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SPACE AND TIME SCALES IN GEOMORPHOLOGY

INTRODUCTION

A long time after G.K. Gilbert (1877) presented the concept of dynamic equilibrium, W.M. Davis (1899) formulated the landscape's way to destiny (being disturbed by tectonic or climatic changes). Leopold & *alii* (1964) described the aim of dynamic geomorphology and Dury (1975) returned to a catastrophic theory of events; Denys Brunsden (1990) put forward ten spectacular commandments of geomorphology. The last two of them, relating to about sensitivity to change and the ability to resist increasing impulses, formed, indeed, a «sack» full of various relations. «Let's open this sack» - In this paper I explore some of Brunsden's ideas, keeping in mind, that observations are inherently intertwined with theoretical presuppositions (Rhoads and Thorn 1996).

The complicated architecture of the earth's surface is a joint product of various forces, which mobilise different substances. But relief itself is not a substance, only a geometric shape of the Earth's surface. This product of various transfers of matter, in the mean time, forms a geometric base for all on going transportation of material in the environment.

The elements of landscape we may see, touch, measure -belong to those features of the environment, which are changing very slowly through time.

To explain their origin and evolution the geomorphologist examines substratum (structures building the relief) as well as processes of construction and destruction. Other scientists, geologists and geophysicists, study the same context, but from different perspective (cf. Twidale 1996).

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With reference to the various space and time scales of a landscape's form we should consider that different types of scale should be commensurable (Kirkby 1990, Church 1996). Going from a smaller to a larger spatial scale, when explaining landforms, we must replace stochastic models with deterministic theories and dynamic models. When studying large samples we use extensive methods, on the contrary when studying small samples - intensive methods. One of the most difficult methodological questions is generalisation or transfer of methods and results from small objects to large ones (Richards 1996).

SPATIAL SCALES

Using Brunsden's (1996) terminology we may distinguish mega-, macro-, meso, micro-, nano- and pico-forms. Here, one common feature is their coexistence in space, although the length of their life is different. This means that another common feature of forms of different orders is their equal exposure to external factors and simultaneous transformation. A frequent assumption made by geomorphologists is that the larger forms are more stable and the pico- and nano-forms are ephemeral. Therefore, the greater forms should be older in origin than the smaller ones.

Among landscape elements we can distinguish various forms of genesis, created by different independent factors either of tectonic or climatic origin. In the second group are forms created by gravitational forces (by water, ice, mass movements), difference in pressure (by wind) or difference in density (by freezing, leaching, liquefaction).

The majority of forms was initiated or developed by interaction of various factors e.g. fluvial processes and mass movements, karstic processes and piping etc. This simultaneous, alternate or consecutive passing of various thresholds in a given site creates polygenetic forms.

One of the spatial differences in form evolution is a multifold action of processes. Different processes may act parallel, accelerating the development of a linear pattern of the forms. This is the case of the Scotch mountains, where the direction of fluvial processes and ice cap expansion were parallel. Two different factors may also act in opposite directions, for instant, the Polish lowland has been drainèd toward the north and invaded several time by the Scandinavian ice sheets. If two different factors act in transversal di rections, then, for example, the dune fields may be formed from sands blown perpendicular from the braided river channels.

Forms of similar origin may have different areal extent, starting from localised features controlled by lithological differences or by local heavy downpours, up to great forms or form complexes, mainly related to morphostructures or morphoclimatic regions.

There are various types of spatial pattern of forms, controlled by endogenic or by exogenic processes. Endogenic processes produce active tectonic structures, which, depending on differentiated uplift rate and inherited relief, show the largest depth and density of dissection either at their margins (cf. the Western Ghats bordering the Deccan Plateau) or, in contrast, in their central part (central Himalaya). In the first case the interior of the plateau still preserves the inherited mature landscape.

A different, convergent spatial pattern is represented by a fluvial system (Schumm 1977). It is characterised by a directed transfer of water and matter along water courses. The slope and channel subsystems are interrelated, but their time of response and time of passing thresholds may differ. Both subsystems are either sensitive to various forming events (slopes – to downpours, channels – to continuous rains) or they may react synchronously, during catastrophic events (Starkel, 1976).

A completely opposite, divergent system is exposed after the decay of an ice sheet. The radial pattern of subglacial channels, striation, eskers and drumlins mark this divergent pattern.

TIME SCALES

Relief is a product of long evolution, it is a result of coexistence of forms of various age. Many authors distinguish various time scales (minutes, hours, days, years, decades, millennia, millions of years) and relate to them the forms of various sizes, from ripples to the mountain ranges and lowlands (Thornes & Brunsden 1977; Barsch, 1990).

Recently, Brunsden (1996), after discussion with Yatsu (1993) and others, has modified his concept of events (Brunsden, 1990) and identified instantaneous events (natural hazards), short term events (of order of centuries), long-term events (glacial stages) and geological events (ice ages, orogenies). Each of these «events» should be characterised by a process intensity higher than the mean, and preceded and followed by a steady phase. During every effective event the threshold of the form stability is passed (Wolman & Gerson, 1978). During longer phases or cycles some thresholds are also passed. But can we measure the limits of such long events using existing methods, both in time and in space?

In my opinion there is no reason to change the meaning of event and extend it over longer time units. Such longer «events» incorporate events of lower order (shorter duration). Every longer time period is composed of shorter events of various intensity and duration. The last ones expressed in landform evolution (called formative, effective or extreme) may be concentrated in various time scales which should be named with terms commonly used in geochronology.

As an alternative I present the following hierarchy of time scales, expressed in terms of relief evolution:

A) Singular extreme events represent the lowest level and exist ageinst a background of secular processes. The extreme event may vary in duration from seconds to days or months and cause an effective or even a creative change of form. These events are generally incorporated in the existing climatic regime (e.g. floods, landslides) or have a character of geocatastrophe or cataclysmic event (Baker 1988) with recurrence intervals from decades to millennia.

In contrast the secular processes operating over a duration of days to years and centuries are represented by processes of lower intensity, continuing during the interevent or steady period. But even during such periods there are many events associated with active slope wash, solifluction, leaching, deflation etc., when the intensity of processes is still higher than the mean value, measured as the total product of diurnal or annual activity.

B) The clustering of events can be assigned duration from years to decades and was described from the present century as well from the past (Grove, 1979; Starkel, 1984, 1996). Kirby (1987) calls this the «Hurst effect». Heavy rains, floods or tornados, repeating in the consecutive years, may cause a substantial change in transformation of the forms, before the full relaxation follows.

C) Phases with high frequency of the extreme events of duration from centuries to millennia. These may cause substantial disturbances in the geomorphic systems. Such phases have been well recognised during the Holocene in several advances of mountain glaciers (Grove, 1979; Karlen, 1991), parallel reactivating of solifluction processes and other mass movements (Gamper, 1993; Kotarba, 1995; Starkel, 1985), and in transformation of alluvial plains with channel avulsions (Starkel, 1991).

D) Cyclic changes (during the Quaternary) of duration from tens to hundreds of millennia, which include stages of various climatic or various tectonic activity and are manifested in alternate, different process complexes and their intensity, with numerous lower range phases, clustering and events. These alternate stages are reflected in such features as sequences of terraces and piedmont surfaces (Soergel, 1921; Penck, 1924; Starkel, 1986b), in alternate periods of intensive denudation and in soil regolith formation. Due to superposition of cyclic climatic changes over tectonically stable areas, usually in a former periglacial zone, we observe that mainly the sediments and forms of the last cold stage are preserved (Dylik, 1953; Starkel, 1987a). According to various concepts, the highest rate of transformation in the fluvial system takes place during the transitional phases from glacial to interglacial (Jahn, 1956; Knox, 1976).

E) The above described cyclic changes may also form a clustering of a higher order, among them glacial epochs (Quaternary) or orogenic phases millions of years long, responsible for the total transformation of landscapes in a regional, continental or global scale (King, 1953). In a general sense for example, the Alpine orogeny was the most important «event» in the evolution of the Mediterranean landscapes.

FORMS TROUGH TIME

In discussing the evolution of the forms in time, we should distinguish three parameters of their age: time of the onset of their creation, time of their formation and expansion, and time of adaptation (transformation).

Time of creation is an initial stage when, due to climatic or tectonic events (or their clustering) or even due to the passing an intrinsic threshold (Schumm, 1977), a new form comes to existence.

Time of formation is a total period of a build-up and includes several consecutive events with relaxation phases in-between. With older forms (e.g. developing during Pliocene, mid-Pleistocene etc.) this may include a longer time unit, when this form reaches its stage of maturity.

Time of transformation of old landscapes or adjustment is especially long in the case of river valleys and slopes, which even during the mid-upper Quaternary have been adapting several times to alternating climatic conditions. Each change to a periglacial climate provoked reactivation (rejuvenation) of slope forms, while each change to temperate forest climate caused their stabilisation and soil formation (or dissection).

In the case of tectonic change we observe an uplift followed by rejuvenation (dissection) of existing relief or fossilisation (aggradation) connected with the subsidence.

Relations between age and size of the forms are not simple. The traditional assumption and belief that the greater forms are older and smaller forms -younger (group A) is not valid under all circumstances. There are several deviations from this assumption and these may be exemplified as follows:

B) Larger forms are younger than the inventory of smaller forms. This is a case, when an old erosional platform has been dismembered by active tectonic faults (in California, Meghalaya Plateau).

C) A whole landscape is composed of young features, which are dominated by meso and microforms. This happened during continuous intensive uplift of the Neogene-Quaternary unconsolidated deposits at the margin of Alpine orogenic chains (Southern Italy, Romanian Subcarpathians - Starkel, 1978).

D) A structure controlled relief may be either totally inherited from a distant era (the Australian interior), and the forms of various order are generally old (D_1), or may result from the dissection of structures and the resistant finer beds start to be manifested much later (D_2). Resistance of bedrock controls the rate of transformation. Therefore, depending on variations in lithology and tectonics the relations between the form size and its age may be different and even oscillate from place to place.

E) A landscape generated by a large, cataclysmic event may be composed of young forms-great and small ones, of similar age.

Old and young forms exist together and develop in parallel (Starkel, 1987a). This coexistence is well visible especially in the landscapes which undergo rejuvenation. There, we find side by side the inherited upper valley reaches which in higher mountains are or were occupied by glaciers (Klimaszewski, 1960). Another example is the Meghalaya Plateau in India where a high uplift rate and resistant limestone beds facilitated the preservation of shallow and mature valley heads (Starkel, 1978).

But there are some specific exceptions from this diversified picture. Such landscapes as the Western Siwaliks reveal structural elements from their first formation, when a rapid rise of folded sedimentary beds exposed the more resistant beds from the very beginning (Starkel, 1978). Such landscapes may be called «mature from birth».

An opposite situation exists on the fully unconsolidated, Neogene-Quaternary, clays and sands of the eastern corner of the Caucasus Mts where the denudation rate of gentle slopes is high. We may call this landscape as being «young till late maturity».

CONTINUOUS ADAPTATION

From the previous discussion on relief evolution through time we conclude that the continuous adjustment of inherited forms to new conditions is an essential part of all geomorphological considerations (Starkel, 1987a). In the present-day landscape various generations and groups of forms coexist:

older (inherited) forms, adapted
old (inherited) forms, dissected
old (inherited) forms, fossilised
new (superimposed) generation of forms.

Budel (1977), discussing the morphogenetic zonation of the earth, differentiates between the clima-genetic and clima-dynamic approaches. Brunsden (1990), in the last two commandments of geomorphology, distinguishes a great spatial variety in sensitivity to change reflecting relations between resisting and disturbing forces and, then formulates a rule that «the landscape's ability to resist impulses of change tends to increase with time».

This rate of adaptation of each landscape is related to climatic and tectonic changes. It also depends on rock resistance and on the relations between the effectiveness of extreme and secular processes.

The climatic changes influence the transformation of different systems at various scales. The slopes of the former periglacial zone have undergone a relatively small transformation during the Holocene (Dylik, 1967, Starkel, 1987a). In contrast, the river channels reacted to every change in water discharge and sediment load (Starkel, 1983, 1990). Therefore, the alternation of meandering and braided channel pattern is particularly well expressed in the middle valley reaches.

The rate of uplift and subsidence is directly reflected in the incision rate and later in the denudation rate (Selby, 1974; Starkel, 1987b; Yoshikawa, 1985).

Rejuvenation (dissection) of every highland or plateau expands mainly from its margin (base level) while the upper valley segments remain still not dissected and preserve inherited relief features. But opposed to this, rejuvenation may also start from the upper section. The higher gradient of valley heads and concentration of drainage make formation of a badland network possible.

The non dissected or non fossilised older forms, nevertheless, are being incorporated into the existing landscape system in various ways. The most diverse incorporation is on the slopes and in the valley floors. Slope fragments of various origin act as one slope system. This happened to the sides of the former glacial troughs or to the cryopediments over the Mongolian Plateau (Kowalkowski & Starkel, 1984). The new valley network created after the ice sheet decay is composed of the segments of various origin (Koutaniemi & Rachocki, 1981; Koutaniemi, 1991). Many of the former wide streamways take the form of underfed river valleys (Dury, 1964).

A supplementary factor which disrupted the continuity in the slope or river channel development and even caused a full dispersion of processes over the system is the anthropogenic one. The terraced slopes with cart-roads, regulated and cascaded river channels - create new space patterns and new thresholds for various processes (Gregory & Walling, 1987).

In the chain of the relief evolution and continuous adaptation, the incorporation of products of the events, of their clustering and of the phases takes place. Depending on the frequency, areal extent and size of transformation the secular (slow and frequent) processes may also produce new shapes of slopes, as well as new forms as cryoplanation terraces, dune fields, karstic caves etc. The extreme (rapid and rare) events are restricted in space but cause substantial changes. One cataclysmic event may destroy the whole construction, until now the enclave of senility. Among them a special role played by extremes which change in time the type and intensity of processes. Several debris flows in the valley floors start and end as hyperconcentrated flows (Costa, 1988). Similar are large landslides; the mechanism of their movement changes both in space and time (Froehlich & *alii*, 1992).

In the slowly transforming landscapes the role of extreme events is different. Besides a distinct rejuvenation, after long relaxation phase new features may finally become incorporated in the inherited relief.

On longer time scales, the phases with frequent events creating the separate alluvial fills become finally incorporated in the Holocene floodplains (Starkel, 1983) that might be easily detected from the Last Cold Stage alluvial fills, interfingering with periglacial colluvia and deluvia.

In this continuous adjustment of the relief an important role is played by symbiosis and convergence of various processes and forms. The symbiosis is expresses by the polygenetic form, created by the co-operation of various processes, acting sometimes in different directions and in different seasons of the year. The convergence of relief features of different origins is relatively rare. A good example is the braided pattern of the river channels, which (1) in some dry valleys of the arid zone may be inherited from the distant past, (2) may reflect the sediment load regime in active gravel-bed channels, but also may characterise (3) a section of high infiltration and sinking of water or (4) a section with formation of seasonal icings (in Mongolia). The combination of various factors is also not excluded.

SEARCHING FOR REGULARITIES IN THE RELIEF EVOLUTION

There are several physical rules describing circulation of matter and regulating for example the evolution of the earth's surface. In reconstruction of the evolutionary chain we simplify and reduce all factors to endogenic and exogenic. For explanation we produce tentative hypotheses and search for evidence (Baker, 1996). The controlling factors are ordered into leading genetic factors (distinguishing events, their clustering, phases, stages ...) and in space (after size, in latitudinal and vertical zones). We evaluate the role of tectonic activity and diversified resistance of bedrock. We try to put all the information into a mathematical model of the land surface development (Lawrence, 1996). One of the latest attempts to order systems mentioned in the introduction, are the spectacular commandments of geomorphology (Brunsden, 1990).

I find that the whole theory of the landscape evolution could be concentrated in the following three principal regularities: A - drive at planation, B - adjustment or adaptation, C - diversity and coexistence. These are characterised as:

A) The hypothesis of planation (peneplain). It is a geomorphological concept of a destiny to which all forms modelled by denudational processes tend. The final stage, defined by W.M. Davis (1899) and H. Baulig (1952), may be reached only in the exceptional cases and is balanced by the concept of perpetual dynamic equilibrium of G.K. Gilbert (1877).

This pathway to destiny is mainly controlled by the rock resistance and stability of the old morphostructures. Therefore, the planated landscapes exist especially in stable cratonic regions of the former Gondwana land.

B) The continuous adjustment (or adaptation) of relief to new conditions is created by endo- and exogenic processes changing their intensity and direction with time. In almost every landscape there are old roots (inherited from the past) and superimposed younger forms (products of events). Going back to the past our knowledge about the mechanism and sequences of changes in time is more and more hypothetical (Dorn, 1996; Starkel, 1991). Most of universal forms like slopes are the joint product of alternate formative and stable phases or of perennial adaptation during thousands and millions of years. Therefore, only as the exception (from the rule) may be preserved the «tote Landschaften» *(sensu* Budel, 1977) mainly related to the penultimate morphogenesis (e.g. Last Cold Stage).

C) Diversity and coexistence

The great diversity of the Earth's surface features reflects the perpetual spatial and temporal variations in energy exchange and transfer of matter, in their acceleration or delay, in continuous destruction and creation.

There exist landscapes with high and low intensity of various processes, with different rates of transformation as well as composed of forms of various origin and age. The complexity of some geomorphic systems may be so high that the linear dynamic model is not acceptable and the system seems to be unstable and chaotic (Phillips, 1996).

Among the intensively transforming landscapes are the ecotonal zones of main morphoclimatic regions and the margins of elevated morphostructures. The lithological diversity and random spatial distribution of extreme events explains the local differences.

Analysing the nature of existence (life) we touch a fundamental question of Creation and Destruction, in which past and future are incorporated.

The old Persian holy book tells what is the Life over the Earth:

...it sleeps in stone,
wakes in a plant,
moves in an animal
and may be fully realised in the man,
sounding the question of existence...
Where is the Relief in this context?
May be... it is the life's playground, created during
the perpetual energy exchange and circulation of matter
showing its resistant but slowly changing face...
...during repeating waking up, falling asleep and waking up...

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In studying the origin and evolution of landscape, we use various scales, both in space and time. Most landforms result from interaction of various factors. The author suggests distinguishing the following effective time scales of landform evolution: formative extreme events and secular processes, clusterings of events, phases of higher frequency of extreme events, cyclic changes of longer duration. The assumption about positive correlation between size and age of the forms is frequently not valid.

The existing relief incorporates forms of various origin and age, which have undergone continuous adaptation to new conditions. The author underlines three principal regularities in relief evolution: way to destiny (planation), continuous adjustment to new conditions, coexistence of diverse forms controlled both by tectonic and climatic factors as well as by lithology.

KEY WORDS: Geomorphology, Space and time scale.

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