TECTONIC AND SURFACE PROCESSES INTERACTION

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Summary

Geomorphological processes are natural mechanisms of weathering, erosion, and deposition that result in the modification of the surficial materials and landforms at the Earth's surface. The landforms that are found on the surface of the Earth are tectonic landforms—landforms that are created by massive Earth movements due to plate tectonics. This includes landforms with some of the following geomorphic features: fold mountains, rift valleys, volcanoes, and weathering landforms created by the physical or chemical decomposition of rock through weathering. Weathering produces landforms

where rocks and sediments are decomposed and disintegrated. Erosional landforms—landforms formed from the removal of weathered and eroded surface materials by wind, water, glaciers, and gravity. This includes landforms with some of the following geomorphic features: river valleys, glacial valleys, coastal cliffs, and depositional landforms—landforms formed from the deposition of weathered and eroded surface materials. On occasion, these deposits can be compressed, altered by pressure, heat, and chemical processes to become sedimentary rocks. This includes landforms with some of the following geomorphic features: beaches, deltas, flood plains, and glacial moraines. Landforms are polygenetic because they show the influence of several of the above processes that can also change over time, and a single landscape can undergo several cycles of development.

1. Introduction

The surface of the Earth acts as a limiting surface between tectonic processes that deform the lithosphere, and geomorphic processes that redistribute material across its surface. The Earth is still a planet with a broadly fluid behavior therefore, as it is positioned out in space; the more stable shape is spherical, slightly modified to an ellipsoidal geoid by rotation. Since the Earth is hotter than its surrounding space, the undergoing cooling process generates a relatively thin solid carapace called “lithosphere.” Constant variations during this cooling process affect the stability of the solid skin and modify its geometry and surface design.

The Earth’s surface system is constantly changing as a consequence of the interaction of climate and topography. The energy required for this change comes from solar radiation and the Earth’s internal heat. Solar radiation drives a global hydrological cycle, which stabilizes the climatic zones of the Earth because it controls both atmospheric circulation and the Earth’s water budget balance and provides the energy for biological activity. Furthermore, the Earth has a planetary mechanical energy because of its position within the solar system powered by gravitational forces. As it moves around the sun, it rotates on its axis so that the water in its oceans is affected by the gravitational pull of the moon and, to a lesser extent, of the sun.

Internal energy is primarily responsible for the Earth’s topography on various scales. Heat generated within the Earth, largely from radioactive decay, drives a slow, deep convection. Thermal convection in turn is responsible for the very long-wavelength topography of the Earth’s surface, and indirectly for the relative motion of a number of rigid lithospheric plates across the Earth’s surface, whose interactions generate much of the surface topography by means of deformation. Deformation within the crust results from the relief of stress along discontinuities and within volumes of deforming rocks. The plates, which comprise the relatively cool lithosphere, collide and override each other, forming oceanic trenches, island arcs, mountains, and plateaus. Where they separate, mid ocean ridges, oceanic basins, continental margins, and continental rifts are formed. Relative motions also generate earthquakes and volcanoes. This internal energy is therefore primarily responsible for providing potential energy for a host of denudation, transport, and depositional processes.

Most natural systems exist in a delicate balance, in which a change in one part of the system will cause adjustments in other parts of the system. Usually the effect of these adjustments is to maintain a stable or predictable behavior in the system as a whole. Equilibrium conditions are typically described as steady-state (average condition not changing), dynamic (average condition increasing or decreasing), or meta-stable (system shifting between stable conditions). Sometimes, extreme events (floods, earthquakes, and so on) can surpass the tolerance of the system to absorb changes. These threshold-breaking events often lead to a period of unpredictable new behavior until a new equilibrium can be established

2. Fundamental Processes

The geomorphic processes are all the physical and chemical changes, which modify the Earth's surface. Classical long-term landform evolution was considered as time dependent and as leading to planation. The introduction of plate tectonics provoked a change in this assumption and this evolution is now considered to depend on crustal properties. Present views of landscape evolution emphasize the balance between erosion and tectonic uplift. If uplift is faster, the mountains rise; if erosion is faster, the mountains are lowered. The concept of cycle of erosion linked with fluvial systems controlled by a base level implies that landforms evolve towards a low and uniform relief but it cannot explain why some areas are in permanent uplift and, on the contrary, others are subsiding. This leads to the idea that on analyzing surface morphology, crustal anisotropy, and the state of stress due to plate tectonics, erosion (wearing away) and isostatic rebound must be taken into account.

The surface of the Earth is a result of the complex interaction between processes operating either on the surface of the Earth or in its oceans that can be divided into *exogenic* and *endogene*.

The *exogenic* processes originate externally to the solid Earth, including water, river, wind, and glacial action on land, and tides, currents, and waves in the ocean. The *endogene* processes originate within the Earth including volcanic activity, Earthquakes, and horizontal and vertical motions of the Earth's surface caused by plate tectonics (see *Tectonic Processes*) and mantle convection.

Additionally, the surface of our planet is modified at a different scale by extraterrestrial processes (for example, meteoritic impact) and also by living creatures. The primary energy source for the Earth is solar radiation, being 99.98 % of all energy received: heat flow from the interior of the Earth accounts for 0.018 % and tidal energy 0.002 %.

As a consequence, since the formation of the lithosphere, the Earth's surface has exhibited different modifications that made its external geometry irregular. Nevertheless, Earth's relief—either positive or negative—is a small-scale feature in relation with the Earth's diameter. The highest point is Mount Everest in the Himalayas, at 8848 m above sea level (in fact, the Ojos del Salado volcano, on the Argentine–Chilean border, is the farthest point from the Earth's center at 6893 m above sea level due to its more equatorial position). The minimal relief of the solid crust is the Marianas Trench, under the Pacific Ocean, with 11 034 m under sea level. Both topographic extremes are insignificant if compared with the 6371 km Earth's radius.

2.1. Endogene Processes

Endogene processes are the changes that the rocks suffer in the Earth's interior. They are expressed as intimately related processes: tectonics that imply the relative motion and deformation of the lithosphere, and magmatism that refers to the movement of molten materials either inside the Earth, or towards and onto the Earth's surface. These processes are ultimately responsible for producing Earthquakes (see *Earthquake Mechanics*), mountain ranges and volcanoes (see *Volcanology: Volcanic Activities, Chemistry,* and *Effects on Environment*) on the Earth. Stresses in the lithosphere may be driven by tectonic forces, thermal forces causing flexure of the crust, and intrusion, and also by gravitational forces resulting in isostatic adjustment of the crust.

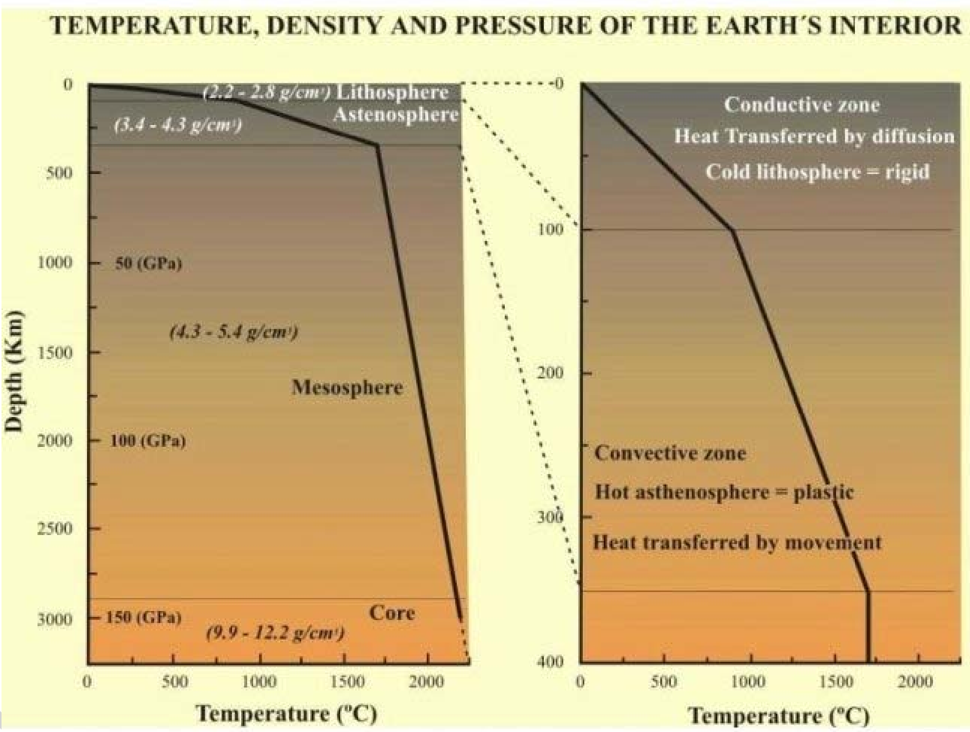

Figure 1. Layering of physical properties in the Earth. The rock temperature, density, and pressure increase with depth. The geothermal gradient (rate of temperature increase) varies with depth and from place to place in the world. The range is from 15 to 75 ºC/km. The heat is transferred by diffusion (conduction) in the rigid lithosphere and by movement of material (convection) in the plastic asthenosphere.

Heat dissipation and terrestrial gravity are the two major physical mechanisms that control the energy flow through the different layers that made up the Earth (Figure 1**).** Internal heat dissipation gives rise to a concentric temperature distribution with lower temperatures towards the surface (see *Terrestrial Heat Flow*) allowing the heat to come out to the outer space. The Earth's internal heat results from original or primordial heat that was accumulated during the processes of accretion and formation some 4.5 billion years ago, together with heat generated by natural radioactivity, as isotopes of elements such as K, U, and Th decay through time.

The principal mechanism for transferring heat from the deep interior to the surface is convection. Inside the terrestrial mantle, radial convection cells are formed. As material heats up at the base of the mantle, as much as 2900 km below the surface, it buoyantly rises because it expands slightly and becomes less dense than its immediate surroundings. At the top of the mantle (approximately 20 to 60 km below the continental surface or about 8 km below the oceanic crust), the material cools and becomes denser, sinking back down in a return flow. The mantle is a viscous fluid, and moves at rates of only millimeters to centimeters per year. As a result, over short time scales it behaves more like a plastic material than a liquid. This simple model is complicated by the existence of the rigid and brittle lithosphere that covers the surface of the Earth beneath the atmosphere and hydrosphere.

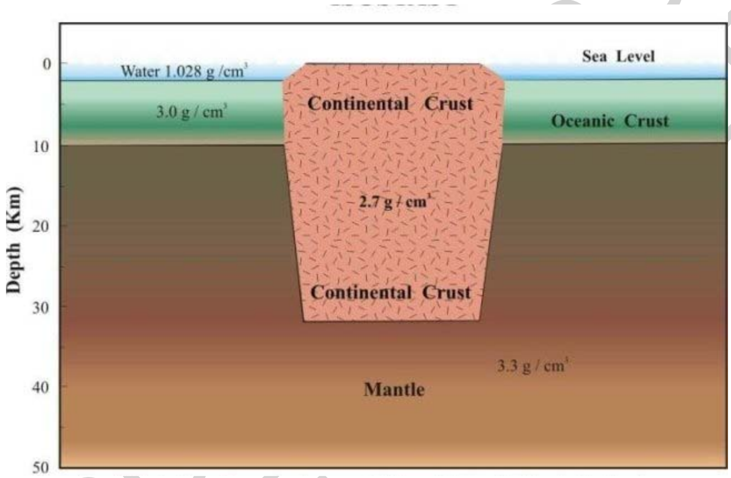

Figure 2. Section through the crust and upper part of the mantle to illustrate the principle of isostasy. There is a flotation balance between low-density rocks and high-density rock i.e. low-density crustal rocks float on higher density mantle rocks. The height at which the low-density rocks float is dependent of the thickness of the low-density rocks and the density contrast. Continents stand high because they are composed of low-density rocks (granitic composition). Ocean crust stands low, because it is composed of denser basaltic and gabbroic rocks.

The lithosphere, which includes both the crust and the brittle uppermost part of the mantle, is typically 70–120 km thick and is broken into several large fragments called tectonic plates. The plates move relative to each other and relative to the underlying convecting mantle (Figure 2). The radial movements in the mantle are then counterbalanced by tangential either convergent or divergent adjustments of the superficial more rigid portions into which the Earth is divided.

The base of the lithosphere slides over a weak zone of upper mantle called the asthenosphere. The weakness of the asthenosphere is due to it being at, or near, the temperature at which it begins to melt. Consequently, some regions of the asthenosphere are partially molten although for the most part it is solid. This leads to an apparent paradox: the mantle flows by convection even though it is largely solid. The paradox is resolved only when it is realized that the behavior fluid versus solid is dependent on the time scales under consideration. For geophysical purposes the solid mantle can be considered a high viscosity fluid.

Terrestrial gravity (see *Gravimetry*) tends to order the different components of the Earth in density controlled concentric layers, the denser towards the nucleus in a geotropic arrangement (Figure 1**).** Continents are composed of a thicker (ca. 35 km), less competent, lower density crust (see *Continental Crust*) with average ages of typically 1–2 billion years. In contrast, oceanic crust (see *Oceanic Crust*) is thin (ca. 7 km), relatively hard, denser, and with ages no greater than 200 million years old. The surface of the continents is largely above sea level because the thicker, less dense crust tends to "float" higher in the underlying mantle than the oceanic crust (Figure 2). The equilibrium level at which crust resides due to its density is controlled by a principle known as "isostasy."

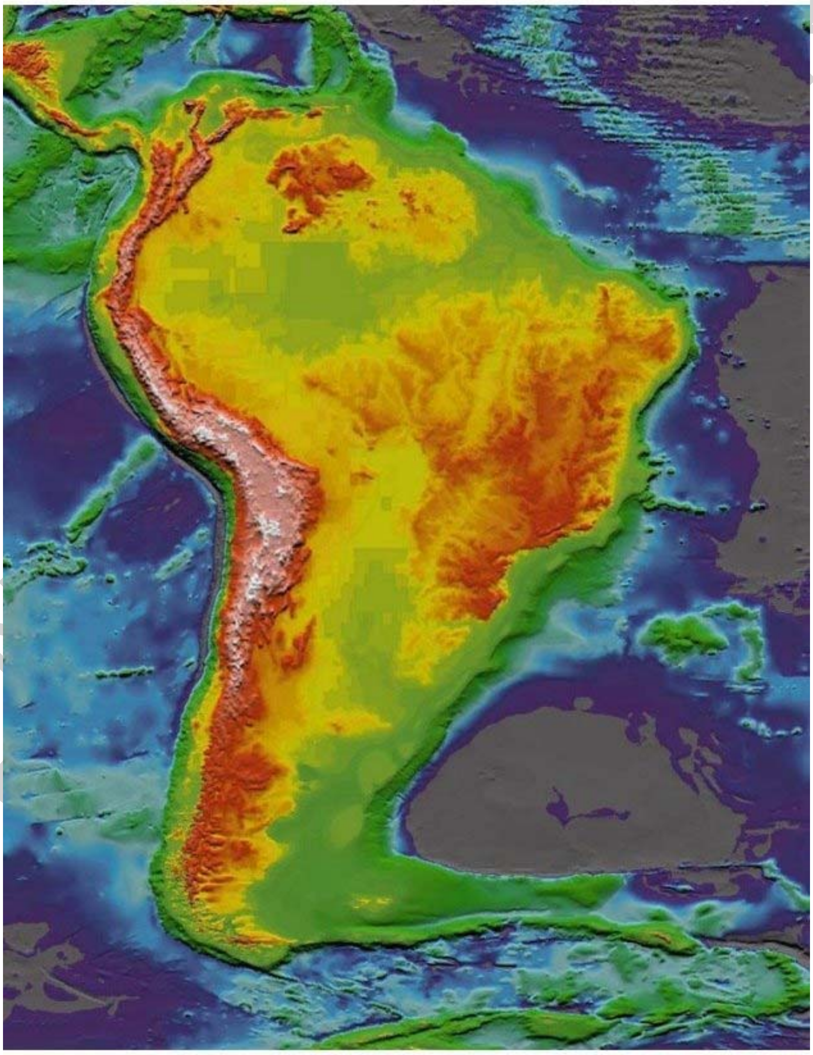

Figure 3. The topography of Southern America is a consequence of the subduction of the Nazca Plate (Pacific Ocean). The Cordillera de los Andes is placed along the western border showing the main shortening of the continent.

Plate tectonics refer to the relative movement of the rigid lithospheric plates. As the lithosphere is made up of the upper part of the mantle and the crust is compositionally inhomogeneous, it is rock strength that controls its rigid behavior. The crust is thinner than the entire lithosphere, therefore on a global scale; the process that modifies the Earth's surface acts on minor wrinkles that will tend to be smoothed. All the major features of the Earth's surface, either submerged beneath the sea or exposed on land, arise directly or indirectly from plate tectonic activity. Mountains ranges grow when plates collide, then the ranges are worn away to attain finally an equilibrium profile (Figure 3).

2.2. Exogenic Processes

The exogenic processes that operate at or near the Earth's solid surface are called erosion and sedimentation. They comprise a series of processes by which rocks are broken down by physical and chemical liberation and the product moved. These processes are gradational in the sense that they tend to bring the surface of the Earth to a level at which they can minimize the potential energy. The addition of material into the surface system by means of tectonic deformation, and the effects of climate, controls the geomorphic redistribution of material.

Two categories of exogenic processes can be defined: *aggradation* is applied to those processes that build up the surface and *degradation* to those that level down the surface (Figure 4).

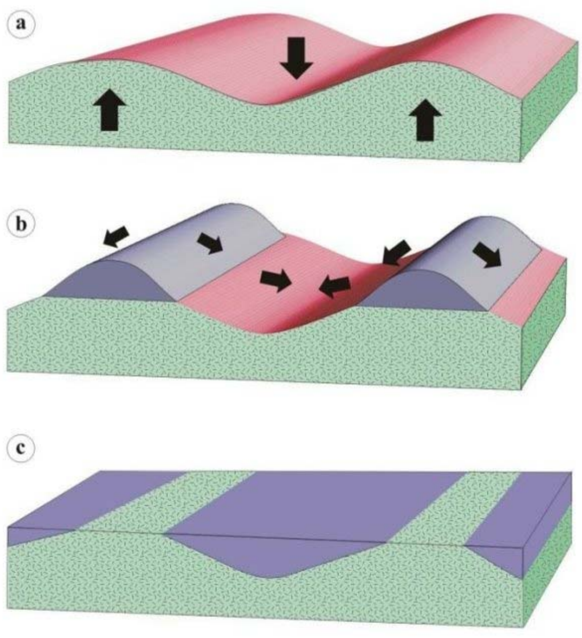

Figure 4. Relationships between topography, sedimentation, and erosion: a) Tectonics or volcanism generate new topography—the equilibrium is lost. b) Erosion is concentrated at the high potential energy uplifted regions (Source areas). The clastic material is transported and deposited into depocenters at lower areas (aggradation). c) The equilibrium is re-established through the topographic leveling by erosion of the higher areas and filling of the lower areas (aggradation).

Aggradation refers to the building up of the Earth's surface and in consequence is intimately coupled with degradation. The agents that intervene are water (such as running water, groundwater, waves, currents, tides) glaciers, mass wasting, and wind.

The erosion causes the leveling of the relief and the deposition of the weathered and eroded material. It has been active throughout geological record due to a variety of mountainous uplifts, folding and faulting events, and intrusion of igneous rocks in different areas. In this process, two factors are determinative: a) gravity, which allows the downslope movement of material and b) solar energy, which is the principal agent for the water, wind, and stream movements on the Earth's surface. Other factors that affect erosion are: climate, saturation of surface materials, type of material at and near the surface, vegetation, and degree of weathering, steepness of slope, earthquake activity, and human disturbance. Erosion may actually promote tectonic uplift.

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discusses surficial processes—mass wasting, streams and drainage, groundwater, glaciation, deserts, and the oceans. Then it deal with internal processes—rock deformation, Earthquakes, and global tectonics.]

Biographical Sketches

María C. Pomposiello, was born in Buenos Aires, Argentina, and graduated from the Physics Department of the School of Natural and Pure Sciences (SNPS) of University of Buenos Aires (UBA) in 1969 with a Lic. in Physics degree. In 1967, she entered in the laboratory of Molecular Spectroscopy in the Physics Department of SNPS (UBA). She completed. Her PhD was completed in 1978 at the University of Buenos Aires, Argentina, (with the thesis entitled “Infrared Spectra in Polarized Light of Crystalline Chloroform”).From 1966 to 1974 she was Teaching Assistant at University of Buenos Aires. In 1971, she was Visiting Lecturer at the University of Salford, Lancashire, England. Since 1974, she has been Associate Professor, National Technical University of Buenos Aires.Since 1981 María C. Pomposiello has been a research scientist at National Council on Scientific and Technical Research (CONICET) working on Electromagnetic Geophysics. So far, she has performed research tasks in geophysical evaluation of geothermal resources in Argentina and magnetotelluric studies in Pampean Ranges, northwest of Argentina. She has published about 50 papers, including internal reports and presented more than 80 talks at national and international meetings.

Mónica G. López de Luchi ,was born in Buenos Aires, Argentina, and graduated from the Geology Department of the Faculty of Pure and Natural Sciences of University of Buenos Aires (UBA) in 1979 with a Licenciature. in Geology degree. In 1980, she got her first research grant from the National research Council of Argentina. She completed her PhD in 1986 in the University of Buenos Aires, Argentina (with the thesis entitled Geología y Petrología del basamento de la Sierra de San Luis, Región del Batolito de Renca).

From 1980 to 1987 she got different research grants. In 1990-1992, she was Visiting Researcher at the University of Barcelona, España. Since 1988 she has been a research scientist at National Council on Scientific and Technical Research (CONICET) working on Petrology of igneous and metamorphic rocks. So far, she has performed research tasks in basement geology in Sierras Pampeanas and in the North Patagonian Massif.She has published about 70 papers, including internal reports and presented more than 40 talks at national and international meetings.

Eduardo A. Rossello ,was born in Mercedes, Buenos Aires, Argentina, and graduated from the Geology Department of the Faculty of Pure and Natural Sciences of University of Buenos Aires (UBA) with a Licenciatura (1979) and PhD (1983) degrees.He started his career at the University of Buenos Aires as Teaching Assistant in 1977. From 1985 on he has been Assistant Professor as well as Independent Research at National Council on Scientific and Technical Research (CONICET).His research is focused on Structural and Economic Geology with emphasis on the physical controls of economic deposits. He was also Visiting Professor of diverse Universities in Argentina, France, Uruguay and Brazil.During 1986 and 1987 he was Associated Researcher at the University of Rennes 1 (France). He was co-responsible for different international projects on Tectonics of Argentina and he has published more than 180 papers in journals, books and special national and international meetings.