic soils which have formed in part under environments different from those of the present" (Lavkulich, 1969, p. 26). Age estimates of soils based on assumptions of linear weathering or leaching rates are grossly simplistic (Ruhe, 1975, p. 202). Vreeken (1984) reviews methods of dating soils by dating surfaces, average pedogenic index, variable pedogenic index, paleopedogenic index, and soil-landscape analysis. He exposes the assumptions and circular reasoning that render these methods untenable. "Evidence has been presented that pedogenic processes have either been discontinuous through time, or there has been considerable variation in intensity of process. This work shows that soils scientists should be cautious about conjectures regarding soil genesis based largely upon soil-profile characteristics" (Daniels, Gamble, and Cady, 1971, p. 76). Because soil formation is so complex and site specific, obtaining a quantitative mathematical description of pedogenesis is virtually impossible. "In order to compare soil data on even a semiquantitative basis, a time scale must be adopted" (Birkeland, 1974, p. 153). Thus, *the view of natural history one adopts determines his bias in evaluating soil data.* We believe that even the cursory presentation of findings presented in this paper is sufficient to demonstrate that, in general, the diluvial approach to pedogenesis is more compatible with the data than the traditional, EGP view.

The Apparent Problem of Paleosols

While many soils may have formed much more rapidly than commonly thought, what of paleosols? Even soils formed in centuries or millennia must indicate the passage of great periods of time if sufficient numbers are superposed. While this is significant to neither creationism nor catastrophism *per se*, it does call into question the biblical historical record and the DGP. It has caused heartburn for some creationists (Robinson, 1996). Leighton and MacClintock (1962) state, "Recognizing the proper distinctions between a profile of weathering and a soil profile is of the greatest importance to both geologists and pedologists." Yet it is seldom possible to distinguish between a weathering profile and a soil profile (Ruhe, 1975, p. 36), and even argillic horizons and clay films have been observed to form sedimentologically (Valentine and Dalrymple, 1976, pp. 210, 211). Identification of ancient B_k horizons (caliche) is difficult at best. "Correct recognition of ancient caliche is an art and, as with most art, the experts often disagree among themselves concerning the criteria to be used in an evaluation" (Blatt, Middleton, and Murray, 1972, p. 259). "It is the similarity of the processes and products of pedogenesis to those of diagenesis that is one of the major causes of confusion in the recognition of buried paleosols" (Valentine and Dalrymple, 1976, pp. 210). Various laboratory techniques, including mineral and ion ratios, although often useful, are rife with pitfalls and often equivocal in their results (Brady, 1974, p. 312; Valentine and Dalrymple, 1976, pp. 211–213). Alternative explanations abound for features some think diagnostic of paleosols, and the alternative explanations are often more likely (White, 1998). Paleosols would not be likely according to the DGP view of earth history. Nonetheless, based on the relative rapidity of soil formation predicted by the DGP and observed in many modern environments, actual paleosols are not inimical to the DGP, a fact observed by some diluvialists (Froede, 1998, p. 27). Ultimately, since paleosols are historic by definition, they are not essentially scientific, though science is useful in testing EGP predictions to potentially disprove the interpretation of a given weathering profile as a paleosol.

Conclusions

Soil formation is ultimately an historic question with scientific implications. One's view of earth history establishes his bias in evaluating the pedologic data. Arguments for long times of formation hinge on faulty or questionable assumptions that include the following:

- Parent material is often assumed to be unweathered, unstratified, and barren of "mature" physils or organic matter.
- Rates of soil-forming mechanisms are often assumed to be nearly linear and approximately the same as modern rates, even though evidence of significant past climate change is mounting and soil profile development would affect the rates of soil-forming mechanisms.
- Radiometric "dating," "dating" of geomorphic surfaces, and other methods that *assume* the EGP are used to estimate soil formation rates.
- Physical weathering over long periods is sometimes invoked where chemical weathering may actually have caused a particular feature relatively rapidly.
- Pedologic explanations are sometimes sought where geologic explanations are more likely or even virtually certain (e.g. bauxite bone beds).

Current knowledge of pedogenesis permits the following assertions about "problem" soils:

- Oxisols may form more rapidly than commonly believed. They probably reflect parent material much more strongly and climate much less than traditionally thought. Evidence for formation of oxisols entirely pedologically is inherently equivocal, while evidence for a geologic, rather than pedologic, origin of at least some deposits classified as oxisols is well demonstrated. Many oxisols may be polygenetic.
- Ultisols and alfisols may have formed much more quickly than commonly believed if climates were generally warmer and wetter in the past and if one recognizes the probable nonlinearity of soil-forming mechanism rates.
- Histosol and mollisol formation is readily accommodated within the DGP, even using the rates of organic matter accumulation assumed by EGP adherents. The formation of these profiles may, in fact, be too quick for the EGP for some soils.
- Many "paleosols" are more readily explained as results of sedimentation or diagenetic processes. Being historic inferences, paleosols are interpretations of scientific data and not scientific "facts." Each must be evaluated by comparing predictions of the EGP paleosol scenario with scientific observations.

The natural history scenario of the DGP (based on the biblical record) generally predicts more rapid soil formation than does the EGP, and accumulated data are more readily explained by the DGP than by the EGP. Even oxisols and ultisols can form within the 4,000 to 5,000 years (Genesis 11, Exodus 12:40, Judges 11:26, I & II Chronicles, Matthew 1:1–17) since the Deluge. Careful distinction between scientific data and pedogenic inferences indicates that the biblical record of earth history is not contradicted by the pedologic data and in many cases is superior to the traditional view in interpreting observed soil characteristics and rates of pedogenesis.

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Glossary

allochthonous: said of sediments or materials whose place of origin appears to be different from present location, implying transport.

antediluvian: pertaining to the period of earth history between creation and the Deluge.

Deluge: the unique global Flood cataclysm (*mabbul* in Hebrew) that occurred during Noah's lifetime as described in the Bible.

diamict: a heterogenous, unconsolidated, unsorted sediment, typically consisting of coarse material such as gravel in a fine-grained matrix.

postdiluvian: pertaining to the period of earth history from the end of the Deluge to the present.

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CRSQ: Creation Research Society Quarterly

CENTJ: Creation Ex Nihilo Technical Journal

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Book Review

The Extravagant Universe by Robert P. Kirshner
Princeton University Press, Princeton, NJ. 2002, 282 pages, $29.95

Robert Kirshner received his Ph.D. in astronomy from the California Institute of Technology, Pasadena in 1974. He is Clowes Professor of Science at Harvard University and Head of the Optical and Infrared Division at the Harvard-Smithsonian Center for Astrophysics. He also is the leader of the "high-z supernova search team" (p.190), one of two international teams searching for high redshift supernova Ia to show acceleration and deceleration of the expansion of the universe. This book chronicles this quest from the discovery of galactic supernova in 1572 by Tycho Brahe thru the discovery of the high redshift supernova SN1997ff. This supernova leads theorists to an accelerating universe which points to the need for the Einstein cosmological constant, dark energy, and dark matter.

The book subtitle is "Exploding Stars, Dark Energy and the Accelerating Cosmos." Kirshner explains the latest knowledge of how the universe is viewed by most astronomers and how it supposedly evolved. He does it in language understandable to laymen and humor keeps the topics interesting. The book is well organized with eleven chapters, notes, references, and an index. The chapters include introductory material, proposed theories, data gathering procedures, application of the data, and future projects where supernova measurement methods may lead.

In general the book presents a strong case for the standard Big Bang theory including inflation and stellar evolution. However, it also documents a weakness in this theory, namely the lack of enough time since the Big Bang for supernova type Ia to evolve. Kirshner states "Type Ia supernova are responsible for making the iron in the earth's core, in the Eiffel Tower, and in your own blood" (p. 30). He also gives recent measurements of the Hubble constant which date the universe at less than 14 billion years old and the oldest stars in globular clusters at approximately 12 billion years old (p.111). He estimates the age of the sun and earth at 5 billion years (p. 23) as is required for life to have evolved. This leaves only 7 billion years for a sun-size star to form, burn its fuel, evolve into a red giant, blow off its atmosphere, and collapse its core into a white dwarf. The estimate he gives for the lifetime of our sun as a main sequence star is 10 billion years, then a lifetime of at least 1 billion years as a red giant (p. 26). If it is in a binary system it either has to collect 40 percent more mass from its partner or mutually lose enough orbital momentum to collide with its partner to become a supernova Ia. No time estimate is given for these processes but none can be considered fast. The same lack of time is demonstrated by the observation of a supernova 11 billion light years from earth (SN1997ff). How could this supernova have evolved in less than 3 billion years after the Big Bang?

It is evident from observational data presented in this book that God created a large variety of stellar phenomena at the beginning of time including supernova. Most scientists simply have the wrong idea about how and when. The observational data shows a universe that is fairly homogeneous in that galaxies 11 billion light years away do not look significantly different than nearby galaxies. It is mankind's misinterpretation of the data and their flawed theories which lead them away from God's truth about the creation of this universe and life.

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