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INTERPRETATION OF COMPLEX NATURAL SYSTEMS: THE TAFONI PROBLEM

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I. INTRODUCTION

Defining and interpreting landforms in order to better understand natural systems represents a core topic in Geomorphology. The conflict between the different theories reflects the difficult equivalence of those concepts that sustain scientific reasoning and their differing levels of abstraction when elaborating research hypothesis. The idea of form as an integrated natural system in continuous change has its origins in ancient philosophical and scientific approaches.

The recognition of a minor form emerges with its description as a discreet component of landscape. The knowledge begins with a singularity associated with a particular geographic location, and continues to a status of configuration that results from interactive conditions of permanence and change. Forms called *tafoni*, understood as a morphological complex diversified in different stages, are complex natural systems. Different dimensions of geomorphological knowledge underlie their definitions, categories and interpretations throughout time.

II. CONFIGURATION, PROCESS, RESPONSE

The first interpretations of *tafoni*, with volumetric range from cm^3 to m^3, originated from macroscopic features and the presence of weathering products. The explanation was based on observation of cases and the comparison of their natural development environments. Consequently, concepts used to refer to a type of rock and a natural environment where a cause-and-effect relationship was taking place. Analysis was oriented towards knowledge of the exogenous factor and the control exerted by the material affected during the generation and posterior growth of the form. Since then, the general term *caverne* coexists with specific ones such as *tafone, cavernous rock surface* and *niche*. The presence of some typical morphological features still remains as the universal definition (Gourdie, 2004); these features actually refer to a wide range of landscape forms.

The subsequent differentiation of geomorphological categories took into account, for its interpretation, the meaning of paleo-environmental heritage within the context of landscape's irreversible evolution. Fossilized and active forms were described through case studying, starting with a hypothesis about the behaviour of the surface, prone to continuous degradation. The debate remained about the definition of the cause, either physical or chemical, and so did a consensus about configuration controls, their age, and their complex evolution. State conditions that correspond to the approach based on the notions of morphogenetic system and morphoclimatic zone formulated in the central decades of the 20th century (Cholley, 1950; Tricart and Cailleux, 1965). From this perspective, the beginning of the systematic register of the *tafoni* measurements, in order to infer ages and use the results to reconstruct landscape evolution, reasserts its concept as a natural process/response system —interpreted with a two-phase model (Twidale, 1982). The increase of morphological categories, organised into a tree of basic types which connects multiple configurations, demonstrates the behaviour of a network of complex interactions with different evolutionary trajectories.

III. DIVERSITY, PERMANENCE, CHANGE

1. Morphogenesis nature

The dominant research approach provided results about morphological diversity, a diversity deriving from transformations in space and time, related to the existence of geomorphological thresholds. However, the variability of the state conditions was not an exclusive criteria for the similarity ratio —the root of the geomorphological explanation problem according to the process/form approach (Haines-Young and Petch, 1983; Gerrad, 1984; Culling, 1987). Establishing the conditions of a phenomenon where heritage plays an important role was so difficult that the meanings of terminology in use, the state of equilibrium in natural systems and the study of long-term changes became more relevant. Within this context, the concept of relief forms as complex adaptive systems comes from the reformulation of previous ideas; ideas integrated within the landscape evolution approach (Brunsden and Thornes, 1979; Thornes, 1983) which refer to the complex adaptive systems as open natural systems and to their relationship with multiple processes related to episodic events. Tendencies towards regularity —expressed by the preservation of certain form complexes in geomorphology— or towards irregularity —expressed by the experimented changes that ubiquitously, lineally, or diffusely propagate in the landscape— are outlined. The analysis is oriented towards instability, morphological trajectories and variability patterns: the concept of morphogenesis refers to configurations linked by a series of momentary states, whereas the generative field defines a context of diversification regarding the reference of conditions and origin structures. Statistical techniques have an instrumental value, as they discriminate between possibilities of permanence, transition or change, in the development of the form, with certain confidence limits in one or several case samples. This approach moves towards the integrationof geomorphological, historical and functional approaches, where the interpretation of *tafoni* starts from a polyphasic generative model. Proof of *tafoni* morphogenesis being understood in such terms can be found in several researches from the last decades of the 20th century.

2. Meaning of complexity

In any stage of research, the spatial distribution of *tafoni* delimits rock volumes that have gone through higher material losses than those adjacent to them. Multiple states in continuous change are presented where growth models reveal cascade sequences of creation, persistence, or transformation related to critical configurations. Modern absolute dating techniques verify the existence of an evolutionary dynamic of non-linear behaviour, repeatedly taking place with increasing complexity. The analysis of guidelines connecting origin conditions, dimension, and morphology in space and time attained more relevance.

The key to interpreting the phenomena intervening in the form's development is its condition as an away-from-equilibrium system (Nicolis & Prigogine, 1977; Huggett, 1988). The development of the form tends to create states of order with joined structures and functions that are increasingly complex, but also states of disorder that determine new trajectories. This is in the context of a dynamic time, where complexity is a tissue of order, disorder, and self-organisation (Ibáñez et al., 1995). Mellor et al. (1997) stated that a wide range of processes could be related to morphologically alike *tafoni*. Therefore, they interpreted its long temporal development as four stages. Vidal Romaní and Twidale (2005) also established four steps for basal-type *tafoni*.

The behaviour of *tafoni* combines linear and non-linear phases. Multiple states connecting multiple responses with dimension thresholds —depth, empty volume— towards an increase of the void limited by functionally active designs. The growth rate slows down when the form's size and complexity increase, regardless of the spatial-temporal scale subject to consideration. There is a tendency towards uniformity deviation, where certain components may modify their roles as change agents or undergo modifications faster than others. The acknowledged categories have a meaning within the context of a polyphasic morphogenesis interpreting development as the interaction between persistence, transition and change; a framework in which to analyse the phenomena connecting these categories to the landscape in which they occur. The complexity of t*afoni* reveals the evolution of a self-organised complex system, with varied levels of spatial-temporal connections with regard to the area in which morphogenesis conditions can be defined, and the dynamics of other landscape elements such as residual reliefs, moraines, platforms, escarpments, slopes. In a particular way, there is potential for the relationship between these interactions as well as those of bio-geomorphological complexes to be studied, since these elements are often home to biotic communities.

Taking into account the results from the dimensional analysis and the study of growth patterns during evolutionary stages in different conditions, this phenomenon develops complexity through self-organisation. Occurrence patterns and morphological diversity highlight unstable conditions. *Tafoni* have been defined as unstable weathering systems (Turkington and Phillips, 2004) which can generate configurations corresponding to dissipative structures on any kind of rock or environment (Galán, 2007). From a holistic approach to geomorphological systems, analysing complexity implies a multidimensional approach from the possible generative field. Morphogenesis of voids suggests a relational guideline between constant and changeable states —in the sense of an ability to face changes regarding a previous design.

IV. CONCLUSION

Tafoni interpretation has created a range of nominal categories defined by morphological and dimensional features. Differentiation of types starts from qualitative registers organised by the similarity ratio in different stages. Throughout time, uncertainty about common genesis and difficulty regarding evolutionary patterns has revealed the characteristics of a phenomenon that cannot be reduced to simple parameters. When dealing with an interpretation based on multiple variables and interdependent events, linked to a concept of forms as temporary states, qualitative and quantitative registers within the context of different landscape units highlight its complexity.

The acknowledgement of complexity emerges from local archetype analysis which has contributed to the interpretation of critical situations along with the general tendency to increase rock volume losses. Previous concepts such as equilibrium, or open natural systems stability undergo a reformulation in the context of a geomorphological zone or landscape. *Tafoni* are interpreted according in light of the theory of complex adaptive systems, defined in terms of a conditioned instability which fits into landscape evolution. The meaning of a specific nomenclature is integrated into the non-linear behaviour of natural phenomena, where those irreversible phenomena can be interpreted as dissipative structures.

The potential features of morphological design and the representative dimensions of these phenomena are, regarding the *tafoni*, related to the starting control of potential generative fields; a notion that works as a tool to elaborate research hypothesis. *Tafoni*'s existence allows the differentiation of highly erosionable rock volumes by acting as propagation nodes in precise magnitudes —through its own form— linear magnitudes —through limiting discontinuities— or diffuse magnitudes —through the slopes. It represents a transverse irreversible condition on different scales. Interpreting in a global/local scale, landscape/form, requires a holistic approach towards the behaviour of those elements that host forms, such as blocks, slopes, and watersheds, and those inside its configuration like edges, vaults, or supports, each with multiple possible states.