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Place formation and axioms for reading the natural landscape

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Abstract
Nine axioms for interpreting landscapes from a geoscience perspective are presented, and illustrated via a case study. The axioms are the self-evident portions of several key theoretical frameworks: multiple causality; the law–place–history triad; individualism; evolution space; selection principles; and place as historically contingent process. Reading of natural landscapes is approached from a perspective of place formation. Six of the axioms relate to processes or phenomena: (1) spatial structuring and differentiation processes occur due to fluxes of mass, energy, and information; (2) some structures and patterns associated with those fluxes are preferentially preserved and enhanced; (3) coalescence occurs as structuring and selection solidify portions of space into zones (places) that are internally defined or linked by mass or energy fluxes or other functional relationships, and/or characterized by distinctive internal similarity of traits; (4) landscapes have unique, individualistic aspects, but development is bounded by an evolution space defined by applicable laws and available energy, matter, and space resources; (5) mutual adjustments occur between process and form (pattern, structure), and among environmental archetypes, historical imprinting, and environmental transformations; and (6) place formation is canalized (constrained) between clock-resetting events. The other three axioms recognize that Earth surface systems are always changing or subject to change; that some place formation processes are reversible; and that all the relevant phenomena may manifest across a range of spatial and temporal scales. The axioms are applied to a study of soil landscape evolution in central Kentucky, USA.

Keywords
Landscape interpretation, place formation, Earth surface systems, spatial structuring, soil geomorphology

I Introduction

About 40 years ago, cultural geographer Pierce Lewis (1979) published a widely cited paper on axioms for reading the landscape, focusing on cultural landscapes and the historical geography of the US. This paper is in the same spirit, but is focused on the natural rather than the cultural landscape. "Natural" is used here to simply and broadly refer to aspects of the environment not *primarily* made or caused by humankind (though pervasive impacts of human agency are acknowledged).

Through most of the later 20th century, geoscientists were in the midst of largely distancing themselves from the historical, regional, and interpretive traditions of geology, geography, ecology, and soil science. More recently, however, geoscientists have recognized landscape

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interpretation as a critical skill and as a necessity (along with, rather than instead of, other approaches) for understanding Earth surface systems (ESS). Cotterill and Foissner (2010: 291), for instance, decry how a "pervasive denigration of natural history" undermines biodiversity studies. In pedology, despite major advances in pedometrics, digital soil mapping, and pedological process studies, field-based interpretations of soil–landscape relationships remain the backbone of soil surveying, mapping, and geomorphology (Bui, 2004; Schaetzl and Thompson, 2015). In geomorphology, landscape interpretive aspects are embedded in arguments directing increased (or renewed) attention to historical and geographical contingency along with universal principles (e.g. Marden et al., 2018; Phillips, 2015; Preston et al., 2011; Wilcock et al., 2013). While the role of interpretation and place formation may be most evident for local- and regional-scale studies, they are also relevant for global-scale Earth system science (Bockheim and Gennadiyev, 2010; Richards and Clifford, 2008).

The geosciences increasingly rely on remotely acquired data and make use of many automated procedures. This has long been the case for climatology and landscape ecology, and is becoming increasingly so in pedology and soil geography, largely in the form of digital soil mapping. In geomorphology, geomorphometric approaches based largely on digital elevation models have been facilitated and even revolutionized by advances in technology related to both data availability and analysis. However, at least at the landscape scale, these methods complement rather than replace landscape interpretation, as argued by the authors cited previously. Further, the underlying conceptual frameworks of the axioms are as applicable to, for example, satellite or radar-based observations as they are to muddy-boots fieldwork.

Theories tell us what to look for. That idea has typically been framed in terms of limiting what scientists notice and the range of potential meanings attached (e.g. Johnson, 2002; Pimm, 1991; Simmons, 1993; Trudgill, 2012). However, theoretical frameworks encompassing new ideas and information may allow us to see new and different aspects of landscapes, as Johnson (2002) showed for bioturbation in pedology and geomorphology, and Trudgill (2012) recounted with respect to observations of glaciation. The axioms presented in the following do not represent a new theory or model. Rather, they are an attempt to distill the axiomatic aspects of several theoretical and conceptual frameworks of the past few decades to a set of guidelines to facilitate reading the landscape by telling us what to look for. They will also, ideally, be useful in facilitating broader, more deductive inferences from inductive case studies.

While no axioms for interpreting natural landscapes have previously been proposed, this is not the first attempt to set out axioms for physical geography and its subdisciplines. Bryson (1997) outlined an axiomatic approach to climatology, and Sokolov and Konyushkov (2002) for pedogenesis and soil geography. Kikuzawa and Lechowicz (2016) proposed a theory of plant productivity based on ecological axioms. The main elements of the soil–landscape paradigm of soil survey are essentially axioms, though Hudson (1992) does not use the term. Brunsden (1990) proposed "ten commandments" of geomorphology, some of which might be considered axiomatic. However, some of the propositions are not necessarily self-evident or generally accepted, and Brunsden (1990) did not make any such claims. The same generalization applies to King's (1953) "canons of landscape evolution." *To Interpret the Earth: Ten Ways to Be Wrong* (Schumm, 1991) outlined principles of interpretation in the context of key potential problems related to basic principles of Earth science.

Landscape interpretation is approached from the perspective of place formation. There exists an extensive literature in human geography and the humanities on the construction of places. Though biophysical frameworks and environmental constraints are sometimes acknowledged, this work is overwhelmingly focused on political, social, cultural, and economic aspects of place-making, and on human perceptual and philosophical aspects of places and their meanings (see reviews by Agnew, 2011; Cresswell, 2014; Sack, 1997). In addition to de-emphasizing the non-human environment, this work also rarely addresses how the contemporaneous construction of multiple places affects or results in spatial structuring. On the other hand, the natural sciences have largely ignored the concept of place formation as such. Extensive work exists on case studies of particular landscapes, environments, or features. There is also a strong tradition of mapping, classifying, and delineating regions and environmental types (e.g. Bailey, 1998; Omernik, 1987). However, there is little or no work that explicitly addresses the processes or phenomena of place-making in geomorphic, hydrologic, soil, climate, or ecosystems.

The purpose of this paper is to identify the axiomatic (unquestioned) components of some key conceptual frameworks relevant to place formation in ESS useful for reading landscapes. These axioms are illustrated by a case study of the development of soil landscapes in the Inner Bluegrass region of Kentucky, USA. This framework also seeks to link place formation to spatial structuring, as both a consequence and cause of the latter. Place formation thus refers to the phenomena by which locations acquire their environmental characteristics and their specific, often unique, traits. Spatial structuring refers to the development of geographical patterns and flux networks and the differentiation of geographical space. Homogenization also occurs, but is not emphasized here.

Space is defined here in terms of geometric space occupied by multiple overlaid, overlapping spatial distributions. These distributions may be continuous, patchy, or points, and may or may not occupy the entire geometric space. Spatial distributions are dynamic, with any representation characterizing a snapshot in time. *Places* are regions or subsets of space. As such, they may be defined at a variety of spatial scales – in the case of soils, for instance, from pedons to soil regions; or in climatology, from microclimates to global climate regions. Places circumscribe the set of spatially distributed phenomena that occur within their boundaries. Place boundaries may overlap, and may be dynamic, and possibly fuzzy or transitional in nature.

Human agency is at least indirectly significant in all ESS, and is directly important in many. Human impacts, therefore, cannot be ignored. However, anthropogenic factors are treated here only with respect to their influence on biophysical processes. Underlying political, social, cultural, and economic factors are certainly important, but are beyond the scope of this work. Certainly geographical traditions suggest both the possibility and the eventual necessity of addressing biophysical and human factors as recursive, mutually adjusting factors in place formation. Sauer (1925), for instance, articulated an approach incorporating natural influences on human agency coupled with human adaptations to and modifications of the natural environment. Thus, perhaps axioms for reading cultural and natural landscapes could (or should?) eventually be simultaneously applied.

II Conceptual framework

There exist at least apparent tensions between rigorous attempts to explain nature as much as possible (ideally, completely) on the basis of generally applicable principles and laws, and the inherent idiosyncrasies and historical and geographical contingencies of ESS. Thus, as described below, this work draws on frameworks that explicitly acknowledge the role of both global (in the sense of being generally applicable) and local (contingent on place and time) factors. The proposed axioms of place formation are in essence an attempt to facilitate geoscientific storytelling. Though some scientists eschew narrative as "mere" storytelling, scientific communication inevitably involves some form of storytelling, though this is rarely acknowledged. The axioms draw on several existing concepts: multiple causality, the law–place–history framework, individualism, resource or evolution space, selection, and place as historically contingent process. These are briefly discussed in the following sections.

1 Multiple causality

Multiple causality refers to the fact that ESS – and geographical and environmental phenomena in general – are rarely adequately explained or interpreted based on simple cause-and-effect relationships with a single dominant controlling factor. ESS are polygenetic (see, e.g., Johnson et al., 1990) and the factors that control or influence them are not necessarily bottom-up from an atomistic level or top-down, but rather operate at a range of spatial scales both broader and more detailed than that of ESS. This is consistent with a state-factor approach. Factorial models, originally developed in soil geography, interpret soil as a function of the combined, interacting effects of environmental factors (typically climate, geology or parent material, biota, and topography) that vary over time. Dokuchaev (1883) pioneered this approach, though Jenny (1941) refined and popularized it in the English-speaking world. Huggett (1995) extended the factorial approach to ESS more generally. Earlier versions implicitly, and later uses explicitly, acknowledged that the state factors operate at multiple spatial and temporal scales, both individually and in the aggregate (e.g. Huggett, 1995; Schaetzl and Thompson, 2015). For example, climate factors influence soil processes and properties both in terms of regional climates, and locally varying microclimates.

2 Laws, place, history

The multiple causes or factors may be categorized as global or universal factors (laws), and local, contingent factors, which may be further considered in terms of geographical and historical contingency. Earlier work outlined a notion of ESS as representing the combined, interacting influences of laws, place, and history. Laws refer to the general principles and relationships that are independent of location and time and would thus apply to any (e.g.) watershed, hillslope, or food web. Place represents the geographical and environmental setting that provides both context and boundary conditions for the operation of laws. History refers to time-contingent variables and influences such as age or stage of development, inherited characteristics and legacy effects, disturbances, and land and resource-use history. The law–place–history framework is described in more detail, with brief examples, in Phillips (2017a). A more detailed application is Phillips (2017b). The framework is partly an elaboration of the "perfect landscape" concept (Phillips, 2007), and closely related to individualism, discussed in the following section. Earlier, Gersmehl (1976) articulated an approach to biogeography based on general principles related to mass and energy fluxes, but recognizing the importance of local, contingent effects.

3 Individualism

Simpson (1963) distinguished "immanent" and "configurational" processes and controls. The former are universal, at least within appropriate domains; the latter are historically contingent states arising from interactions of the immanent (e.g. laws) with historical circumstances. Geological events are unique, Simpson (1963: 29) maintained, because the immanent phenomena are acting on and within particular contexts (configurations). Lane and Richards (1997) applied these ideas to fluvial systems. In a similar vein, Schumm (1991) referred to singularities – the characteristics of landforms, geological formations, etc. that make each to some extent unique – as a fundamental trait in ESS. Marston (2010), Preston et al. (2011), and Wilcock et al. (2013) expanded on these ideas and linked singularity to complexity (often associated with thresholds and multiple stable states) and historical contingency, which may involve path-dependence, legacy effects, or hysteresis. Phillips (2007) argued that even where the laws or immanent factors of a given type of ESS are well known and operationalized, the probability of any two ESS having the same set of local, contingent, or configurational factors is vanishingly small. Thus, all ESS are "perfect" in the sense of having irreducible idiosyncrasies.

Phillips (2015) developed an individualistic concept of landscape evolution (ICLE), broadly analogous to Gleason's (1939) individualistic concept of plant associations in ecology. The ICLE is based on three propositions: (1) landscapes have positive evolution space (Phillips, 2009) – mass, energy, space, and time sufficient to allow for geomorphic evolution to occur; (2) every landform can change or evolve; and (3) the environment within and encompassing any landscape is variable (at a variety of temporal scales). The environment exerts selection pressure so that only some landforms are able to be formed and to persist. This framework connects perfect landscape concepts directly to some notion of finite bounds for evolution, and nonrandom, nonuniform survival and replication of entities.

4 Evolution space

The bounds – or potentials, depending on perspective – are provided by an evolution space, at least superficially similar to the original conception of ecological niches (Hutchinson, 1957). While niches are sometimes equated approximately to habitats, trophic levels, or biogeochemical roles and functions, Hutchinson (1957) originally defined the term as a hypervolume characterized by geographical space and the range of necessary resources such as sunlight, water, and nutrients. Phillips (2008), drawing on Smith (1986) and Lapenis (2002), considered this multidimensional space with respect to ecological systems (rather than individuals or taxa). He defined an ecological resource space based on the availability of matter and energy resources and geographical space, which could be modified by the biota within the system as well as by external changes. The changes in productivity and diversity of an ecological system can be interpreted with respect to the partitioning of these resources (Cochran et al., 2016; Lapenis, 2002; Phillips, 2008). A broadly analogous landscape evolution space can be defined based on available mass and energy resources for geomorphic processes, again modified by the development of the landscape itself (Phillips, 2009; Rósa and Novák, 2011).

5 Selection

As ESS develop under multiple and changing influences, and often affected by disturbances and chance, numerous forms, structures, and processes arise. Selection refers to the fact that some of these are more likely to survive, persist, grow, and replicate, while others have a higher probability of destruction and diminution, and a lower probability of replication or recurrence. Selection is best known in the context of biological evolution, but also applies to system-scale phenomena and to partly or wholly abiotic processes as well. In the latter cases, selection is generally based on the preferential preservation of phenomena that are more resistant, resilient (dynamically stable), or efficient (e.g. Leopold, 1994; Nanson and Huang, 2008; 2017; Phillips, 2011; Twidale, 2004).

6 Pred's place model

"Place as historically contingent process" is the title of a highly influential article by Pred

(1984). It was entirely concerned with social science issues, particularly divisions of labor and power relations, and many of the details of his conceptual model are not applicable to this work. However, as the title indicates, Pred's (1984) theory is directly applicable to place formation and strongly concerned with historical contingency. Whereas ESS studies have typically depicted change as historical sequences or cycles, or state-and-transition models, Pred (1984) conceptualizes place-making in terms of multiple processes and controls or influences, acting simultaneously or contemporaneously, and merging or melding into one another. It is this viewpoint that is relevant to the axioms presented here.

Pred's (1984) model of place-making is based on four key notions. The first is that of constant "becoming." Place is viewed as a plastic, malleable entity, where the observed condition is seen as a constantly changing entity rather than a static state. Second, the model considers processes (practice in his terms) on one hand and structures on the other as intricately intertwined, such that they constantly "become one another." Third, environments, historical imprinting, and transformations are also "becoming one another." Fourth, the process–structure and environment–history–transformation dynamics are occurring simultaneously.

III Axioms of spatial structuring and place emergence

The axioms are intended to encompass the phenomena by which space becomes increasingly differentiated into places. They acknowledge that such differentiation may be interrupted or reversed, but focus on the divergent aspects of place formation. The viewpoint is emergent in the sense that places arise as a byproduct of several phenomena rather than as a result of any teleological goals or deterministic endpoints or outcomes. The key phenomena represent groups of processes involved in spatial structuring and differentiation, selection, coalescence, constraints, recursive mutual adjustments, and canalization. Tempting as it may be to view these as sequential stages of place formation, they are not necessarily sequential, and often operate simultaneously. The axioms are summarized in Table 1.

1 The axioms

The axioms are presented as guides to environmental interpretation. They represent key ideas useful in understanding what we see, map, and measure in the landscape. They are termed axioms because they now seem obvious and self-evident, as axioms by definition should be. Others may dispute the use of "axiom" here; but their utility is independent of semantics. Like axioms in general, these propositions serve as a starting point for argument and analysis.

The first six items in Table 1 (spatial structuring, selection, coalescence, constraints, mutual adjustments, and canalization) represent suites of processes of place-making and modification. The latter three (change, reversibility, scale) emphasize that place formation is ongoing and dynamic, that divergence and spatial structuring are reversible, and that place formation manifests at a range of scales.

1.1 Axiom 1: spatial structuring happens and spatial differentiation processes occur. Spatial structuring processes include fluxes of matter, energy, and information, and connections that influence interactions. The roles of matter and energy fluxes are well established. Information here can refer to that exchanged in human systems, which, in turn, influences natural systems, or to, for example, the role of genetic information in evolutionary ecology. These fluxes are, in turn, affected by gradients, corridors, and infrastructure. Examples of gradients include topographic (slope, elevation), atmospheric pressure, and variations in surface roughness or resistance. Corridors are influenced by

Table 1. Summary of axioms for interpreting natural landscapes.

1. Spatial structuring happens; spatial differentiation processes occur.
2. Selection occurs. Some structures and patterns are preferentially preserved and enhanced.
3. Coalescence: structuring and selection solidify portions of space into zones (places) that are internally defined or linked by mass or energy fluxes or other functional relationships; and/or characterized by distinctive internal similarity of traits.
4. Individuality and constraints: places have unique, individualistic (perfect) aspects, but development is bounded by an evolution space defined by applicable laws and available energy, matter, and space resources.
5. Mutual adjustments: recursive, mutually adjusting relationships exist between process and form (pattern, structure), and among environmental archetypes, historical imprinting, and environmental transformations. These occur constantly and contemporaneously, though at variable rates and tempos.
6. Canalization: place formation is increasingly constrained or canalized between CREs.
7. Constant change: though stable, static states can be observed over certain time scales and periods, places are always changing or subject to change.
8. Reversibility: spatial structuring, divergence, and place-making are reversible. Places can merge or coalesce or be obliterated by CREs or convergent–divergent mode shifts.
9. Scale dependence: all phenomena above may occur, or be observed or analyzed, across a range of spatial and temporal scales.

CRE: clock-resetting event.

anthropic infrastructure (e.g. railways, roads, communication lines, water and sewer lines, etc.); patterns of land and water access or ownership; political boundaries; and natural or anthropic storage sites.

Fluxes and connectivity are affected by barriers as well as corridors. Examples include topographic obstacles; zones of high surface roughness or resistance or low conductivity; land–water juxtaposition; inhospitable habitats; political boundaries; patterns of human conflict; and erected boundaries (e.g. fences, fortifications, etc.). Rivers, oceans, or highways that serve as corridors for some entities also serve as barriers for others.

Interactions and fluxes are often organized (in the non-human realm largely via various forms of efficiency selection) into networks of energy, matter, and information flux, and economic and social interaction. Examples include watersheds and drainage networks; karst and other subsurface watersheds and networks; air mass source regions, prevailing winds, and storm tracks; ocean circulation patterns; and transportation, communication, and social networks.

1.2 Axiom 2: selection occurs. Selection applies to transient fluid and energy fluxes (e.g. Kleidon et al., 2010, 2013; Ozawa et al., 2003), semi-permanent flux pathways and networks (e.g. Eagleson, 2002; Hunt, 2016; Smith, 2010), biological selection, and anthropic selection influenced by numerous, sometimes conflicting, criteria. Selection is a probabilistic notion that more stable, durable, and efficient features and phenomena are more likely to persist and be reinforced, relative to those that are less so. Thus, as the pathways and networks described above develop, they are strongly influenced by selection phenomena.

1.3 Axiom 3: place characteristics are solidified by coalescence. Coalescence often occurs around key network nodes, and points of either loss or accumulation of, for example, mass, energy, or capital. Agglomeration and preferential attachment phenomena are positive feedbacks that reinforce locational concentration. Agglomeration is well known in urban and economic geography, and is also common in the development of many ecological concentrations. Preferential flow and attachment dynamics also occur in the development of both surface and subsurface flow and drainage systems, some aspects of soil development, and biological mass and energy fluxes (Berkowitz and Ewing, 1998; Hunt, 2016; O'Neill et al., 1988). Coalescence also occurs due to, or in the context of, economic and political command-and-control apparati, ownerships, and jurisdictions, both formal and informal. Effects may be intended and deliberate or unintended and unanticipated.

1.4 Axiom 4: individuality and constraints. Landscapes and ESS have unique, individualistic (perfect) aspects, but development is constrained by an evolution space defined by applicable laws and available energy, matter, and space resources. This axiom reinforces the idea of idiosyncrasies and singularities in ESS, but recognizes the limits on behaviors and configurations associated with laws and finite resources.

1.5 Corollary: landscape development is historically contingent. Historical incidents and disturbances are rarely simultaneous and equivalent over large areas, and are thus important in differentiating space. Historical imprinting may occur via inheritance or legacy effects, triggering of new developmental trajectories, or disproportionate growth effects due to dynamical instabilities. Agglomeration and efficiency selection may also play a role in fixing disturbance effects.

1.6 Axiom 5: mutual adjustments. Recursive, interactive relationships exist between processes on the one hand, and forms on the other. Mutual adjustments also occur among environmental archetypes, historical imprinting, and environmental transformations. These occur constantly and contemporaneously, though at variable rates and tempos.

1.7 Axiom 6: canalization. Place formation is increasingly constrained or canalized between clock-resetting events (CREs) – major changes or disturbances that herald a new path of landscape evolution. This is partly attributable to historical contingency and path dependence, but also to the ongoing modification of evolution space as ESS evolve.

1.8 Axiom 7: constant change. Landscapes and ESS are always changing (though at varying rates), or at least subject to change.

1.9 Corollary. Though stable, static features can be observed at some time scales and periods, the observed environment must be understood as a historically contingent snapshot.

1.10 Axiom 8: reversibility. Irreversible physical, chemical, and biological processes are important in the functioning and evolution of landscapes. However, the phenomena of spatial structuring, divergence, and place-making are reversible. Places can merge, and convergent evolution can occur. ESS may be wiped out by CREs, and divergent–convergent mode shifts can occur.

1.11 Axiom 9: scale dependence. All phenomena described in axioms 1–8 may occur across a range of spatial and temporal scales.

1.12 Corollary. The controls over process–response relationships and the state of ESS may vary at different spatial and temporal scales.

2 Discussion

The axioms can be applied from either a nomothetic (law-based) or idiographic (focused on particulars) perspective. These concepts are related to, but not the same as, deductive or inductive approaches, as deductive reasoning is frequently applied to case studies, and induction is often law-seeking. The nomothetic viewpoint starts with the applicable laws germane to the ESS. The geographically contingent place factors provide a template and boundary condition for the operation of relevant laws. The operation of law-governed processes within this context results in changes over time, further influenced by disturbances and externally stimulated changes (history). These modify the geographical constraints, and, in turn, the operation of law-governed processes. Thus, a place or an ESS is, as Pred (1984) would likely put it, always becoming.

This perspective suggests that in the absence of (or between) major clock-resetting disturbances, place formation and ESS evolution is progressively constrained and canalized. Potential trajectories that might have been possible at a given point in time may be eliminated, or their probability reduced, by environmental transformation, while other pathways are selectively favored.

The idiographic viewpoint begins with a place or environment, where the perfect landscape, singularity, and individualist concepts assert a degree of uniqueness and idiosyncrasy. From this unique starting point, innumerable possible trajectories and future states can be envisioned. However, these are constrained by general laws, which allow some possibilities and forbid others, and determine that some of the allowable options are more or less probable. Similarly, place characteristics constrain the possibilities, by defining the resource or evolution space (Phillips, 2008, 2009) in which development can occur. Law-governed processes acting on a geographically constrained template result in environmental transformations, and a new (continually evolving) set of singular place characteristics. The implications with respect to development between or absent of major disturbances, and a condition of perpetual becoming, are the same as for the nomothetic perspective.

Figure 1 is an approximate mapping of the axioms to Pred's place as historically contingent process model (compare to Pred, 1984: Figure 1).

In some cases it is straightforward to apply the axioms. One recently published example is the work by De Haas et al. (2018) on the Holocene evolution of tidal systems in the Netherlands. Spatial structuring processes operating on a partly inherited landscape are evident with respect to flooding by rising sea level, land subsidence, tidal fluxes, fluvial water and sediment inputs, and avulsions. Gradient and ecological selection processes selectively enhance or preserve some features, and coalescence occurs in the form of, for example, estuaries, lagoons, dunes, cover sands, marshes, flats, and alluvial floodplains. Individuality is evident in the roles of inherited topography, human impacts, glacial effects, isostatic rebound, and offshore sediments, but the individuality is constrained by base level, tidal range, and laws governing sediment transport and deposition. Mutual adjustments occur; for example, vegetation sedimentation and sedimentary infilling rates versus tidal prism feedbacks. Canalization is associated with constant relative sea-level rise during the Holocene. The axioms of reversibility, scale dependence, and constant change are evident throughout the dynamic Holocene development of Dutch coastal systems (De Haas et al., 2018).

Other examples include the study by Marden et al. (2018) of New Zealand gully and mass movement complexes, and Johnson and Ouimet's (2018) framework for interpreting landscapes through airborne light detection and ranging (LiDAR). In the former case, the link to the axioms is straightforward due to Marden et al.'s (2018) explicit framing of the work in terms of several of the same conceptual frameworks underpinning the axioms. In the latter case, it is the explicit concern with landscapes as palimpsests that makes the interpretive approach evident (Johnson and Ouimet, 2018).

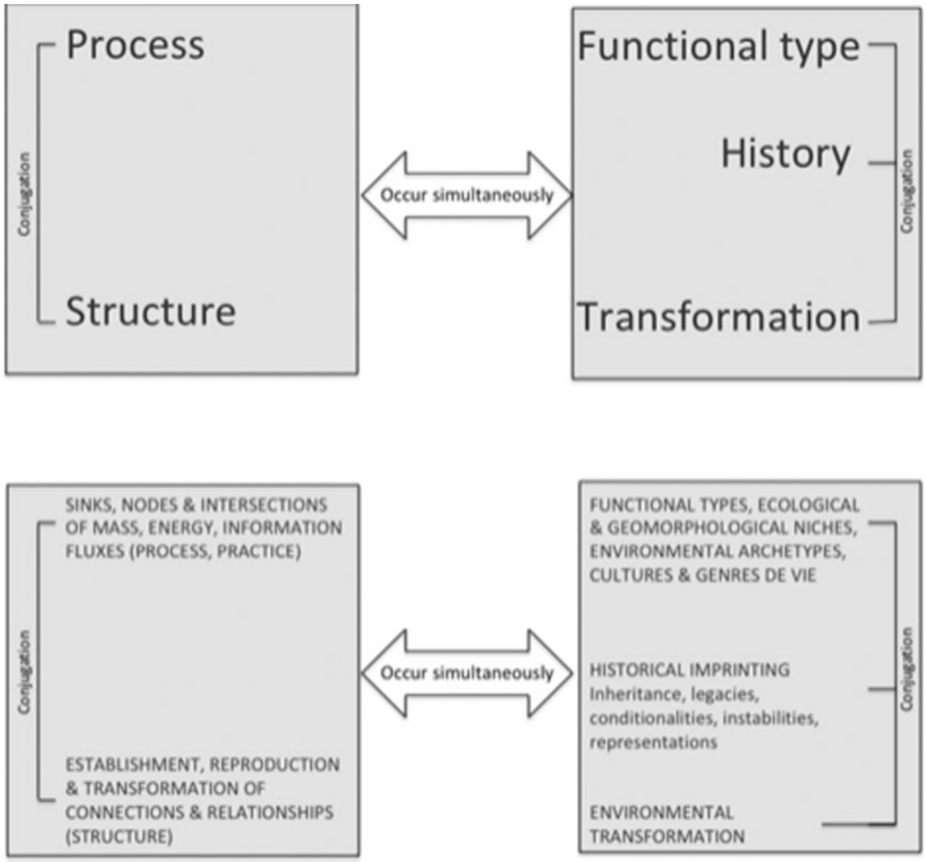

Figure 1. Conceptual representation of the framework underpinning the axioms, with a simplified version at the top and an expanded version at the bottom.

Application of the axioms is best illustrated, however, via a case study where they are consciously applied during the research.

IV Interpretation of Inner Bluegrass soil landscapes

The development of soil landscapes is only one of many possible examples of use of the axioms in assessment of place formation. However, it is an apt illustration, as soils represent the combined, interacting influences of other environmental factors, such as geology, climate, biota, topography, hydrology, and human agency, along with feedbacks of the soil itself.

The study area, the Inner Bluegrass region of central Kentucky (Figure 2), features a humid subtropical climate, with mean annual precipitation of 1100 to 1200 mm, spread relatively evenly throughout the year. Underlying geology is mainly horizontally bedded Ordovician limestones, with small amounts of dolomite, calcitic shale, and bentonite. The highest upland surfaces are underlain by the Lexington Limestone formation. The Lexington and underlying formations are horizontally bedded, with irregularly spaced vertical and sub-vertical joints. Though older faults are found throughout the region, the area has been tectonically stable during the Quaternary.

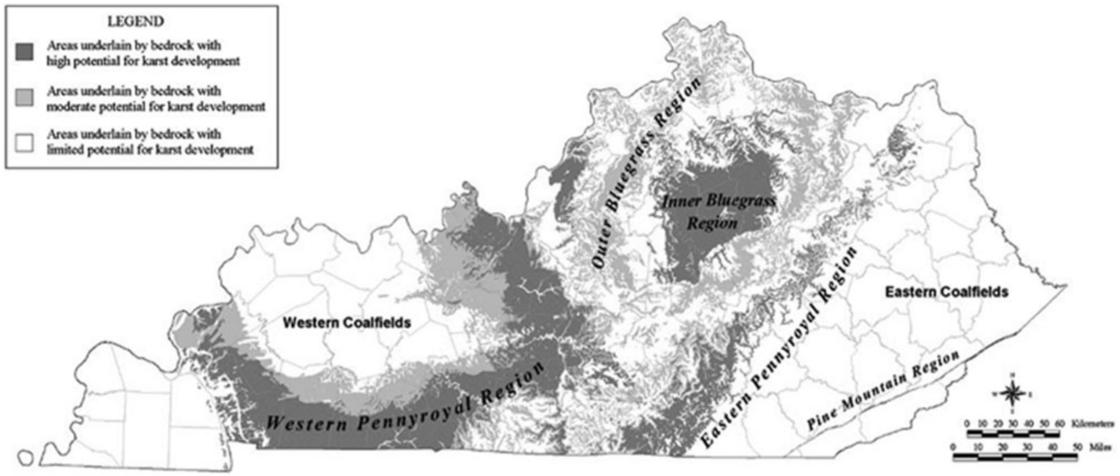

Figure 2. Kentucky Geological Survey map of major karst regions of Kentucky, showing the Inner Bluegrass study area and surrounding Outer Bluegrass region.

The focus here is on upland soils, defined here as those on surfaces other than alluvial floodplains and terraces. The parent materials for all soils include, or are derived from, weathered limestone. These can be divided into relatively pure phosphatic limestone (referred to as "high-grade" limestone in some older soil surveys) and non-phosphatic limestone interbedded with shale (mostly calcitic) and siltstones. Wisconsin-era glacially derived loess covers some of the area (Barnhisel et al., 1971), generally interpreted as Peoria loess (Karathanasis and MacNeal, 1994). Though dating studies have not been conducted within the study area, in western Kentucky, Peoria loess appears to have been deposited around 25–12 ka (Nanson and Huang, 2016; Rodbell et al., 1997). Due to presumably uneven deposition and subsequent redistribution, silty cover beds range from nonexistent to >1 m thick.

Given the carbonate rock and humid climate, karst processes and landforms (as well as fluvial processes and forms) are common. The Inner Bluegrass is drained by the Kentucky River (an Ohio River tributary), which provides the base level for both fluvial and karst processes. A key event in recent landscape evolution was the ice damming of the Teays River, ancestor of the Ohio, which flowed across what is now Ohio and Indiana well north of the modern Ohio River. An ice-dammed lake formed, and eventually overflowed, essentially diverting the ancestral Teays to the path of the modern Ohio. Given a much shorter distance to a comparable base level, rivers such as the Kentucky had steeper slopes and accordingly greater shear stress and stream power. This initiated downcutting, which typically amounts to about 100 m in the Kentucky River gorge area of the Inner Bluegrass. Dating of high-level, pre-incision fluvial deposits of the Kentucky and other Ohio tributaries from the unglaciated south suggests that incision began 1.3 to 1.8 Ma (Andrews, 2004). The Teays-Ohio-Kentucky story is outlined in detail by Ray (1974), Teller and Goldthwait (1991), and Andrews (2004).

The steadily lowering base level since the Kentucky River incision began $\sim$1.5 Ma has stimulated both fluvial erosion and karstification. The ongoing geomorphological and hydrological change (as well as climate change,

Table 2. List of soil surveys.

Title: Soil Survey of . . . Kentucky	Year of Publication
Anderson and Franklin Counties	1985
Boyle and Mercer Counties	1983
Bourbon and Nicholas Counties	1982
Clark County	1964
Fayette County	1968
Garrard and Lincoln Counties	2006
Jessamine and Woodford Counties	1983
Madison County	1973
Scott County	1977
Other USDA Soil Survey Resources	*Description*
Official Series Descriptions database	Official profile descriptions & additional information for upland soil series identified in survey data
Soil Web: Soil Series Extent Explorer	Information on taxonomic relationships & mapped soil units for upland soil series identified in survey data

All soil surveys available at: https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=KY. Official series descriptions (OSD) available at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053587. The Soil Series Extent Explorer (including soil data explorer) available at: https://casoilresource.lawr.ucdavis.edu/see/. (All sites accessed 13 December 2017.)

biological influences, and human land uses) has shaped the upland soil landscapes.

1 Methods

Methods used here do not conform to a traditional hypothesis testing or historical reconstruction framework. Rather, they depend on a combination of fieldwork, soil survey data, and published research to develop a narrative of place formation. Field observations are based on work conducted for both site-specific and regional studies of differential landscape development on inner and outer bends of the Kentucky River gorge (Phillips, 2015), soil spatial complexity (Phillips, 2016a), fluviokarst landform transitions (Phillips, 2016a), and landform evolution on chronosequences associated with Kentucky River incision and lateral migration (Phillips, 2018a). Published soil surveys and related data utilized are shown in Table 2.

From the survey data, soil types (series) indicated as occurring within the Inner Bluegrass on upland surfaces, with limestone (or silt-capped limestone) parent material were identified. Each soil represents a set of place characteristics; a set of environmental traits reflecting the influence of soil-forming factors. Then a narrative of place formation – landscape differentiation into the different soil types – was developed.

2 Results

Table 3 shows the identified soil types. Chronologically and rhetorically, a good starting point for soil development is the distinction between relatively pure phosphatic limestone, and limestone interbedded with shales and siltstones (hereafter referred to as pure and interbedded limestone, respectively). These differences are derived from the original depositional environment, subsequently modified by loess deposition, as discussed below.

As fluvial, karst, and hillslope processes operated, along with dissolutional weathering and other pedogenetic processes, some portions of the landscape became dominated by either removal or accumulation. Thus, two soil series,

Table 3. Upland soils of the Inner Bluegrass region, based on US soil taxonomy.

Series	Taxonomy (subgroup)	Parent material
Bluegrass	Typic Paleudalfs	Silt over pure LS
Caleast	Mollic Hapludalfs	Interbedded LS
Caneyville	Typic Hapludalfs	Silt over pure LS
Crider	Typic Paleudalfs	Silt over interbedded LS
Cynthiana	Lithic Hapludalfs	Pure or interbedded LS
Donerail	Oxyaquic Argiudolls	Pure or interbedded LS
Fairmount	Lithic Hapludolls	Pure or interbedded LS
Faywood	Typic Hapludalfs	Interbedded LS
Loradale	Typic Argiudolls	Pure or interbedded LS
Lowell	Typic Hapludalfs	Interbedded LS
Maury	Typic Paleudalfs	Silt over pure LS
McAfee	Mollic Hapludalfs	Pure LS
Mercer	Oxyaquic Fragiudalfs	Silt over pure LS
Nicholson	Oxyaquic Fragiudalfs	Silt over interbedded LS
Salvisa	Mollic Hapludalfs	Interbedded LS
Sandview	Typic Hapludalfs	Silt over interbedded LS
Shelbyville	Mollic Hapludalfs	Silt over interbedded LS

LS: limestone.

Fairmount and Cynthiana, are distinguished from the others based on their limited depth to bedrock, whether pure or interbedded limestone. These series, which differ from each other with respect to a mollic epipedon in the Fairmount, occur on sites where soil erosion has occurred, or where ongoing removal on steep slopes has prevented a thicker regolith from ever occurring. Two other soils, Donerail and Loradale, occur on limestone uplands characterized by accumulations either in concavities (often dolines) or as hillslope colluvium.

Though airborne silt-sized loess presumably influenced the entire landscape, deposition must have been non-uniform. Further, in some cases silt was deposited on steep slopes or along drainageways where it was quickly removed. Thus, both pure and interbedded limestones feature soils formed with and without a silty mantle. On the purer limestones, the Caneyville series is found where the silty layer is thinner, and the Bluegrass and Maury series where it is thicker. Where concretions within these soils have created a fragipan, soils are classified as the Mercer series. The Maury and Bluegrass differ with respect to higher clay content in the former.

Four series occur on interbedded limestones with a loess cover: Crider, Nicholson, Sandview, and Shelbyville. The Shelbyville is distinct from the others by having a mollic epipedon; Nicholson by a fragipan. The Crider, as compared to the Sandview, generally appears more highly weathered, as evidenced by, for example, greater rubification.

On the pure limestones with no silt cap (other than the thin or depositional soils mentioned earlier), the lone series mapped in the surveys is the McAfee. On the interbedded limestones without a silt cap, four series occur, distinguished on the basis of a mollic epipedon and relative thickness. The thicker types are the Lowell and Caleast series; the thinner the Faywood and Salvisa. Caleast and Salvisa have Mollic epipedons.

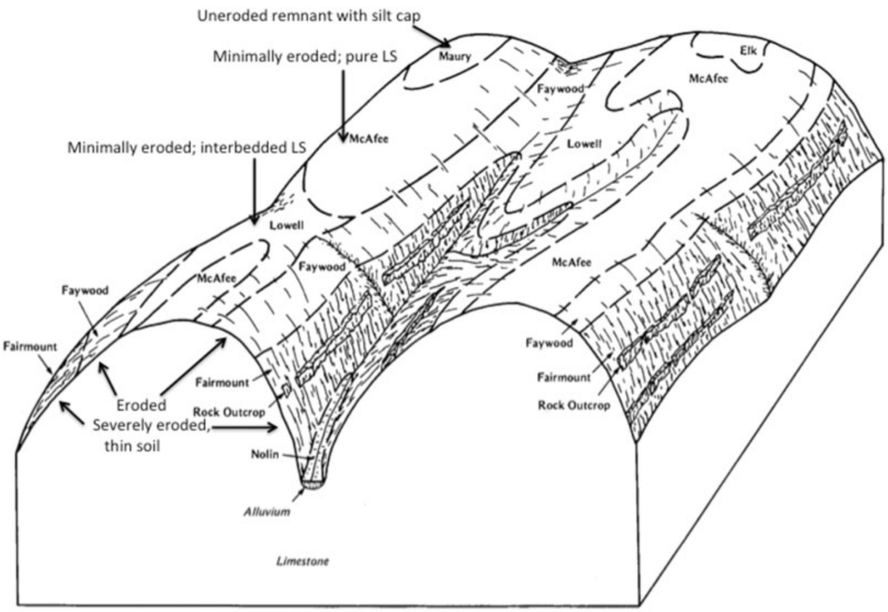

Figure 3. Block diagram from the *Soil Survey of Anderson and Franklin Counties, Kentucky* (All soil surveys available at: https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId¼KY.), showing landscape relationships of soil series. Larger labels and arrows added by author. LS: limestone.

3 Spatial structuring

Spatial structuring of the Inner Bluegrass soil landscape starts with initial lithological and structural variations in the parent rock. The former separate the purer phosphatic from the interbedded limestones. Structural features, especially vertical joints, are preferentially widened in the epikarst, allowing for locally deeper, thicker soil. This accounts for the occurrence of thicker (e.g. Faywood, Lowell) and thinner Fairmount and Cynthiana soils in close proximity. Lithological and structural variations in weathering and erosion resistance also result in the frequent co-occurrence of rock outcrops and soil-covered epikarst.

Weathering, erosion, and deposition not only directly influence soils, but also the topography. This results in the redistribution of soil and of deposited loess, as well as exposure of different lithological units. It is not unusual, for example, for the Maury series to occur on the highest, flattest positions, with the McAfee series on adjacent areas with no silt cap. On adjacent slightly lower positions, the Lowell series is sometimes found where interbedded limestone has been exposed, with Faywood adjacent to that on thinner soils on steeper or more eroded slopes (see Figure 3).

Variations in the original deposition and subsequent redistribution of loess provide an additional level of spatial structuring. In addition to the silt cap versus no silt cap distinction, soils with fragipans are found only in the former – though the presence of similar Fe/Mn concretions in other soils (though not sufficient to result in a fragipan; Phillippe et al., 1972) suggests that aeolian silt inputs have been important even when no silty mantle over weathered limestone is discernible, as the limestone contains minimal Fe and Mn.

Other spatial differentiation processes are highly localized. For example, local dissolutional depressions at scales ranging from a few cm in depth and <0.5 m^2 in area to major dolines allow for material accumulation and (if not under-drained by karst features) less effective soil drainage. Small shallow depressions in underlying limestone allow for the development of mollic properties in the thin Fairmount series, for example, at the sites examined by Phillips (2016a), and depressions and concavities with less effective drainage account for differences between the oxyaquic Donerail series and better-drained colluvial Loradale. Locally restricted drainage also apparently allows for the formation of fragipans in some of the silt-cap soils. In some cases, the effects of tree roots growing into bedrock joints locally deepens soil due to effects on weathering and mass displacement (Phillips, 2016b).

In addition to the aforementioned processes, which would occur with or without human agency, anthropic influences also help structure the soil landscape. For example, at least some eroded areas are or have been strongly influenced by land clearing and farming practices, as had become apparent more than a century ago (e.g. Burke, 1903; Griffen and Ayrs, 1906; Kerr and Averitt, 1921).

4 Selection and coalescence

Selection in this case is primarily in the forms of gradient and resistance selection (Phillips, 2011). Surface-water flow tends to form channels and bifurcating networks, because these are more efficient for mass transport, and are reinforced by positive feedback. Thus, fluvial channels and associated valleys become imprinted on the landscape, defining valley bottoms, valley side slopes, and interfluves. These channels also become local base levels for both surface- and groundwater flow. Even when capture of surface streams by karst conduits occurs, the valleys persist as dry karst valleys.

Karst groundwater fluxes are driven by gravity, but are strongly affected by rock structure (joints, bedding planes, fractures, fissures). The most efficient of these are most likely to be utilized, and, again, are reinforced by positive feedback. These may sometimes be plugged by transported sediment, but such plugging is temporary. When karst-to-fluvial transitions occur in the form of collapse into cave passages and larger conduits, these features persist as karst window streams or pocket valleys.

Gradient selection has been ongoing during Kentucky River incision, driving both karst-to-fluvial and fluvial-to-karst transitions, and rejuvenating both sets of features. This keeps spatial structuring processes active and mitigates against the development of very old, mature soils characterized by uninterrupted progressive pedogenesis.

As the soils evolve in these settings, selection and spatial differentiation lead to coalescence in the form of distinctive soil properties. Some of those are common to many soils around the world, such as accumulation of iron and aluminum oxides, underlying epikarst, formation of argillic horizons, mollic properties, fragipans, base saturation sufficient to qualify as Alfisols or Mollisols, and Fe and Mn concretions. Others, such as stratigraphy derived from silt deposits overlying weathered limestone, are less common but hardly unique to the region. However, the specific combination of properties produces not only distinct soil "places" (soil bodies in the sense of Dokuchaev, 1883) within the Inner Bluegrass, but also a regionally distinct suite of soils. Of the 17 soil series shown in Table 4, eight are found only in the Inner and adjacent Outer Bluegrass regions of Kentucky. Seven others are found primarily in the Inner and Outer Bluegrass, and all 17 are found primarily in Kentucky and adjacent states. The designated type locations for all 17 are in Kentucky, and 11 of these are within the Inner Bluegrass.

5 Constrained individualism

Axiom 4 holds that places have unique, individualistic (perfect) aspects, but development is bounded by an evolution space defined by

Table 4. Distribution and type location for Inner Bluegrass upland soils. Shaded type locations indicate counties lying wholly or partly within the Inner Bluegrass.

Series	Distribution	Type location
Bluegrass	Only in Inner, Outer Bluegrass regions, Kentucky	Fayette County, KY
Caleast	Only in central Kentucky, mainly in Outer Bluegrass	Madison County, KY
Caneyville	Karst regions, Kentucky, Tennessee, Indiana, Missouri, Virginia	Hardin County, KY
Crider	Karst regions, Kentucky, Indiana, Missouri, Tennessee, Ohio	Caldwell County, KY
Cynthiana	Mainly Inner Bluegrass region, but also other karst regions of Kentucky, Tennessee, Ohio	Harrison County, KY
Donerail	Mainly Inner Bluegrass region, but also other karst regions of Kentucky, Tennessee	Fayette County, KY
Fairmount	Mainly Inner and Outer Bluegrass regions, but also other karst regions of Kentucky, Indiana, Ohio	Woodford County, KY
Faywood	Mainly Inner and Outer Bluegrass regions, scattered occurrences in other karst regions of Kentucky, Tennessee, Virginia, Ohio, West Virginia	Woodford County, KY
Loradale	Only in Inner Bluegrass region	Fayette County, KY
Lowell	Mainly Inner and Outer Bluegrass regions and karst areas of eastern Ohio. Also found in other karst regions of Kentucky, Virginia, Pennsylvania, West Virginia	Jessamine County, KY
Maury	Mainly Inner Bluegrass, also Outer Bluegrass and central Tennessee	Fayette County, KY
McAfee	Only in Inner, Outer Bluegrass regions	Mercer County, KY
Mercer	Only in Inner, Outer Bluegrass regions	Fayette County, KY
Nicholson	Mainly Outer Bluegrass, western Pennyroyal regions, KY; also Inner Bluegrass and scattered occurrences in Missouri, Indiana, Ohio, West Virginia, Virginia	Kenton County, KY
Salvisa	Only Inner Bluegrass	Fayette County, KY
Sandview	Only in Inner, Outer Bluegrass regions	Marion County, KY
Shelbyville	Only in Inner, Outer Bluegrass regions (mainly outer)	Shelby County, KY

Distributions from the *Soil Series Extent Explorer* (https://casoilresource.lawr.ucdavis.edu/see/); type locations from the Official Series Descriptions (https://soilseries.sc.egov.usda.gov/osdname.aspx).

applicable laws and available energy, matter, and space resources.

The individualistic aspects at the soil pedon scale are indicated by the local spatial variability of soil and regolith. Mueller et al. (2003), for instance, showed unbounded semivariograms for the spatial variability of soil properties measured by electrical resistivity, and Phillips (2016a) illustrated the spatial complexity of an Inner Bluegrass soil landscape using network analysis of a soil adjacency graph. Figure 4 shows at least six morphologically distinct soils along a 5-m-long exposure of a single lithotype of the Lexington limestone.

The constraints or boundedness are illustrated by the finite population of soil types found in the region, and the repeated patterns and occurrences of soils. That is, soils similar enough to be classified as the same series occur in different locations, as well as catenary sequences and factor sequences (see Phillips, 2016a) of genetically related soils.

6 Mutual adjustments

Recursive, mutually adjusting relationships exist between process and form (pattern, structure), and among environmental archetypes,

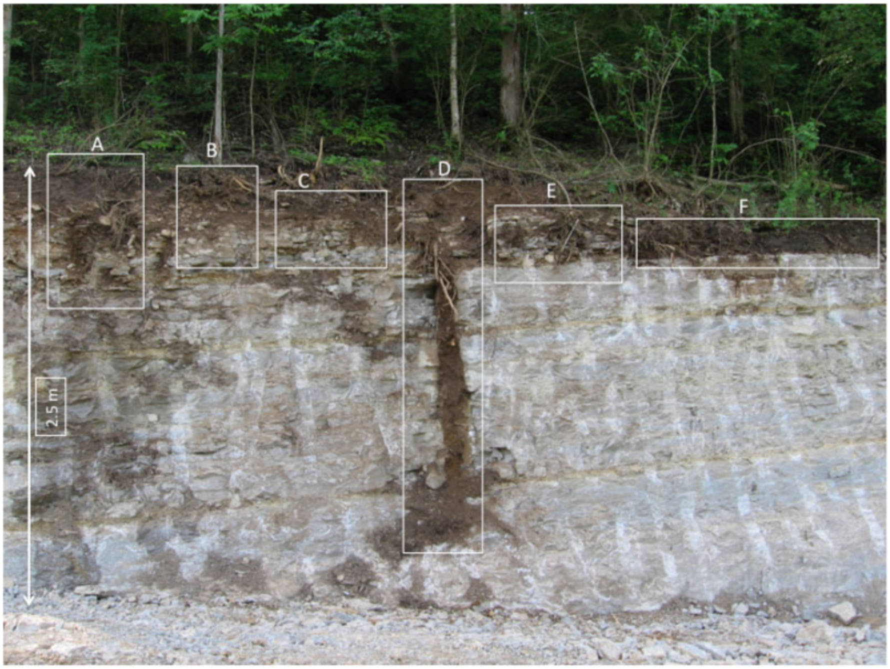

Figure 4. Soil and regolith variability on the Lexington Limestone formation, Madison County, Kentucky. (a) Mollic or umbric surface horizon overlying argillic horizon, and thick transition zone of rock fragments and weathered limestone. (b) Similar to (a), but thinner zone of weathered rock. (c) A horizon directly overlying a thin layer of weathered limestone. (d) Weathered, soil-filled joint with dark surface layer, multiple argillic horizons, and abrupt transition to bedrock. (e) Similar to (c), but greater rock fragment content in surface horizon. (f) Mollic or umbric surface horizon with abrupt transition to bedrock. (a) and (b) are likely Faywood or Salvisa series; (c) and (e) would likely classify as the Cynthiana series; and (f) as Fairmount. (d) would probably be classified as the Maury or Bluegrass series, depending on B horizon clay content.

historical imprinting, and environmental transformations. These occur constantly and contemporaneously, though at variable rates and tempos.

One example is the interactions among tree roots, weathering, and soil thickness (Figure 5). Where soil depth is less than the rooting depth of trees, tree roots may penetrate joints and other openings of the underlying bedrock. Roots (and associated microbial communities) facilitate biochemical weathering and moisture flux into the rock, and may physically displace loosened blocks or slabs. This weathering, reinforced by positive feedback, can result in the local deepening of soil/regolith. Further, uprooting may result in "mining" of bedrock fragments encircled by roots. These locally thicker soils may provide favorable sites for future tree establishment, providing another positive feedback. Evidence supporting these interrelationships has been reported from studies in central Kentucky by Martin (2006), Phillips (2016b, 2018b), and Shouse and Phillips (2016).

Various mutual adjustments also occur between karst erosional processes (dominantly dissolutional and subsurface), and fluvial processes (dominantly mechanical and surface). While older theories of fluviokarst landscape evolution postulate landscape-scale transition from a fluvially dominated to a karst-dominated landscape (or vice-versa) in central

Figure 5. Tree roots exposed by recent erosion of Fairmount soils, Mercer County, KY.

Kentucky, both karst-to-fluvial and fluvial-to-karst transitions are active, often in close proximity (Phillips, 2017b). Karst landform development can sometimes promote transitions to fluvial landforms (e.g. collapse or removal of overburden of large conduits or caves to form pocket valleys or karst window streams), and vice-versa (e.g. channel bed erosion leading to karst groundwater capture of stream flow).

7 Canalization

Pedogenesis may follow progressive or regressive pathways, but some aspects are irreversible. Weathered limestone cannot reconstitute into unweathered parent material, and even though dissolution reactions are reversible, most chemical precipitation of solutes occurs away from the site of dissolution, resulting in permanent loss at the soil pedon scale. Thus, though regressive pedogenesis can make soils thinner and less vertically differentiated, and can disrupt or destroy some pedogenic features, over time the soil evolution space is reduced in the absence of new inputs of mass or gravitational energy.

Inner Bluegrass soils, like most soils, are closely related to topography, and topographic changes are also often irreversible. Once a steep valley side slope has formed, for example, that topographic factor of soil formation can hardly be changed at the hillslope scale until a CRE occurs. Past regional CREs in the study area include the glacially driven reorganization of the Ohio-Teays river system, deposition of the Peoria loess, and several episodes of anthropogenic change.

8 Reversibility

Spatial structuring, divergence, and place-making are reversible, though some specific processes are typically irreversible, as in this example. Places can merge or coalesce, or be obliterated by CREs or divergent–convergent mode shifts. This has certainly occurred locally as landscaping, construction, and major erosion or deposition has provided or exposed fresh parent material for pedogenesis, often in a new or modified topographic context.

Fluvial channel evolution and landscape dissection, such as that occurring in the Kentucky River gorge region, is often unstable and divergent in earlier stages. Flow concentration, shear stress, and fluvial erosion are all mutually reinforcing, as are erosion and weathering (due to exposure of fresh rock). However, such divergence cannot continue indefinitely, and when other factors (e.g. base level, moisture supplies) become limiting, there is often a mode switch to stable, convergent development. This does not presently appear to be the case in the study area, but could certainly occur in the future.

Locally, the development of karst features, such as dissolutional widening of fissures and conduits, often experiences a switch from moisture limitation (weathering is limited by the supply of H_2O) to a mode where geochemical kinetics limit the rate of dissolutional enlargement (Kauffman, 2009). The relationship between soil thickness and weathering also often undergoes a mode switch. As a thin soil cover develops, the rate of weathering of underlying bedrock increases due to the moisture-holding capacity and biological activity of the soil. At some threshold, however, additional thickness reduces weathering at the weathering front as the latter becomes increasingly isolated from meteoric water and biological activity at the ground surface. This is often referred to as the humped soil production function (Humphreys and Wilkinson, 2007); however, these dynamics have been little studied in epikarst.

V Discussion and conclusions

1 Comparison to other frameworks

Axioms of place formation are presented as a framework for interpreting and telling the stories of natural landscape development. These guidelines recognize and highlight both the general laws and principles involved, and the local historically and geographically contingent idiosyncrasies. This axiomatic approach is framed in terms of a view of ESS based on constant change and mutual adjustments of form and process. It does not seek to explain or predict a particular landscape as an endpoint or ultimate attractor state, but rather as a path-dependent sample or snapshot of perpetual (or at least indefinite) becoming.

Any attempt to compare these axioms with those of Lewis (1979) or others for cultural landscapes would be a tenuous apples-and-oranges affair at best. However, some reasonable comparisons can be made to Schumm (1991) and Bryson (1997).

Schumm's (1991) book is framed in terms of problems for interpretation of Earth systems rather than rules or guidelines. Two problems he highlights are time and location – essentially historical and geographical contingency – which are expressed in Axiom 4 (individuality and constraints). Schumm's "space" problem relates to size and scale, and is directly related to Axiom 9 (scale dependence). Schumm's 10 key problems also include complications associated with convergent evolution (e.g. equifinality), and divergence. While the current study acknowledges the possibility of convergence (Axiom 8: reversibility), the axioms overall are concerned with divergence, and Axiom 1 (spatial structuring and differentiation) is explicitly based on divergence principles. Schumm's (1991) "efficiency" problem is related to Axiom 2 (selection), but emphasizes the disproportionality that may sometimes exist between driving forces and responses rather than preferential preservation and enhancement of more efficient forms. Multiplicity in Schumm's framework relates to multiple causality – one of the underpinning principles of the axioms, but not expressed as a specific axiom. Schumm's "singularity" is an important component of individuality (Axiom 4). Sensitivity refers to the propensity to respond to minor

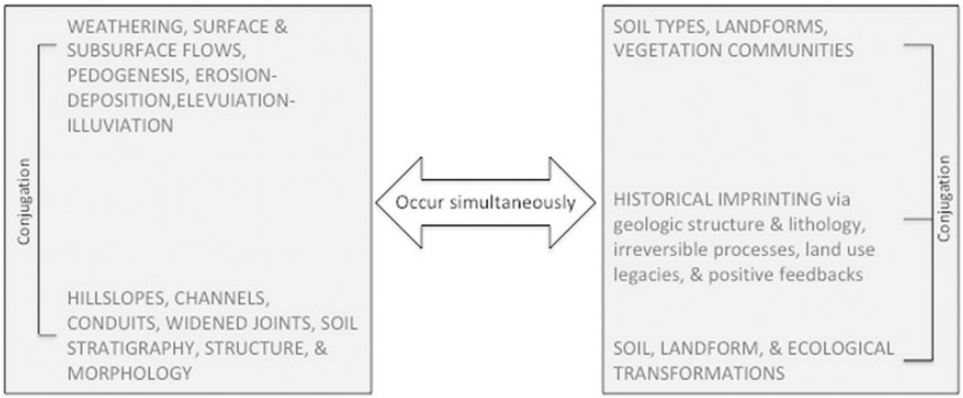

Figure 6. Processes, structures, and entities from the Inner Bluegrass case study are shown in the context of the conceptual model of Figure 1.

changes, due to proximity to thresholds, or dynamical instability (Schumm emphasizes the former), and is consistent with the axioms, but not directly related to them. Complexity in Schumm's (1991) framework encompasses numerous forms of complexity, related to Axioms 4 (individuality and constraints) and 5 (mutual adjustments).

The climate axioms of Bryson (1997) include four axioms and five corollaries. Corollary one – a definition of climate as "the thermodynamic/hydrodynamic status of the global boundary conditions that determine the concurrent array of weather patterns" – and corollary three are not directly related to the axioms for landscape interpretation. Another (climate is a nonstationary time series and its corollary, that there are no true climatic "normals") is related to landscape interpretation Axiom 7 of constant change. Bryson's axiom that environment and climate change on timescales from near instantaneous to geological is linked to Axiom 9 (scale dependence). Its corollary, that there can be no perfect environmental analogs over the past million years, is also related to the maxim of constant change. The final axiom of Bryson (1997) relates to the deviation of microclimates from macroclimates, and is relatable to individuality and constraints (Axiom 4).

2 Place formation and landscape interpretation

In ESS various processes of mass and energy flux lead to spatial differentiation and structuring. Selection phenomena – including positive feedbacks between forms or structures and processes – preferentially imprint certain features on the landscape, reinforcing the spatial structuring. Coalescence further solidifies places linked by functional relationships and/or characteristic traits. Coalescence may be a byproduct of emerging flux networks, based on key network nodes and/or source or sink zones for particular mass and energy flows. Coalescence may also occur due to agglomeration, preferential attachment, symbiosis or other ecological cooperative mechanisms, or other positive feedback phenomena.

Mutual adjustments are key to place formation in this framework, as evolving morphologies and structures influence processes, and vice-versa. The axioms also incorporate the role of material constraints. At any given time, system development must occur within boundaries associated with geographical space, energy, mass, and resource availability – though those resource or evolution spaces may be changed by both external forcings and the system itself.

Place formation is ongoing and dynamic, and though these guides to landscape interpretation are best suited to stories of divergence, they recognize that place formation and spatial structuring are reversible and that convergence can occur. Finally, place formation manifests at a range of scales. For geography and geosciences, this may range from (say) a soil pedon or vegetation patch up to subcontinental scales in the spatial domain (though relevant processes and controls may also operate at smaller and larger scales). Temporally, scales could conceivably range from the rates at which key processes operate to the time spans between major global-scale CREs.

The interpretive model is illustrated by outlining place formation with respect to soil types (at the scale of soil map units or polypedons) of the Inner Bluegrass region of central Kentucky. Figure 6 depicts the specific phenomena of the case study in the context of the conceptual model (compare to Figure 1). The Inner Bluegrass story has unique aspects, but a similar narrative framework could conceivably be applied to any landscape or ESS.

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