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Chapter 1

# Introductory Chapter: Geomorphology

Dericks Praise Shukla

Additional information is available at the end of the chapter

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## 1. Introduction

Over millions of years, the Earth has gone through many changes which have shaped its current form and structure. From a dust ball according to nebular hypothesis, to the current form, the Earth has transformed a lot. Once an inhabitable place, during the Hadean time, our Earth has seen many processes over a long time of more than 4 billion years. Developmental stages which formed the current habitable world include both internal and external forces. The meteoritic impact, volcanic activities, and erosional activities of rivers, winds, glaciers, oceans, etc. along with the sea floor spreading and plate tectonic activities have been constantly working to shape the Earth as we see now. Many of these activities occur during a short interval, while some take millions of years to create various climatic, geologic, and geomorphic regimes. All of these never-ending processes are still continuously going on and shaping our Earth currently. The most notable of all these processes are geomorphic processes since they create the shape and form of the Earth as we see it now. Hence, the study of these geomorphic processes is critical to understand the phenomena and process that are occurring in nature.

Having its derivation from Greek words, γεω (Earth), μορφη (morph/form), and λογος (discuss), geomorphology literally means "a discussion on Earth's form." Hence, it is the study of various features that are found on the Earth, such as mountains, hills, plains, rivers, moraines, cirques, sand dunes, beaches, spits, etc., that are created by various agents such as rivers, glaciers, wind, ocean, etc. Since the fourth century BC, many people have studied the formation of the Earth by relating to various observations in the field. Ancient Greeks and Romans such as Aristotle, Strabo, Herodotus, Xenophanes, and many others discussed about the origin of the valleys, formation of deltas, presence of seashells on mountains, etc. After observing the seashells on the top of the mountains, Xenophanes speculated that the surface of the Earth must have risen and fallen from time to time, thus creating river valleys and mountains (*c.* 580–480 BC). After observing seashells on mountain top and vast expanses of sand, Aristotle (*c.* 384–322 BC) suggested that the areas which are dryland now must be

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covered by sea in the past and those areas where sea is present now must have been dryland once. Hence, he proposed that land and sea change places. Traditionally, the history of the development of landscape was carried out by mapping the sedimentary and morphological features. For understanding the evolution of landscape, the golden rule, "the present is the key to the past," has been followed. This rule assumes that the processes that are visible in action today must have occurred in the past also, which can be used to infer the reasons for formation of the landscape in the past. Hence, the past formation was mainly dependent on the relative information and aging method.

However, the word "geomorphology" was first coined and used between the 1870s and 1880s [1] to describe the morphology of the surface of the Earth. But it was popularized by William Morris Davis who proposed the "geographical cycle" also known as "Davis cycle" [2]. He proposed that the development of landscapes occurs as due to alternate action of uplift and denudation. He assumed that uplift occurs quickly and then the uplifted land mass erodes gradually to form the topography of the region. He hypothesized that upliftment is a quick action, whereas denudation is a time-taking process. Thus, creating high mountains and deep valleys showcases youth, mature, and old age stages of landform development. Though Davis cycle is considered as a classic work, but his hypothesis lacks a basic understanding that both upliftment and denudation occur simultaneously. Both of these phenomena go on hand in hand and are not necessarily alternate. Hence, nearly 35 years later, Walther Penck proposed a variation of "Davis model," where he showed that the interaction of both uplift and denudation occurs simultaneously [3, 4]. He suggested that due to simultaneous actions, the slopes will be developed in three main forms. First, a convex slope where the upliftment rate is higher than denudation rate; next, a steady-state or stationary stage where both the rates are nearly equal, hence creating straight slope; and finally concave slopes when the rate of upliftment is lesser than the rate of denudation. Thus, over a period of time, various aspects of landforms have been studied by geomorphologists. Some geomorphologists have studied the process of formation of these landforms, while some have studied its origin and history, and others have analyzed various forms of landforms for their quantitativeness. Hence, in a nutshell, modern geomorphologists focus mainly on three aspects of landforms: form, process, and history. The form and process studies are commonly termed as functional geomorphology, while the last one as historical geomorphology [5]. The study of various processes that are responsible for the formation of a landscape falls in the purview of functional geomorphology.

All these landforms that are visible on the Earth vary in size from microscale such as potholes, flutes, ripples, etc. to mega-scale features such as mountain ranges, river basins, etc. Hence, the time required to form these features also varies from tens of years to millions of years. It has also been observed that certain features are native to certain climatic zones; hence, development of climatic zones such as arid, tropical, etc. plays a critical role in formation and evolution of these geomorphic features. For example, the landforms observed in higher latitudes show signature of glaciation and deglaciation cycle, which is indicative of quaternary climatic environment, whereas in other parts of the world, such as Grand Canyon of Colorado River Valley in the United States have preserved the signature of various activities, that occurred hundreds of millions of years ago, in its various landforms. Most of the landforms are formed

and deformed due to the two processes, namely, endogenic that occurs within the Earth's crust such as convective heat cycles, rising plume, and magma chambers and exogenic processes that shape the features on the surface of the Earth with the help of various agents of weathering like water, wind, glaciers, seas, etc. All these phenomena of landscape evolution with respect to life span, climatic zones, and processes are shown in **Figure 1**.

A lot of works have been carried out in the field of functional and historical geomorphology. Now, many other fields or kinds of geomorphology have been studied such as tectonic geomorphology, submarine geomorphology, planetary geomorphology, climatic geomorphology, and modeling geomorphology. Interaction of tectonic forces and geomorphic processes deform the Earth's crust regularly, and this led to development of tectonic geomorphology. It uses the techniques and data from other fields of geology mainly structural, geochemistry, geochronology in conjunction with geomorphology, and climate change. As name suggests, submarine geomorphology focuses on the origin, formation, and development of submarine landforms developed in both shallow and deep marine environments. Planetary geomorphology deals with the application of the understanding of the formation of landforms on the Earth to extraterrestrial objects such as moon, planets, exoplanets, etc. This is comparatively the latest branch and is developing very fast. Geomorphic studies of Venus, Mars, Jupiter, Titan, and other planets are a hot cake these days. Climate plays a critical role in developing various landform natives to each climatic zone such as arid, tropical, temperate, etc. This understanding is the basis for the development of climatic geomorphology as a stream. The effect of climatic phenomena along with tectonic activities places a new cross

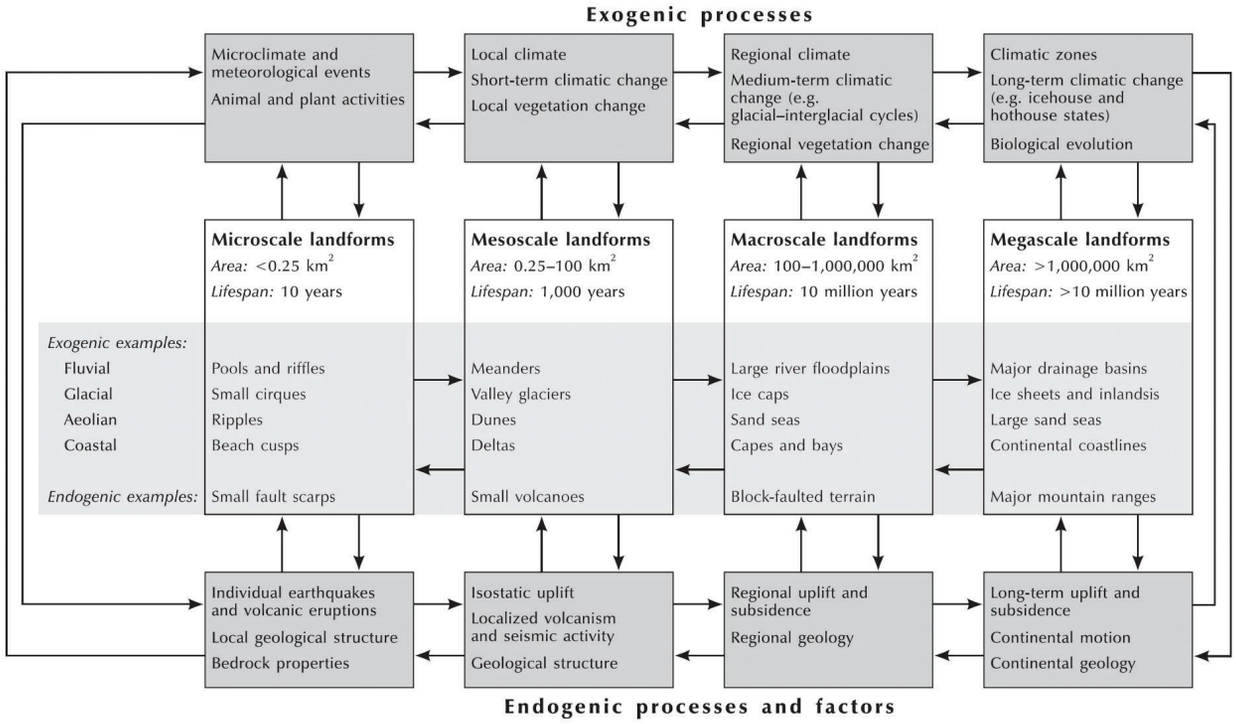



**Figure 1.** Form, process, and their interrelationships for the evolution of various landforms developed due to endogenic and exogenic processes over various scales of time and climatic zones (adapted from [6]).

stream of geomorphology known as climato-tectonic geomorphology. These days, inter- and multidisciplinary approaches have been used in various fields of science, and geomorphology is one of them where cross breeding is highly evident. Till now, various branches and offshoots of geomorphology have been developed, and lots of researches have been carried out in those interdisciplinary areas.

Among all the exogenic agents that are at work to form the landscape, water is the most promising and effective. Hence, fluvial geomorphology has been studied a lot in details. Keeping these aspects in mind, this book has been formulated where the major focus is on geomorphic features developed due to action of water. Hence, two chapters on fluvial geomorphology and one chapter on coastal geomorphology are being presented here. While the last chapter deals with the recent trends of digital elevation model (DEM) that could be very effectively used for morphometric analysis of various streams.

Hydro-geomorphology, the study of hydrological processes, involves surface runoff, baseflow, stream discharge, and the soil and streambed erosion processes, which continuously chisel the geomorphological profile of a basin. The life span of such processes varies from few hundreds of years to even millions of years. Apart from the quantification of the hydrological processes, as well as the soil and streambed erosion processes, the continuous hydro-geomorphologic modeling provides valuable information for the future trend of these physical processes. A wide variety of integrated models that continuously simulate the runoff, soil erosion, and sediment transport processes are available. In Chapter 2, a composite mathematical model is presented aiming at continuous simulations of hydro-geomorphological processes, as well as continuous simulations of soil and streambed erosion processes in Kosynthos River basin (district of Xanthi, Thrace, northeastern Greece) and Nestos River basin (Macedonia-Thrace border, northeastern Greece), the two neighboring basins in northeastern Greece. Their model generates continuous hydrographs and sediment graphs at the outlets of the two basins at fine temporal scales, whose statistical efficiency with the measured quantities at the basin outlet is highly significant providing satisfactory results. The correlation coefficient of modeled values with measured values is more than 80% for both the basins for water and sediment discharge.

Anthropogenic activities have significantly affected the fluvial geomorphological regimes within a very short time span. From construction of dams which increases the sedimentation in the reservoir, thus changing the riverbed profile to the deforestation and urbanization which is enhancing the erosion rates in the river catchment, anthropogenic activities have left its imprints in the natural phenomenon. Similar is the case in St. Lawrence Lowlands of Quebec region of the Canadian Shield where the construction of dams has led to increase in bank-full width, thus decreasing the channel sinuosity and changing the fluvial regimes. Further changes in land-use pattern have also led to higher erosion and sedimentation. Clearing of forests for agricultural practices has led to deforestation, and later afforestation in that region (agricultural areas) due to decline in agricultural work force has impacted the morphological evolution of channels in Quebec region of Canada. Thus, Chapter 3 tries to constrain the impacts of reforestation and hydroclimatic variability on the morphology (width and sinuosity) of the Matambin River channel in Quebec, Canada. They observed

21% decrease in mean channel bank-full width from 1935 to 1964 which was characterized by a low frequency of strong flood flows in the region. After 1964, a trend of increasing mean channel bank-full width was observed which is associated with the increase in frequency of strong flood flows and decrease in the amount of suspended sediments produced by soil erosion.

Higher rates of erosion are observed when the weathering agent is water. And, considering the huge expanses of oceans and the erosion that occurs at the shores takes the first place. This effect is clearly visible in shoreline change and sea-level rise. Most of the populated cities all around the world are situated near the coasts; thus, majority of the population of the world lives within few kilometers of the coast. Thus, a proper coastal land management is required to cater the needs of the ever-increasing population. Shoreline change (cliff erosion) has been studied using predictive models which are based on historical records and the geomorphological data of a certain region. Current historical extrapolation models use historical recession data, but different environments with the same historical values can produce identical annual retreat characteristics despite the potential responses to a changing environment being unequal. For that reason, process-response models are being explained in Chapter 4 based on real data at Holderness coast (UK), to provide quantitative predictions of the effects of natural and human-induced changes that cannot be predicted using other models.

With the advent of satellite technology, it has been absolutely easy to study the surface of the Earth from satellite data. When it comes to identifying various landforms and describing the physical appearances, satellite images or aerial photos come very handy. However, this approach is more qualitative than quantitative and is defined as morphography, where the external shapes are described without giving information about the way of creation of those features. Various methods are used to define the origin of features and the mechanism of development of these features. This comes under morphogenesis, while morphochronology deals with the estimation of age of the forms in the absolute as well as relative terms. Finally, the quantitative estimation carried out by measurements of the geometric features of the landforms is known as morphometry. There are various morphometric parameters and morphometric indices being used in geomorphometry to define the landform analysis and classification. Chapter 5 presents a detailed review by explaining various geomorphometric indices and parameters and shows the utilization of DEM for extraction of these information. He explains these tools with various examples that are available in various GIS packages.

## Author details

Dericks Praise Shukla

Address all correspondence to: dericks.82@gmail.com

Indian Institute of Technology Mandi (IIT Mandi), India

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