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PARADIGM SHIFTS IN GEOMORPHOLOGY: TRENDS AND IMPLICATIONS*

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ABSTRACT: In every field of science there have been outstanding achievements which provide a general framework and establish a tradition for future scientific work. Such achievements, called paradigms, are open-ended and permit a modification or a shift to another paradigm to overcome stresses that develop as a result of accumulated anomalies. There has been a sequence of paradigms in geomorphology, starting from uniformitarianism in the late 18th century or the beginning of the 19th century, to a shift to Davisian cycle in the closing years of the 19th century to one of Dynamic Geomorphology, with an open system approach advocated by A. N. Strahler in the mid-twentieth century. The inadequacies and incorrect propositions in uniformitarianism and Cycle concept and only a partial and tardy acceptance of Dynamic Geomorphology principles are discussed in the paper. The contemporary phase of geomorphology actively promoting process studies as an exercise in theory building has not produced significant results and these, at best, appear geomorphic interpretations of laws of physics, chemistry and mechanics, where force, strength and stresses are fundamental parameters. Yet space as a variable in earth science, brings a fundamental difference in the nature of geomorphology as opposed to sciences. Geomorphic expressions of landforms and processes invariably cover large space which is neither homogeneous nor uniform over time. Thus what can be aimed at is the interpretation of the geomorphic behaviour of processes, largely physical and chemical, as they extend over space creating and modifying landforms.

INTRODUCTION

Geology and geomorphology had almost an identical beginning in the mid-eighteenth century. During the last 250 years, geomorphology like geology or geography has undergone a process of tremendous growth, expanding its scope and acquiring at the same time new and better tools of research, and adopting approaches which could not be conceived of in the beginning of the twentieth century or even a few decades ago. The growth of the subject has, however, not been steady and is comparable to the episodes of orogeny or evolution of life on earth. As new ideas to explain the relief forms on earth's surface or its history appeared on the scene, they were either outright discarded as they did not conform to the time honoured viewpoints or were partially accepted as they failed to provide a comprehensive explanation to the evolution of landscape in conformity with the known facts. Yet, some of the ideas and methods

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remained quite unassailable for a long time till they were considerably modified or totally displaced by principles and laws which had a wider sweep and acceptability. Such principles, laws or theories established as an achievement in science, provide the foundation or guidelines for further research, over a period of time, and are called paradigms.

THE ORIGIN OF THE CONCEPT OF PARADIGM

The notion of paradigm is attributed to Thomas S. Kuhn (1962). It is suggested by him that certain scientific works of great importance like Newton's 'Principia' provide a 'framework of concepts and procedures' which offer the necessary direction for further scientific work. Such a framework based on some outstanding achievement is termed a paradigm. To be accepted as a paradigm, 'a theory must seem better than its competitors, but it need not, and in fact it never does, explain all the facts it can be confronted with (Kuhn, 1962)

To earth scientists Lyell's 'Principles of Geology' could be quoted as a paradigm which for quite some time defined the legitimate problems and methods of research in geology. An achievement that enters the realm of paradigm has two important characteristics:

1. It is exceptionally attractive and unprecedented to attract a group of adherents, and
2. It is sufficiently open ended to leave many problems unresolved to be solved by the scientific community by alternative options.

In practice, paradigm takes precedence over any set of rules for research and often governs normal science activity without the intervention of discoverable rules. In fact, it is adopted by the scientific community as a guideline and is 'upset only in periods of revolutionary science, typically arising in response to an accumulation of anomalies and stresses that cannot be resolved within its framework' (Blackburn, 1994)

PARADIGMS IN GEOMORPHOLOGY

There is no branch of science including geomorphology where some kind of paradigm was not adopted by the scientific community to structure its research work. Since a paradigm does not impose a rigid approach and is open ended, the benefit from adopting a paradigm is not a certainty and would vary with the skill, training and scientific approach of a researcher. In the field of geomorphology, since the beginning of its history, there have been many paradigms developed during a period of controversy or as a fallout of advances, in other sister disciplines. The theory of evolution, the laws of thermodynamics, the principle of randomness find their expression in 'paradigms' in other branches of science as well. A paradigm may, therefore, develop as a result of the extension of the principles of some sister science or may independently emerge, following some major achievement in a discipline that is all embracing in its reach and procedurally very tidy.

SHIFTS IN PARADIGM

Adoption of a fresh paradigm does not mean that the existing paradigm is discarded. It only means that the new paradigm is more effective in solving problems and the analysis of many phenomena. The appearance of quantum physics has not done away with the methods of classical physics. The theory of plate-tectonics, though an indispensable framework within which geological structures are judged, does not imply a redundancy of all known principles of structural geology. There is generally a shift in emphasis, when a new paradigm is adopted to satisfy the anomalies which gradually accumulate and reflect the inadequacy of the existing paradigm.

In geomorphology, as much as in any other branch of science, there has been a sequence of time-honoured paradigms which had a long or short lease of useful life, and yielded place to new paradigms as knowledge accumulated and researches in geomorphology turned more rigorous, demanding a better unified principle and a framework.

EARLY PARADIGMS IN GEOMORPHOLOGY

In the mid-eighteenth century, when there was hardly any scientific geomorphology, earth with its variable features, rocks and landforms, attracted the attention of the scientists trying to evolve a theory of the earth. Many believed that the events responsible for causing relief on earth's surface were catastrophic. James Hutton (1749-1817), founder of geomorphology, as distinct from geology, revoked the idea and propounded the principle of gradual change, a principle commonly known as gradualism. It was clear to him that the streams wear down the continents and deposit the waste into the sea, and the history of the earth is a repetition of the process of denudation and deposition. Hutton had a reasonable idea of geomorphic evolution and published his views in a paper entitled 'Theory of the Earth, or an Investigation of the Laws Observable in the Composition, Dissolution and Restoration of Land upon the Globe' (1788), which was expanded into a two volume work in 1795. As a petrologist Hutton was more a vulcanist as opposed to neptunists and understood the origin of granite correctly.

UNIFORMITARIANISM AS A PARADIGM

The core of this principle was the adequacy of the existing processes in bringing about surface relief of the earth, and as such the dictum that "present is the key to the past". The corollary of this paradigm was the changing nature of landforms, as the forces acting on the surface of the earth were capable of wearing down mountains. The principle was elaborated with great clarity by John Playfair, and subsequently by Sir Charles Lyell. Playfair's elaboration of the Huttonian theory, published as 'Illustrations of Huttonian Theory of the Earth' (1802), elucidated the importance of rivers as significant agents of erosion and transportation. It was established that the river vallies were not rifts caused by catastrophic events but were carved by streams. The evidence of accordant junctions particularly came as a strong evidence to support the fluvial nature of vallies. The following is a quote from Playfair's original writing that supports the fluvial origin of the vallies:

> "Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of vallies, communicating with one another and having such a nice adjustment of their declivities, that non of them join the principal valley, either on too high or too low a level; a circumstance which would be infinitely improbable, if each of these vallies were not the work of the stream that flows in it ... Rivers are the causes of waste, most visible to us and most obviously capable of producing great effects."
>
> – John Playfair, 1802

The integration of a river system, the adjustment of the basin to the size of a river system and the recognition of an equilibrium were important elements which emerged following the principle of uniformitarianism.

The principle of uniformitarianism was more firmly established by Charles Lyell, known as the high priest of uniformitarianism. He proposed a uniformitarian interpretation of geological history, expanded in his three volumes of 'Principles of Geology' (1830-33). His idea of uniformitarianism is based on two propositions: (i) The causes of geologic change, now operating, include all the causes that have acted from the earliest time to which we can look back, and (ii) these causes have always operated at the same average levels of energy as at present. These two propositions add up to a steady state theory of the earth.

Uniformitarianism as a doctrine is opposed to catastrophism. It implies that the present is the key to the past, but is interpreted as geological processes in history being, on the whole, of much the same intensity. It is also interpreted as a condition of 'steady state'. In reality, what Lyell wanted to suggest is that the working of the contemporary geomorphic processes, particularly the fluvial activity, could provide the necessary clue for unravelling the history of the earth.

UNIFORMITARIANISM AS A MISNOMER

The principle, no doubt, is a misnomer in the light of the contemporary geomorphic thought. It served as an apt counter argument to catastrophists. The exponents of this school did not subscribe to violent and catastrophic changes. Not that the catastrophic events were ruled out. Gradualism was a more appropriate word. While talking of uniformitarianism, its exponents had all the time in their mind, the fluvial action of the rivers, since the controversy had its beginning in the origin of the valleys, whether of structural or fluvial origin, and their fluvial origin was well established. Hutton, Playfair and Lyell could have more aptly termed their doctrine '**fluvialism**', a term far more appropriate than 'uniformitarianism', which, though opposed to catastrophism, does not assail the latter altogether. Fluvialism, on the other hand, establishes the role of rivers in carving valleys and gradual denudation of the earth's surface., a fact, time and again emphasised by Hutton, Playfair and finally Lyell. Here is a quote from Charles Lyell's 'Principles of Geomorphology' (1830):

> "The readiest way, perhaps of persuading the readers that we may dispense with great and sudden revolutions in the geological order of events, is by showing him how a regular and uninterrupted series of changes in the animate and inanimate world may give rise to such breaks in the sequence and such unconformability of stratified rocks as are usually thought to imply convulsions and catastrophes (p. 174)... The effects of the rivers may be subdivided into those of a destroying and those of a renovating nature; in the destroying are included the erosion of the rocks, and the transportation of matter to lower levels; in the renovating class, the formation of deltas by the influx of sediment, and the shallowing of the seas (p. 192)."

All through his work, Lyell repeatedly emphasised the importance of rivers as agents of erosion, transport and deposition, yet his principle of 'uniformitarianism' gained pre-eminence over 'fluvialism'. The idea of uniformitarianism was floated to resist the ghost of catastrophism, not so much to elaborate the process of landscape development.

THE FALSITY AND REDUNDANCE OF UNIFORMITARIANISM

The principle of uniformitarianism was soon confined to geology books as a scientific landmark in the evolution of geologic thought, and it did not take long for the succeeding generations of geomorphologists to abandon the idea of 'uniformity of change'. The origin of the idea may have found its source in the revolt against catastrophism, but it can be argued from the hind sight that in no small a measure it derived its inspiration from the philosophical thinking and the writings of David Hume (1711-76), a Scottish philosopher and a most influential naturalist in modern philosophy. In his doctrine of causality, Hume believed in two propositions: (i.) the events themselves are causally related and (ii.) *that they will be related in the future in the same ways as they were in the past* (Encyclopaedia Britannica, 1986, vol. 20, p.. 736). Surely, the uniformitarianists like Hutton (1726-1797) and Playfair (1748-1819) who were contemporaries of Hume, and Lyell who came a little later could not have been unfamiliar with Hume's scholarly work mainly 'Treatise of Human Nature'. Hume believed that the success of natural science, culminating in Newtonian mechanics, lay in finding *the few simple principles that would enable one to discern order in the apparent chaos of natural systems. Events in nature are themselves loose and separate,* and the art of the scientist is to determine the patterns in which they fall Blackburn, 1994, p. 179). The philosophical principle known as '*uniformity of nature*' appeared as 'uniformitarianism' in the principles of Hutton, Playfair and Lyell, with a modified statement in which 'Present is the key to the past' instead of 'Past being the key to the future'. The flaw in the argument is that while 'uniformity of nature' talks of the 'relationship between the events' and not of their occurrence, the uniformitarianism believes in the uniformity of natural events, which philosophically will be an absurd proposition. This was well argued by Whewell in his 'Philosophy of the Inductive Sciences' saying that the assumption that the known causes have always operated at their present rate is philosophically unsound and scientifically suspect (William Whewell, 1847, pp. 665-700).

INFLUENCE OF UNIFORMITARIANISM ON DARWIN

The uniformitarian view is in essence anti-evolutionary, and it took Lyell a long time to abandon his idea of creation, but 'naturalism, gradualism and long lasting geological sequences' were some of the its elements that enabled Darwin to visualise the process of evolution. The theory of evolution did conceive of changes in the organism through a series of small mutations and natural selection. Darwin had read the three volumes of 'Principles of Geology' during his voyage on the Beagle, and acknowledges his indebtedness to Lyell in his autobiography. He says: "After my return to England, it appeared to me that by following the example of Lyell in Geology and by collecting all facts which bore in any way on the variation of animal and plants.... Some light might perhaps be thrown on the whole subject" (J. Pardis, 1981). Darwin was of course, deeply influenced by Lyell's 'Principles' and the two distinct principles of Lyell's uniformitarianism, gradualism and actualism, are implicit in the 'The Origin'. It was largely the combination of Lyell's Principles and the Beagle observations which ultimately led to 'The Orgin of Species' and all that implied for the transformation of the nineteenth century thought (Stoddart, 1986). Thus uniformitarianism was a forerunner to the theory of evolution, and its impact on Darwin was pervasive.

UNIFORMITARIANISM TODAY

The principle does not seem to offer today even a working hypothesis in view of the known geological history of the earth, full of periods of orogeny, a fact directly negating the principle of uniformitarianism. The present status of the doctrine is best expressed by S. J. Gould (1965) who grouped the various formulations of the principle into two classes: Substantive uniformity and methodological uniformity. The first part of the principle is discredited in view of the fact that the earth as a terrestrial heat machine could not have maintained a steady state through a long history of over four billion years. Even empirically, the palaeontological records show varying rates of growth and extinction of species. The recent theory of Plate Tectonics is the final nail in the coffin of the dying uniformitarianism. Methodological uniformitarianism is applied to the causes of geological change and would imply that 'there are no more causes than what are operating at present': This procedural assumption rests on the belief that all geological causes were known to Lyell which is not the case. In defence of procedural uniformity one can only say that laws of nature are constant to the extent that the inherent properties of matter and energy remain constant through time and space. But this basic principle hardly subserves the cause of geomorphology.

FROM UNIFORMITARIANISM TO GEOGRAPHICAL CYCLE OR CYCLE OF EROSION

It took almost a century for another paradigm after the principle of 'Uniformitarianism', enunciated first by Hutton in 1788, to appear on the scene. This was the concept of 'Geographical cycle' propounded by William Morris Davis in 1899, though it was at the 33rd meeting of the American Association for the Advancement of Science in 1884 that Davis gave the first broad idea of the cycle of erosion in his article on geographic classification (Chorley et al., 1973). The concept briefly defined in Davis's words is as follows:

> "The cycle begins with crustal movements that place a given landmass in a certain altitude with respect to base level. The surface forms thus produced are called initial. Destructive processes set to work upon initial forms, carving a whole series of sequential forms and finally reducing the surface to its ultimate form, a low plain of imperceptible relief. The sequential forms thus constitute a normal series by which the initial and ultimate forms are connected" (Davis, 1905)..."all the varied forms of land are dependent upon, or, as the mathematician would say, are functions of three variable quantities, which may be called structure, process and time" (Davis, 1889).

Davis borrowed the idea of 'gradualism' and an almost uninterrupted reduction of landmass in his ideal cycle from the 'uniformitarians', the concept of base level, the limit of subaerial erosion from Powell (Challinor, 1964, p. 21), the idea of grade from Gilbert and the concept of evolution from Darwin. Davis himself wrote "that the sequence in the developmental changes of landforms is, in its own way, as systematic as the changes found in the more evident development of organic forms (Davis, 1899), and thus established the analogue between the life cycle of a landscape with that of an organism. While the theory of evolution may have been a basic inspiration in Davis's thinking, it is significant that he took his illustrations not from the evolution of organic species but from the life cycle of a single organism. In his hands, geomorphology became more the study of the origin of landforms that was readily channelled into the restricted field of denudation chronology.

Davis presented an attractive and simplified model of the evolution of landforms.

THE VALIDITY AND POPULARITY OF THE CYCLE PARADIGM

The cycle of erosion proved a very effective model with universal appeal that could be used as a working hypothesis for the evolution of landforms. The theory had adherents from all parts of the world. To name a few, S. W. Wooldridge, D. W. Johnson, a student of Davis, and Henry Baulig accepted Davis as the 'master of the craft' and worked within the framework of the cycle concept. The concept spawned a very popular theme of 'denudation chronology', as exemplified in the approach of Wooldridge and Linton in the discussion of 'Structure, Surface and Drainage in South East England' (1955). In fact, denudation chronology was the principal heritage of the cycle concept and sequential development of erosional forms became a major theme of geomorphology in U. K., France, and U. S. A.

The cycle concept could not carry with it some of the leading German geomorphologists of the time, viz. Albrecht and Walther Penck, the father and son duo, Siegfried Passarge and Alfred Hettner. 'Levelling without base-levelling' in arid regions enunciated by Passarge's early work 'Die Kalahari' (1904) took the ground from under Davis who had adopted base-level as the ultimate level of reduction. The main opposition, and non-acceptability, however, came from the young geologist Walther Penck who criticised 'cycle of erosion' as a concept based on false assumptions and did not fit the observed facts (Chorley, et. al. 1973), p. 519). The 'cycle-scheme' of Davis as W. Penck saw it and truly so, separated uplift and erosion instead of examining their concurrent and constant interaction. W. Penck, working in the Alpine region, could not shed the idea of continuing uplift and mobility of the mountains, and very seriously believed that "Landforms" result from 'erosion versus uplift, rather than erosion after uplift' (Penck's reply to Davis's letter, 28th March 1921, quoted from Chorley et al., 1973). And the valley slopes depended upon, for Penck, not on their age but on the prevailing relationship between erosion and uplift. W. Penck elaborated his ideas in his posthumous publication, "Die Morphologische Analyse. Ein Kapitel der Physikalischen Geologie" (1924), subsequently translated into English in 1953.

Despite the acclaim Davis received and the criticism his concept suffered, the 'cycle of erosion' remained not only popular but a focal concept with geomorphologists all over the world. The cycle concept originally based on normal erosion was extended by Davis himself to other climates like arid and glacial where the modes of erosion were altogether different. The Davisian cycle became so popular that not only considerable space was devoted to it in most of the text books, but it also became a starting point to most learners of geomorphology who were trained to see landscape, its evolution and forms in the Davisian mould. For more than half a century, it remained a grand theory of landscape evolution and provided the basic philosophy of land sculpture. Even today, it cannot be denied that geomorphology has retained the stamp of Davisian authority longer than any other single geomorphologist so far.

THE CONCEPT OF DYNAMIC GEO-MORPGOLOGY, OPEN SYSTEM AND DYNAMIC EQUILIBRIUM

Whether the concept of 'Dynamic' geomorphology has attained the status of a paradigm, as defined by Kuhn, could well form a topic of debate. There is no doubt that the status of 'Davis as the master of method' (Baulig, 1950) gradually declined in the latter half of the 20th century. This, it appears, is largely because of the developments in other physical and biological sciences, where a more precise and rigorous analysis took the place of a deductive reasoning based on qualitative field observations. One of the main ideas which appeared convincing was that of 'equilibrium' advanced earlier by Davis's contemporaries, G. K. Gilbert and W. Penck. Gilbert recognised a state of equilibrium in graded streams or their parts where the carrying capacity of the streams just matches the load to be transported (Gilbert, G. K., 1914). Penck, on the other hand, thought of equilibrium not in terms of capacity of the streams, but in terms of a balance between the forces of uplift and erosion in a landscape. Others like I. T. Hack thought of equilibrium in terms of topographic forms (1960) as a relative concept.

DYNAMIC GEOMORPHOLOGY: THE DYNAMIC BASIS OF GEOMORPHOLOGY

A. N. Strahler appears to be the leader in the field who realised the inadequacies of the cycle paradigm and came out with the idea of 'Dynamic Geomorphology', which, while containig the equilibrium principle, emphasized of the relationships between mass, energy and time in the working of the geomorphic processes. He advocated the treatment of geomorphic processes "as gravitational or molecular shear stresses acting upon clastic, plastic or fluid earth material to produce a varieties of strain or failure to constitute weathering, erosion, transportation and deposition. Shear stresses affecting such earth materials are divided into two major categories: gravitational and molecular. Gravitational stresses activate all downslope movements of matter, hence include all mass movements, all fluvial and glacial processes. Molecular stresses are those induced by temperature changes, crystallisation or melting, absorption or desiccation, or osmosis" (A. N. Strahler, 1952). The analysis of geomorphic forces, caused by gravitational or molecular stresses, has to be done in terms of 'clearly defined open systems' which are self regulatory and tend to achieve a steady state.

Strahler appears to have been very much influenced by the works of W. H. Bucher (1941), Karl Terzaghi (1947) and von Bertalanffy (1943), the father of 'general system theory', all of whom he cites in his references, besides, W. C. Krumbein, who had long adopted a quasi mathematical approach in the study of sediments. He, it appears, was impressed with Bucher's classification of geological knowledge being time bound and timeless, and his dynamic geomorphology aimed at producing knowledge which is timeless, like the laws of physics or chemistry. The geomorphic processes are basically the various forms of shear or failure of materials and unless the fundamental nature of materials is understood, there is hardly any hope of adding anything worthwhile to what is already self-evident, concerning the behaviour of streams, landslides, glaciers or wave induced currents.

Strahler advocates two types of mathematical procedures for understanding the geomorphic processes. The first relates to the statistical analysis of experimental and sample field data to derive some empirical equations. This kind of empirical equation may assume one of the two forms: The first involves the degree of relationship between two form elements like meander length and width of the channel, a case where the two variables, though well correlated are not causally interrelated. The second type of empirical equation establishes a relationship between a force, an independent variable and a landform element, a dependent variable. The second, a mathematical procedure, involves the formulation of a 'relatively simple mathematical model which is a quantitative statement of some point of important general theory, otherwise definable only qualitatively. The establishment of such mathematical models may be regarded as the highest form of scientific achievement (Strahler, 1952, p. 936)[1].

SYSTEMS APPROACH IN DYNAMIC GEOMORPHOLOGY

To be effective, Strahler qualifies his dynamic geomorphology by introducing the 'systems approach', as he believes that geomorphology will achieve its fullest development only when forms and processes are related in terms of dynamic systems, since geomorphic processes operate largely in well defined systems. In this, he follows von Bertalanffy (1950), but clearly anticipates R. J. Chorley (1962, 1971). In fact, it is obvious that Chorley, who was trained at Columbia with Strahler, was inspired or at least induced to elaborate on the original systems approach, once Strahler outlined its rudiments, as enunciated by Bertalanffy, in the context of geomorphology.

Von Bertalanffy recognised two types of thermodynamic systems - closed and open system. Most systems in geomorphology are open systems in which there is a constant exchange of matter or energy or both. The application and the validity of open system approach is demonstrated by a stream or a segment of it, in uniform flow in which a steady state ensues when energy of the stream is dissipated in overcoming resistance to shear within the fluid, against the channel boundary or to the movement of bed load, but should the discharge change or stop, the form will change - open systems are able to adjust internally to changes in supply of material or energy from outside. Like discharge, when the bed load increases or decreases, the stream changes its slope so as to adjust afresh to a steady state. The state of equilibrium requires constant adjustment which is maintained by an open system by an input of energy or material from outside.

Dynamic geomorphology, thus, has a number of significant yet related components, summarised by Strahler in his classic paper (1952, p. 937). These include:

1. Study of geomorphology processes and landforms as various kinds of responses to gravitational and molecular shear stresses acting upon material behaving characteristically as elastic or plastic, solids or viscous fluids.
2. Quantitative determination of landform characteristics and causative factors.
3. Formation of empirical equations by methods of mathematical statistics.
4. Building of the concept of open dynamic systems and steady states for all phases of geomorphic processes.
5. The deduction of general mathematical models to serve as quantitative natural laws.

[1] *The elaboration of 'dynamic geomorphology' is based exclusively on Strahler's paper and some sentences and particularly the summary is literally taken from the paper to overcome any risk of distortion.*

The dynamic geomorpholgy concept of Strahler is a far more potent paradigm than any supposed earlier. It discusses in philosophical terms the meaning and status of geomorphology, the approach adopted precisely from a scientific point of view and the methodology proposed to be followed, thus setting a task before future geomorpholgists. As he himself admits 'the program is vast and qualified investigators few, and we are half a century behind, if development is to be measured against chemistry, physics and biological sciences'.

From the tenor of the paper, besides its content, it is evident that Strahler wanted a scientific geomorphology which is precise, predictive and develops its own laws.

RESPONSE TO DYNAMIC GEOMORPHOLOGY APPROACH

The most significant response to the concept of dynamic geomorphology has been a progressive increase in the process studies. Not that the forms are altogether left out: In fact, they cannot be left out as they are symptomatic of the processes and their influence on human activity as important as the processes.

This shift in emphasis can be noticed in an avalanche of process studies in different environments and associated with different geomorphic agencies. This has resulted in what is defined as a 'functional approach' different from the 'historical approach' of Davis which reconstructed the evolutionary events with the help of existing geomorphic features (Chorley et al., 1984, p. 1). The functional approach is directed towards prediction, precisely what was suggested by Strahler four decades earlier. The advocacy of mathematical analysis had its response in a sequence of studies starting from empirical formulations and statistical relationship to purely mathematical deductions. The empirical process study response came largely from hydrologists, geologists, sedimentologists and hydraulic and civil engineers from the U. S. A., as seen in their contributions related to hydrology, channel morphology, sediment yield and rates of denudation and deposition. Led by Strahler (1945, 1950, 1958, 1964), S. A. Schumm (!956, 1973, 1977, 1981, 1983), W. B. Langbein (1964, 1966, 1968) and finally L. B. Leopold (1953, 1957, 1976) and Wolman (1955, 1960, 1978) studied not only the form and geometry of the channels but also the magnitude of forces involved and their relative effectiveness during episodic events.

Two important concepts underlying 'dynamic geomorphology' which were experimented with and had a large measure of acceptance were the 'idea of equilibrium' and the 'systems approach'. Geomorphologists all over, following the scientists in other fields, adopted the 'systems approach' which meant seeing geomorphic processes and the forms as a part of an open system. This is further established by the publication of the well known work of Schumm, 'The Fluvial System' (1977). The concept of equilibrium is not only accepted but has undergone situational refinements and a variety of equilibria, with short term interruptions has emerged. A geomorphic system in equilibrium can be recognised both by the rate of transfer of material and the maintenance of forms, or by the balance of energy required and expended in the system. Chorley recognises four types of equilibrium (Chorley, 1980) called by him, decay equilibrium, steady state equilibrium, dynamic equilibrium and dynamic metastable equilibrium. These states relate to fluctuations from the mean, implying short periods of accelerated erosion separated by periods of relative stability.

The principle of equilibrium has been extended by the addition of some more concepts, but notably those of 'geomorphic thresholds' and 'complex response' (Schumm, 1973). The concept of "geomorphic 'thresholds' suggests that there can be changes within the fluvial system that are not due to external influences but rather they are due to geomorphic control inherent in the eroding system. The 'complex response' system refers to the system responding to rejuvenation not simply by incising, but by hunting for a new equilibrium by incision, aggradation or renewed incision" (Schumm, 1975, quoted from 'Theories of Landform Development, ed. W. N. Melhorn, and R. C. Femal).

MATHEMATICAL DEVELOPMENT OF GEOMORPHIC LAWS:

Strahler's idea of the development of geomorphic laws of higher order has found expression in increasing use of mathematics in formulating the laws of erosion and deposition, soil creep and landslides and different aspects of fluvial, glacial, aeolian and marine processes. But the response to Strahler's challenge has been relatively meagre. To quote M. A. Carson (1971) "Strahler tried valiantly to infuse a genetic approach into the subject, but was greeted with meagre response. To be sure, the challenge of his quantitative research was met by a surge of field studies, but sadly, little was undertaken in the way of providing a rational framework for the collection' of such data, as his 'Dynamic Basis of Geomorphology' had urged. Even today, geomorphologists seem to show a marked reluctance to delve into the genetic, as against the descriptive side of landscape studies. "There is something strange about a subject in which the research workers are willing to dabble at the application of the jargon of thermodynamics, but unwilling to apply even the most rudimentary aspects of mechanics to these problems. One suspects that geomorphology will emerge as a reputable discipline only when its students have become well versed in the established principles of natural science" (Carson, M.A., 1971, p. 166). These remarks of Carson made two decades after Strahler's classic paper of 1952, remained unnoticed and subject ran into multiple specialisations without much effort made by its practitioners to unify the processes in a mathematically formulated variation of laws. There were a few studies that attempted a mathematical treatment of processes (Bagnold, R. A., 1953, Leopold, L. B., Wolman, M. G. and Miller, J. P., 1964; Scheidegger, A. E., 1970, Carson, M. A., 1971, Carson, M. A. and Kirkby, M., 1971). Bagnold's classic 'The physics of the Blown Sand and Desert Dunes' still remains a work of unsurpassed quality, based on principles of physics. 'Theoretical Geomorphology' of Scheidegger has yet to find wide acceptance among geomorpholgists because of its mathematical content, and Carson and Kirkby are gradually reaching the students of geomorphology through the introduction of mathematics based courses in the universities. What has happened instead, is a mushrooming of specialised subdisciplines in the late seventies and eighties. These specialisations, whether they relate to climate, structure, time or the application of geomorphology, have been largely promoted by British geomorphologists. The dynamic geomorphology of Strahler has assumed the form of process studies. These may relate to processes in geomorphology in general, or in different environments like fluvial, glacial, periglacial, aeolian or marine. Whether process studies have assumed or will take the form of a new paradigm is highly debatable, but there is a strong trend that suggests that process will replace forms in due course, the latter being obvious, only their explanations will remain challenging.

RESURGENCE OF THE TIME ELEMENT FROM THE DAVISIAN CYCLE

Some elements of the Davisian paradigm still attract the attention of geomorphologists because of variations in perspective, through which landforms can be examined. Besides the processes, time as an element in the cyclic evolution of landforms is vital, as different time scales are needed for a variety of processes and the resulting landforms. Tricart (1965) in a classification of geomorphic features has suggested a 'Time span or persistence' valid for different geomorphic features. This does not necessarily involve the tracing of sequential development of landforms, but involves the application of dating principle, especially of Quaternary sequences, and the changes during the historical times. Time as a factor in any process will give the rate of change and in turn the rapidity of the processes. Thus, time and time scale, if carefully looked into, throw light on paleo-environment, more specifically palaeo-climate and is a very effective tool used by environmental archaeologists. The utility of time as an element of geomorphology is well illustrated by Thornes and Brunsden (Thornes, J. B. and Brunsden, D., 1977) who emphasise the fact that 'time pervades all fields of geomorphology'. There is nothing like a time-independent process and the rate, frequency and magnitude of the processes always form the base of geomorphic analysis. Changes over time in the past geomorphic processes have produced variation in the landforms as much as they do now. Time is also an important element in a predictive model.

In fact, a fascinating specialisation like 'Palaeo-geomorphology' is in the offing corresponding to palaeo-botany. This would not be the same as denudation chronology, and would mean the geomorphology of a specific period in earth's history of a large part of the earth and not concentrate on geomorphic evolution of a small unit.

CLIMATIC GEOMORPHOLOGY: CAN IT BECOME A PARADIGM?

Climatic geomorphology, largely based on the role of environment on geomorphic processes is one branch of geomorphology which has been promoted largely by geographers. That the geomorphic processes vary with climate as suggested by the dominance of specific geomorphic processes in different climatic milieu, is an accepted principle, but the central concern of climatic geomorphology is the extent to which variations in the elements of climate, notable solar energy and moisture, are reflected in the geomorphic processes to produce distinctive suites of landforms (Derbyshire, 1976, p. 1).

The concept of climatic geomorphology is based on the zonation of climates and the consequent emergence of zonal landforms like zonal climate and zonal vegetation. Thus, the landforms could be zonal or azonal. Many geomorphologists may have discussed the concept of climate as an important determinant in the global distribution of landforms, but the subject was promoted as an independent branch by Julius Büdel (1948, 1963) and Tricart and Cailleux (1965, 1972). Immediately after the publication of Büdel's paper, Peltier (1950) thought of geographic cycle in a periglacial region recognising in his references the contribution of Sapper (1935) and Cotton / 1942), besides several others. Sapper was perhaps the earliest geomorphologist who talked of 'geomorphology of the wet tropics' independent of the erosional cycle. He acknowledges the influence of A. Penck (1910), Davis (1912) and C. Troll (1947). Of the nine climatic regimes and corresponding cycles postulated by him, seven had already been described as producing unique geomorphic features. Yet, Peltier systematised the concept of morphogenic regions for the English speaking world. This was more clearly stated by Thornburry (1954, p. 63) in writing that Büdel had already suggested the existence of *Formkreisen* what were called morphogenetic regions by Peltier, who divided the world into nine morphogenetic regions (glacial, periglacial, boreal, maritime, selva, moderate, savanna, semiarid and arid).

The credit for a full fledged development of climatic geomorphology goes to J. Büdel of Germany and J. Tricart and A. Cailleux of France. All these authors have shown a distinctive assemblage of landforms for a specific climate. The result has been the study of landforms not only of specific regions, but based on specific climates like glacial, desert and tropical. Climate geomorphology, if pursued to its logical end, in terms of processes, has, and will provide valuable data relating to climate-specific processes, and their intensity. The variable role of chemical or mechanical weathering and the fluvial and other transport agencies, with divergent processes, provide the insight into the way geomorphic processes operate in different environments. Climatic geomorphology has, thus, assumed the mantle of a very specialised theme, yet its overemphasis on climate is likely to lead to the neglect of many equally, if not more, important elements in the evolution of landscape. A highly specialised segment of the discipline, despite its extensive practice and considerable achievement in explaining processes in different climates does not come to the status of a paradigm and ends up as one of the specialised branches like structural geomorphology.

THEMATIC GEOMORPHOLOGY

During the last four decades the form and process studies in geomorphology have yielded place to the study of specialised themes under a broad title one may call 'thematic geomorphology'. This is induced by the benefits of an analytical approach, where the entire complex of global earth forms can be broken down into forms associated with structural units and climatic regimes, and the processes operating over a wide area of the earth can be isolated according to their characteristics, and studied. The fluvial system incorporating channel morphology, hydraulic geometry, behaviour of fluids and the channel flow characteristics, erosion, sedimentation and other elements of the system, is the focal theme of many geomorphic researches., as fluvial processes are by far the most effective and most widespread in nature. Equally important are the hill slopes and hill slope processes that erode the hill slopes and transport the material down to the streams. Besides these two, which together may broadly cover entire earth surface, there are qualitative aspects of the subject like 'time and place in geomorphology', 'Nature of geomorphology', 'Models in geomorphology'. There are still other themes which are concerned with history, methods and application of the discipline. There is an abundance of publications on techniques developed over time or borrowed from other disciplines. Highly specialised themes like weathering, soil creep, wave action or coastal sedimentation have come handy as challenging themes to more enterprising researchers who may use their expertise in physics, chemistry and mathematics. The dynamic system in geomorphology involves a variety of movements in different segments of relief. These include the fluvial, glacial, aeolian systems or the processes working on the slope. Each one of these subsystems in a landscape has attracted specialised studies, wandering into peripheral themes of physics, chemistry or engineering. The specialisation is endless and like other scientific disciplines may involve a facet of relief, micro relief or microform.

An extreme specialisation in geomorphology leads to as better understanding of any area or event specific phenomenon, or may outline a sequence of events that follow a given geomorphic event, but does not provide fundamental principles. This statement may appear debatable in view of the fact that a fundamental principle in geomorphology, though limited to the sequence of events or their relationships has to depend on the principles of physics involving material and force. Thus, one may justifiably wonder 'How fundamental are the fundamental findings of geomorphology?' And, if, on the other hand, geomorphology is seen to attain its maximum usefulness by its extension into palaeogeomorphology, it is nothing more than an explanatory history of landforms.

PLATE TECTONICS, MEGA-GEOMORPHOLOGY AND STRUCTURAL FORMS

The most outstanding achievement of the latter half of the 20th century in the field of earth sciences is the discovery of the reversal of magnetic polarity and its sequence, leading to the idea of sea floor spreading and finally to a comprehensive theory of plate tectonics, which involves the movement of 70 to 150 km thick lithospheric plates, moving away from the mid-oceanic ridges, producing in the process the existing configuration of landmasses, oceans and major relief features. Thus, much of what is termed mega-geomorphology is directly linked with the configuration and the movement of plates. The plate tectonics, as a paradigm, explains the configuration of mid-ocean ridges, oceanic basins, continental slope and shelf, ocean trenches and deeps, marginal sea basins and the continental platforms and the folded mountains. In the field of mega-geomorphology, plate tectonics is not only a paradigm providing a framework but also virtually all the explanations. This forms the basis of a geological and a structural geomorphology capable of existing independent of erosional geomorphology. Structure was a basic element even in the Davisian geomorphology which advocated cyclic evolution of landforms. Though the geomorphologist have taken note of the impact of plate tectonics, the work of relating mega geomorphic features or explaining them in the light of plate tectonics has largely rested with the geologists like K. C. Kondie (1976), J. F. Dewey (1973), P. A. Rona (1980), or geomorphologists with a geology background like C. D. Ollier (1981).

The process geomorphologists have confined their work to sub-aerial processes depending on geologists for the structural base of geomorphology.

LIMITATIONS OF PLATE TECTONICS THEORY AS A PARADIGM IN GEOMORPHOLOGY:

There are serious difficulties in accepting plate tectonics as a paradigm for geomorphology, the most apparent being its limited application, as it explains only the mega structural features like mid-oceanic ridges and a host of other features associated with the convergent boundaries of plates. It hardly touches the geomorphic features in the continental interiors. Secondly, since the movement of plates does not go beyond 180-200 million years in the past, the earlier orogeny of mid-Cambrian, the traces of which are visible in Caledonian or Hercynian bases cannot be explained with the present arrangement of plates.

More importantly, the microforms, the vast alluvial plains or plateau regions, the regions which have undergone the impact of Quaternary glaciation, or other geomorphic forms remain beyond the impact of plate movement. The orogenic belts and their association with subduction zones, the sedimentation near the trailing edges of the plates, the association of deep sea trenches and islands with oceanic plate offer unfailing explanations of major landforms usually included in mega-geomorphology.

It will be suicidal not to adopt plate tectonics as a paradigm as a starting point in structural geomorphology and the explanation of major relief features, but plate tectonics fails to provide a framework inclusive enough to accommodate all geomorphic aspects.

PROCESS STUDY AND THEORY DEVELOPMENT IN GEOMORPHOLGY

The contemporary emphasis on process studies has, in the background, its aim to formulate and understand geomorphic laws. Such studies take different forms like observations over a span of time, establishing a variety of relationships. The findings have a crude texture and interpret the behaviour of a specific geomorphic agent expressed in an equation beset with uncertainties of all kinds, since situations in space vary and the character of the variables changes. At best, it results in working out a relationship for a specific situation. One is tempted to state that the process studies of a geomorphologist don't look for fundamental principles but try to explain geomorphic events, or, fit them in the framework of known principles of mechanics. The importance of the studies, nevertheless, lies in stringing together interrelated natural events following the law of science. In a fluvial system what are involved is the channel, and the stream. These may be further qualified depending upon their character and magnitude. There is nothing in the stream flow that cannot be resolved by the principles of fluid mechanics, yet it is the geomorphologist who notices the impact of the flow, following heavy precipitation, causing erosion, transport and sedimentation. At every point, in the final analysis, it is the nature of the material, the force and movement which are involved, but together they create the landscape of a situation which needs the perception of an earth scientist who strings together these events, such that these include time. space and causality. In doing so, the geomorphologist is more an interpreter as he can visualise the spatial and temporal changes and establish causality between the events.

The case with the development of theories is quite different. In geomorphology, the term theory is rather loosely used and quite often it refers to a hypothetical model of reality, the authenticity of which is not rigorously tested. Theories in geomorphology have been either a model of logical intellectual constructs like the 'cycle concept' of Davis, or simply statements related to grade, equilibrium or systems approach, not in any sense predictive. "Theories in geomorphology commonly developed from basic laws of physics and chemistry, and the basic propositions comprise the fundamental laws of mechanics, fluid mechanics or statistical mechanics " (Thornes, J. B., 1978, p. 15). Many of these concepts like geomorphic thresholds or steady state or 'cascading process systems' are generalised statements and fall far short of theory. There is a large gap between a concept, usually a hypothesis, and the theory, which remains unbridged for lack of experimentation, and many of these concepts remain sterile. In fact, the theories, geomorphology claims, would be either general concepts, like the equilibrium concept, and result from the geomorphic interpretation of the laws of science.

A good theory is a theory that predicts a large number of singular propositions that are accessible to an empirical check by observation and experimentation

(Mohr, 1977). Where are such theories in geomorphology? The predictive power in geomorpholgy will depend on the skilled application of laws of other physical sciences.

Chorley (1978) has recognised the historical development of a variety of phases each associated with a specific nature of geomorphic theory (teleological, immanent, taxonomic, functional, realist and conventionalist). All the theories must be tested against their power of prediction. It is futile to include all possible explanations in a theory. Theories, in geomorphology, are far from being laws and are more like strong hypotheses with successful tests in certain situations. A wider applicability and the power of prediction should be the hall mark of a good geomorphology theory. Since space is a very significant parameter in geomorphology, which is basic to all landforms, applicability over large areas is always a problem with a geomorphic theory as much as with its power of prediction.

Geomorphic theory would thus be largely interpretational, interpreting the geomorphic processes and forms in the light of known laws and theory of physical science.

TRENDS AND IMPLICATIONS

There is no thrust area in geomorphology. The description of landforms, their history, and the explanation of the processes remain the eternal theme. What progress geomorphology has made in the last hundred years is difficult to articulate. Practitioners of geomorphology will talk in terms of specialisation and a better understanding of processes, and the way they operate in different structural provinces, different climates and on different segments of the landscape.

Having failed to secure the status of a theoretical science for the discipline, there is a temptation among geomorphologists to discover facts, sequence of events and principles that may help other scientists or planners engaged in devising strategies for the conservation of resources, or evading natural disasters like floods and landslides. The study may help prevention of soil erosion or degrada-tion and the optimal utilisation of land, soil and water. Thus has emerged a branch of geomorphology known as applied geomorphology.

The implication of ever increasing scope of applied geomorphology is the tendency to neglect the theoretical structure of the subject, as is evident from the remote sensing laboratories of different state governments of India. Geomorphology stands the risk of being mistaken as an art or an exercise in resource management that will, no doubt, make valuable contribution of its own. At the same time, it hardly needs to be emphasised that a century of serious research in geomorphic principles has brought the subject to a level when it finds a place in applied field of engineering or resource conservation. This reinforces the need for serious research in the discipline, with or without an all inclusive paradigm.

One of the reasons for there being no definite paradigm in the contemporary geomorphic scene is the rapidity with which ideas have changed, as more serious researches have thrown fresh challenges. The scope is ever expanding, as the principles of geomorpholgy are both timeless and time dependent and its coverage of space embraces the entire globe.

R. J. Chorley	**Theoretical Ideas**	
		Mega-Geomorphology
		↑
D. Brunsden	**Applied Geomorphology**	**Plate Tectonics**
		↑
		Structural Geomorpholgy
M. A. Carson **N. J. Kirkby**	**Slope Processes**	
L. B. Leopold **M. G. Wolman** **W. B. Langbein** **S.A. Schumm**	**Fluvial Processes**	
J. Büdel	**Climatic Geomorphology**	
	Specialisations **Process Studies** **Geomorphic Theory**	
A. E. Scheidegger (1962)	**Theoretical Geomorphology**	
	↑	
A. N. Strahler (1952)	**Dynamic Geomorphology**	
	↑	
	Theory of Open Systems	**L. Von Bertalanffy** (1950)
	↑	
	Eco-System	**A. G. Tansley** (1935)
	↑	
	Plant Succession	**F. E. Clements** (1928)
	↑	
W. M. Davis	**Cycle of Erosion**	
	↑	
	Evolution (origin of species)	**Charles R. Darwin** (1809-82)
	↑	
Sir Charles Lyell (1797-1875)	**Uniformitarianism**	
J. Playfair (1748-1819) **James Hutton** (1726-97)	↑	
David Hume (1711-76) **Adam Smith** (1723-90)	**Uniformity of Nature**	(Past will resemble the future)

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