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GEOMORPHIC ANALOGS AND CLIMAX MORPHOGENESIS

by

H. F. Garner

Current geomorphic thought encompasses the idea that climates modify landforms. King (1953) was an early advocate of this concept though he subsequently (1957) expressed doubt that climates affect hillslopes definitively. And among those who have recently taken a positive view (e. g., Tricart and Cailleux, 1955; Cotton, 1958; Garner, 1959; Hack, 1960; Chorley, 1962; Bigarella, 1965; Schumm, and Lichty, 1963; Howard, 1965; Garner, 1966) there is sufficient disagreement to establish that the nature of climate control is not fully understood.

The problem is as old as geology. How does one determine specific climatic effects that will serve as analogs, when said effects are known to be imposed over immensely long periods of time? Clearly, observers are hampered by their necessarily short-term perspective (even with access to so-called vigil networks). They are additionally plagued by an inability to gage the relative genetic significance of an event or effect observed within a particular setting, even when its statistical frequency of occurrence is known (see Frye, 1958; Garner, 1963b).

These analytical difficulties should diminish if the following requirements (listed in order of subsequent discussion) are met. (1) We must discriminate between **meteorological climate areas** and **morphogenetic response areas** which are rarely coextensive as said climates are generally defined. (2) We should abandon the apparently popular assumption that the existence of a meteorologic climate area is **a priori** evidence that the landscape therein is in some form of dynamic equilibrium with that climate. Environmental equilibria are not achieved quickly in most instances and Pleistocene climatic history precludes the present general occurrence of said equilibria. (3) We must learn more of the nature of environmental systems equilibria as aspects of a space-time continuum, for such equilibria constitute the only plausible genetic relation between landforms and climate that could provide analogs. Indeed, several physiographic and meteorologic reasons exist for the selective distribution of equilibrium morphogenetic expressions **within** the meteorologic climate zones **where they do occur**. (4) Ultimately, we must consider that the mere statistical magnification in space and/or time of isolated, brief, degradational incidents and effects does not reasonably approximate long-term regional morphogenesis. **A climatically valid analog can only occur as a product of long-term agency interaction under morphogenetic controls that develop as the conditions endure.**

Meteorologic versus Morphogenetic Criteria

A meteorologic climate area is a geographic expanse within which a given range of atmospheric parameters have been recorded — e. g.

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averages of precipitation, temperature, cloud cover, etcetera. Such climatic areas are depicted on the climatic maps of geographers. And they are useful when the issue is one of immediate utilization — e. g. crops, habitation, etcetera. Unfortunately, geomorphologists commonly select meteorologic climate areas for analysis with the stated expectation that landforms, processes and deposits therein will fall within a particular climate-keyed pattern. The general presence of relicts inherited from former environments, in itself, makes said expectation unrealistic. But relict recognition is the root of our problem.

Most meteorologic climate areas are too broadly defined for precise morphogenetic analysis. And the excessive diversity of geomorphic reactions under specific meteorologic categories is dramatically demonstrated by variations in vegetal cover. For example, Schumm and Lichty (1963) discuss erosion and deposition under **semiaridity** (meteorologic) in a low-relief area of southwest Kansas vegetated by grass and some trees. Under the sub-heading, "Erosion and sedimentation in a **semiarid** environment, Lustig (1965) discusses an area with orographic precipitation variations from 3 to 13 inches and corresponding floral changes from lowland sage and barren areas to upland forests of juniperpiñon and bristlecone pine. Leopold *et al* (1966) term a New Mexico study area **semiarid** in the title, elsewhere (p. 195), "arid", and say that plant cover ranges from barren sandy-floored washes to sparsely vegetated interfleuves (the latter is a "woodland association, including juniper, piñon, sage, and a low-density understorey of grasses.") Annual rainfall there averages less than 10 inches. Typical of geographic treatments is that of Bartholomew (1950) in which, in areas designated **semiarid** southwest of Colorado Springs, Colorado, there are barren lowlands, lowland areas with sparse sage, greasewood, bunch grass, prickley pear and chorro cactus groundcover, scrub oak and salt cedar foothills vegetation and upland coniferous forests.

It is too much to expect a unified morphogenetic picture from data assembled within vaguely proscribed meteorologic settings. As noted by Quinn (1957), Garner (1959a) and Bigarella (1965) the only overt phenomenon that readily demonstrates **and maintains** the climatic unity or disunity of a region is the groundcover — plant, ice or none. Unlike meteorologic climatic criteria such as rainfall and temperature ranges or ratios, plant responses are relatively unambiguous. Glacial ice is much the same. The proof of the effective condition is in the pudding, so to speak. As Tricart and Cailleux point out (1955, p. 67), a given area includes as many major geomorphic settings (genetically) as it does major degrees of plant cover, regardless of the stability or diversity of recorded atmospheric-climatic parameters. Gregory and Brown (1966, p. 238) reach a similar conclusion.

Not all vegetal diversity cited above is of equal morphogenetic significance. But the observations of Bennett (1939) clearly demonstrate that major changes in erosion rates equate with barren, grass-covered

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and forested areas. His data further show that the critical first-order morphogenetic change (a 1725-fold increase in erosion and an 800 per cent increase in runoff) is that from continuous plant cover to discontinuous plant cover without particular regard to specific taxa. Thus, there either is continuous cover, and direct access to bare land surfaces by atmospheric agents is restricted to watercourses, or there is discontinuous cover, and access to bare land surfaces is essentially general. Grassland appears to be the most continuous plant cover that can survive a relatively low effective moisture situation. And for all the immediate limitations they impose on detrital load acquisitions, eolian activity, overland flow and sediment deposition, the sparse desert xerophytic plant assemblages might as well not occur at all.

The various major expressions of plant cover constitute the only **immediate** non-glacial response to climate that, once established or eliminated, is not materially changed by weather or seasons. If present it is not usually eliminated by drouths and if absent it is not established by unusually wet years. A rain in a barren desert which gives rise to flowers that die in a few weeks, materially no more alters the general vegetation state than a drouth which merely kills the diseased trees in a forest. As a consequence, only those atmospheric shifts which protractedly displace or replace plant cover over a region are morphogenetically significant.

It is concluded that plant cover and the absence of same are the two principal non-glacial conditions directly relatable to climate which are of sufficient duration and surficial influence to protractedly alter landforms and/or deposits **in a special manner**. Morphogenetic study areas should therefore be delineated by these particular degrees of plant cover.

The Morphogenetic Mechanism

According to Cotton (1958) a morphogenetic system consists of a group of agencies or processes interacting under a particular climate to produce a particular landscape. Climate, in present context, is taken to be the atmospheric condition which evokes a single vegetal response in terms of per cent ground cover. Such morphogenetic areas tend to be elevationally restricted unless they occur within very broad, intense, geographic-climatic belts. Thus, in Ecuador, in the doldrum belt of calms, forests range through some 10,000 feet of elevation. In southern Peru and northern Chili barren deserts have a similar vertical scope. Broad, Horse-Latitude deserts such as the Sahara are essentially barren throughout, regardless of elevation. Temperate forests before the advent of man were the densely vegetated counterpart. Some grasslands (stepps) are very extensive. But elsewhere uniform ground-cover occurs in relatively narrow strips and patches.

Within vegetally homogeneous regions agencies of morphogenetic systems respond to groundcover by functioning at particular magnitudes, rates and in particular places. This applies to eolian and fluvial

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erosion and deposition, weathering, profile soil development, meteoric water infiltration, solifluction and mass movement, to name several interrelated phenomena. In the presence of specific types of groundcover, various interacting agencies cannot exceed certain levels of intensity with any degree of frequency. Given time, this limitation establishes an equilibrium character for each related process and hence for each product. Climate does not act solely through plant cover, for such phenomena as the groundwater table tend to reflect the gain or loss of groundcover. But plant cover is directly involved in the movement and effects of the main agencies of erosion and deposition, notably wind and overland water flow. Thus in areas of heavy plant cover, flow friction on hillslopes and flat interflueves restricts effective fluvial erosion. Accelerated flow is limited to depressions which eventually become watercourses. The invariable water surplus forces the extension of resultant channels to or beyond environmental limits. Channeled runoff is therefore an integral part of the humid equilibrium relation. But in barren deserts overland flow is not confined to depressions. It is erosively curbed by excessive detrital loads and spatially limited to uplands because evaporation and infiltration leave no water surplus. Thus, as Gignoux (1955, p. 3) notes, deserts are not drained. Neither are they channeled toward their margins. Desert morphogenetic equilibria therefore simply cannot include systematic, external channeled drainages (see Carlson, 1966; Garner, 1966a).

Under the influence of the various types of groundcover, distinct morphogenetic systems **may** create distinct landscapes. For this to occur the systemic activity must be prolonged. Where it is greatly prolonged, environmental equilibria for agencies and products may be approached. But where environments are but recently instituted, little-modified relicts of former environments are invariably present. **Such relicts reflect alternative equilibria and they render associated processes (e. g. runoff) atypical of the existing morphogenesis and to that extent create a measure of disequilibrium.** Most morphogenetic areas include features showing various degrees of equilibrium.

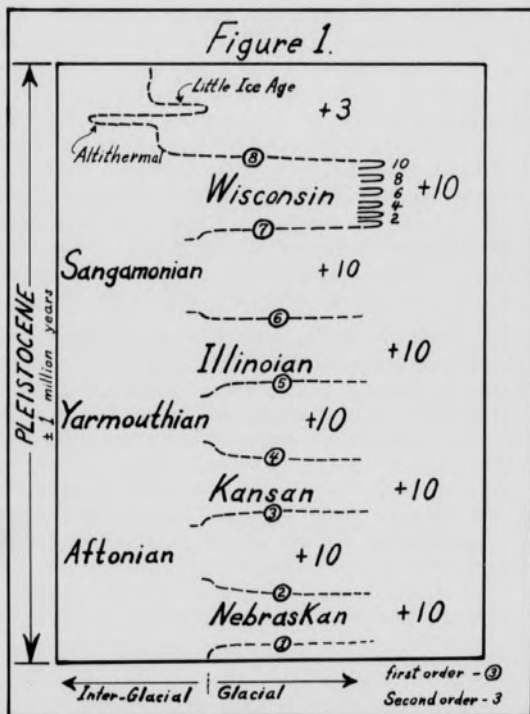
Morphogenetic Area Displacement Frequency

There is abundant evidence that climates have changed. How much and for how long is rather well indicated by the glacial aspects of the Pleistocene record. And there is abundant indication that the glacial changes were accompanied by changes in plant cover in nonglaciated areas. These adjustments thus provide an indirect measurement of the amount of time various morphogenetic systems have functioned and thereby indicate the climatic distinctness of the results.

During the approximately one million years of the Pleistocene Epoch there were at least four major glacial stages and at least three major interglacial stages. It is here assumed that each major onset or withdrawal of a continental ice sheet reflects a first-order climate change. In this manner there were **at least** eight such changes during the Pleistocene (Fig. 1). And on the basis of geographic extent, the

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last glacial stage (Wisconsin) was the briefest and weakest of all the North American glaciations. Yet (Frye *et al*, 1965) recognize at least six Wisconsin glacial advances and at least five intervening retreats superimposed on the main glacial scheme. Assuming that each second magnitude ice fluctuation reflects a second-order climate change, there were at least ten during the Wisconsin (Fig. 1). And assuming that the longer and more intense pre-Wisconsin glacial stages had at least an equal number of second-order glacio-climatic fluctuations, a total of at least 40 second-order glacial climate changes are indicated for the Pleistocene Epoch.



As noted by Bigarella (1965) interglacial stages were also not climatically uniform. The 8,000-10,000 year interval since the disappearance of Wisconsin ice includes the Altithermal and the Little Ice Age (to note two changes of probable second-order magnitude). Since the duration of prior interglacial stages was apparently longer than the related glacial stages one may conservatively assume as many second-order interglacial climate changes as there were second-order glacial changes. This adds an additional 30 second-order Pleistocene climate fluctuations to the 40 already cited (Fig. 1). Inclusion of three

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post-Wisconsin changes brings the total to **at least 73** second-order and 8 first-order climate changes in the past one million years.

It is apparent that few regions on earth escaped repeated morphogenetic change during the Pleistocene Epoch. The majority of existing morphogenetic areas are so recently emplaced that morphogenesis has hardly modified the landscape. In many cases an environmentally homogeneous plant cover (climax flora of botanists) is not yet even established. In Arkansas, for example, prickly pear cactus clings to patches of rocky, very dry ground in a region otherwise characterized by maple-oak-hickory hardwood forests with grassy mulch ground-cover. The relation presumably reflects prior aridity.

In south Ecuador as noted by Garner (1966b), orchids grow in the tops of cactii in the coastal desert. The orchids denote a very sharp atmospheric temperature-inversion boundary and accentuated air moisture exists 15-20 feet above ground (20-30 feet above sea level). The growth sites are in the path of prevailing onshore winds and the nearest rainforests are 25-50 miles inland and upslope. It seems unlikely that the orchids could have migrated upwind into a desert. Yet orchids yield the smallest of all seeds, readily moved by birds or weak air currents. The desert-dwelling air plants of coastal Ecuador therefore probably mean less in terms of climate change than the cactii in adjacent deciduous mahogany forests which suggest increased humidity.

Even a conservative estimate that omits minor variations shows Pleistocene climates have changed frequently. Most regions, as Tricart and Cailleux (1955) note, include landscape relicts of prior environments being acted upon by existing morphogenetic systems. The statistical probability is thus remote that even a uniformly vegetated area will ubiquitously contain landforms genetically reflecting the enclosing environment. But environment space-time considerations may permit the precise location of climatically typical phenomena.

Climatic Space-time Continuum

Climates in their immediate morphogenetic responses (plant cover types) have discernible geographic extents. Any change in the size or location of an area typified by a particular groundcover gives the correlative morphogenesis a finite duration (intensity) **in those places**. The climatic typicality of the results is best measured in terms of product-agency equilibria relative to the existing morphogenetic system. Specifically, the vegetal control determines the equilibrium characters of the related processes and their products. The duration of effective control determines the extent to which the processes and heir products approach equilibrium. And the degree of equilibrium attained determines the extent to which the processes and products typify the specific morphogenesis and related climate.

Botanists use the term "climax" to express a floral association in equilibrium with an environment. Sensius (1958) applied the term to

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soils in environmental equilibrium and it is here extended to other morphogenetic features following the earlier practice of Tricart and Cailleux (1955, p. 142). In this context, a search for climax morphogenetic effects must acknowledge the fact that morphogenetic response areas move. A given response area will show the least genetic relation between plant cover, landforms and processes in the region into which the characteristic plant cover has just moved. Conversely, the most nearly climax expressions should occur where a response area has endured the longest — climatic nuclei of Garner (1959b).

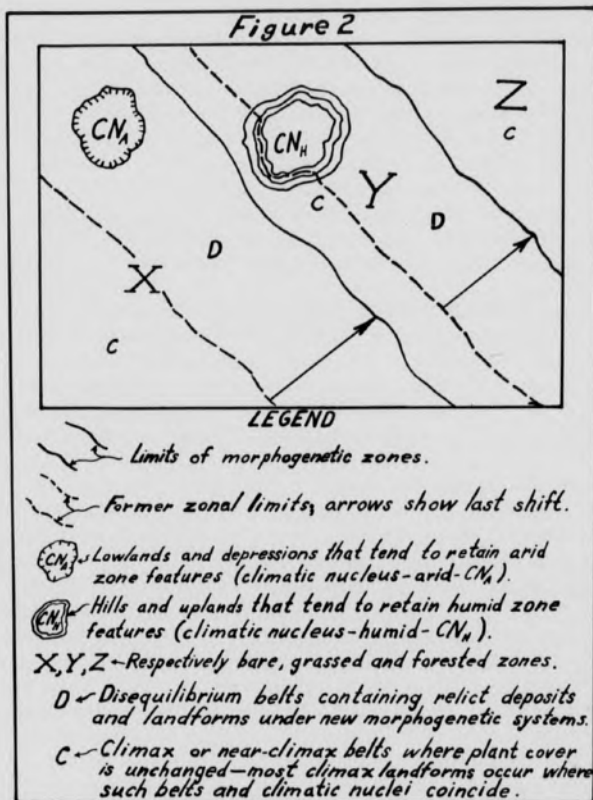
The space-time attributes of climate reflect the tendency for the most distinctive vegetal responses to occur in patches, zones or geographic belts. Büdel (1959) and Butzer (1957; 1958; 1959) propose wide swings in climate belts in low latitudes during Pleistocene glacial oscillations. They equate glacial episodes in the northern hemisphere with pluvial times near the equator. Tricart and Cailleux (1955) equate glacial episodes with extensive, low-elevation equatorial aridity as do Garner (1958; 1959; 1966) and Bigarella (1961; 1965).

As one might expect, an examination of climate zones (e. g. the barren Sahara) discloses marginal transitions where non-climax floras occur. Relative to this, it seems clear that the most typical morphogenesis of a given plant cover will exist well within the area where the flora is at climax. Therefore, regardless of which direction a morphogenetic area has most recently moved, processes and products in area margins will display at least some environmental dis-equilibrium and probably a great deal. Where it is possible to ascertain the direction of morphogenetic area shift (Garner, 1967), on a low relief terrain the greatest equilibrium relations will occur toward the trailing edge. Climax features, if attained, will occur there also. Conversely, the greatest dis-equilibrium relations should occur along the leading edge of the displaced area (Fig. 2).

In an earlier discussion of morphogenetic area displacements (Garner, 1959b) the writer noted topographic environmental intensification and perpetuation. Adiabatic and/or orographic effects virtually insure that localized uplands below the perpetual frost level within relatively broad vegetated zones will tend to be most densely vegetated and tend to remain so — humid climate nuclei, (Fig. 2). Subsequent study (Garner, 1966b) verified the prior indications and documented the perpetuation of dense plant cover, chemical weathering, and humid drainage forms in near-climax expressions on isolated mountains and plateaus rising above the often-arid Venezuelan-Brazilian shield. Bigarella (1965) recorded similar relations in central and southeastern Brazil. And Cole (1960) noted the migration of floral types following climate change from aridity to humidity in the same region.

In North America, the ridge-top bauxite deposits of north Georgia and eastern Tennessee signify protracted leaching under plant cover (Personnal communication, 1966, R. H. König). Allied morphogenesis possibly endured there throughout the Pleistocene, and one immediately

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notes the associated thick lateritic clay soils, high-density drainages, and feral landscape extending into eastern Kentucky. Periodic aridity in lower land areas to the west and south (Garner, 1959c; 1967) during the same interval establishes a space-time climatic relation like that suggested herein with near-climax humid relations concentrated on the intermediate uplands.

The converse of the vegetated morphogenetic situation prevails in relatively broad arid regions of limited elevation scope. Therein, localized lowlands and coasts tend to be most barren and to remain so (Fig. 2). The causal relations for this were outlined by the writer (1965; 1966b) and empirical verification have been provided by Garner (1959a, 1966a), Bigarella (1965) and Mabbutt (1966). Near-climax arid aggradation relations were noted in the lower coastal Atacama Desert of Peru and northern Chili, portions of central Australia and in some intermontaine depressions of the American southwest.

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In spite of local "topographic" advantages that may preserve near-climax relations for our inspection, evidence suggests this is rare. Butzer's studies of the Sahara (1957) show that much of that great barren area supported at least grass cover and a velt mammalian fauna several times during the Pleistocene. Conversely the work of Grove (1958), Forbes (1958) and Prescott and White (1960) shows that free blowing sand and barren lands periodically extended south of the present Sahara. Garner (1959a; 1967) indicates vegetal shifts of 200-500 miles in that region and similar morphogenetic area displacements in North America and elsewhere. Mabbutt's (1966) studies in Australia indicate comparable relations.

The extensive geographic displacements of morphogenetic areas recorded in broad regions of limited elevation range contrast sharply with the very limited shifts of many zoned climates on steep slopes noted by Garner (1965). If the latter analysis is correct, lateral displacements of morphogenetic areas correspond to vertical shifts of atmospheric moisture-temperature zones. The rate of change is inversely proportional to the slope and the frequency of change is directly proportional to the proximity of mean land elevation and the proximity of the mean location of the nearest morphogenetic area boundary. In the last analysis, these relations show that climax morphogenesis is truly rare and near-climax relations will be selectively disposed **within** morphogenetic areas **where they occur**.

Climax Morphogenetic Expressions

This is a topic about which one is tempted to say much and should probably say little. It is also an area of interest that needs the most discriminating, selective and quantitative treatment and has received the least. There has, in fact, been much indiscriminate geomorphic quantification in the sense that landforms, deposits and agencies of diverse origin — some contemporary, some relict — have been measured and mathematically "lumped" into numerical conglomerations definitive only of some composite hypothetical environment. Meaningful quantification requires sound theory and the basic ideas of the morphogenetic system and dynamic equilibrium are in a state of some confusion.

Howard (1965) discusses the "erosion system" and relates it to Strahler (1952) but Tricart (1951) seems more correct where he attributes the original concept to A Cholley (1950). Tricart and Cailleux (1955, p. 42) expanded the concept to include depositional phenomena, renamed it the "morphogenetic system," and as restated by them, Cotton (1958, p. 125) and herein (The Morphogenetic Mechanism) the idea seems clear enough. Relative to the morphogenetic system, dynamic equilibrium merely expresses the state toward which the interacting agencies and processes evolve under a particular vegetal condition.

The findings of the writer (1959a; 1965; 1966;) are in substantial agreement with those of Cotton (1958) and Langbein and Leopold (1964) that dynamic equilibrium expresses a tendency toward minimum total

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work and equal area energy expenditure. These criteria seem preferable as standards of morphogenetic attainment to those advocated by Hack (1960) who discusses dynamic equilibrium (p. 80) where, "... topography is in equilibrium and erosional energy remains the same," where (p. 89) he equates "equilibrium topography" with "erosionally graded" topography.

The expression "graded" has probably sponsored more diverse opinion and less ultimate unanimity than any other word in the geologic literature. Moreover, in the morphogenetic system — which is open — erosional energy necessarily changes constantly as the system matures and the character of the processes evolves. But the merit of the expression "dynamic" is that the steady state is probably never attained. Furthermore, the developing equilibrium expressions are of both process and product and the dynamism is in part a result of feedback between these. Thus elements of the system tend to reflect systemic as well as individual equilibrium. Hack (1960, p. 85) claims, "... that many elements of the landscape are in dynamic equilibrium with the processes acting upon them." This is suspect as an operative regional generality. It holds an element of validity for some climatic nuclei. But the earth's regional Pleistocene morphogenetic instability precludes more than a local climax lagacy.

As Howard (1965) notes, the general existence of time-independent landforms (climax features) would deprive the geomorphologist of the cyclic landscape concept. It would also inhibit our subjective consideration of environment in a space-time continuum. Fortunately, the steady-state **regional** relation does not seem to exist. **Local** near-climax relations can provide us with climatic standards for comparison with the countless landforms and deposits in varying states of dis-equilibrium. The same climax phenomena constitute the geomorphic analogs which can serve for evaluating paleo-environmental relicts, both those which truly typify particular climatic conditions and those which are transitional. In this context, the morphogenetic cycle provides the framework for analysis.

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