THE ORGANIZED EARTH

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Summary

The evolution of Earth's surface bears the hallmarks of a planet that is organizing itself to minimize its rate of energy loss. Cooling and tectonic activity have driven the formation of continents and their distribution with respect to the world's oceans. Interactions between the continents, oceans, and atmosphere have then organized the conditions that happen to support life. The global organization of tectonic plates also controls, through crustal deformation and mantle melting, both local and global rates of seismicity and volcanic eruption. Earthquakes and eruptions are themselves intimately linked because the magma feeding eruptions must use cracks in the crust to arrive at the surface. Rare, but extreme, volcanic episodes produce what are known as "large igneous provinces," spectacular accumulations of millions to tens of millions of cubic kilometers of basaltic lava. These provinces are associated with major changes in tectonic behavior and may have been triggered by giant impacts with meteors or comets. Despite such impacts, the Earth has persistently returned to its preferred style of surface organization. A key result of such organization is that recurring patterns can be perceived for interpreting geological history, and so provide the foundation for the studies described in this topic.

1. Introduction

The history of Earth is the story of a planet becoming more complex with time. From a protoplanet of molten rock (see *The Earth as a Planet*), Earth has cooled into a compositionally-zoned sphere, consisting of an iron-and-nickel-rich central core (about 3500 km in radius) enclosed by a silicate mantle (rich in iron and magnesium and about 2800 km thick), itself covered by a three-layer veneer (200 to 500 km thick) of rock, water, and gas—our crust, oceans, and atmosphere. Under the influence of gravity and creep movements in the mantle, Earth's crust has arranged itself into a small number of tectonic plates that continually jostle against each other (Figure 1). The plates consist of preferred assemblages of silicate minerals: minerals rich in calcium, iron, and magnesium are predominant in the ocean crust, while those rich in sodium and potassium dominate the continents (see *The Composition of the Earth: Rocks and Minerals*). The compositional differences favor variations in surface elevation, such that the lighter continents and denser ocean floors are typically about 1 km above and 3 km below sea level, respectively. The difference in elevation drives the gravitational transport of eroded surface material from the continents to the oceans, and is a key component in shaping Earth's landscape (see *The Evolution of Landscape*). Deposited as a sequence of layers, the transported material is transformed into sedimentary rock and the hardened layers, later raised up by tectonic movement, have been fundamental for understanding the enormous periods of time for which the Earth has been evolving (see *Using the Earth to Measure Time*). Concentrated along plate margins, the same tectonic movements drive the extreme geological disturbances—from the uplift of mountains to the triggering of earthquakes and volcanic eruptions—that today present a major hazard to human activity (see *The Hazardous Earth*). Geological processes at all scales can thus ultimately be related to how the cooling Earth has organized itself into a core, mantle, crust, oceans, and atmosphere, and to how the dynamic connection between these layers has shaped the surface of the planet.

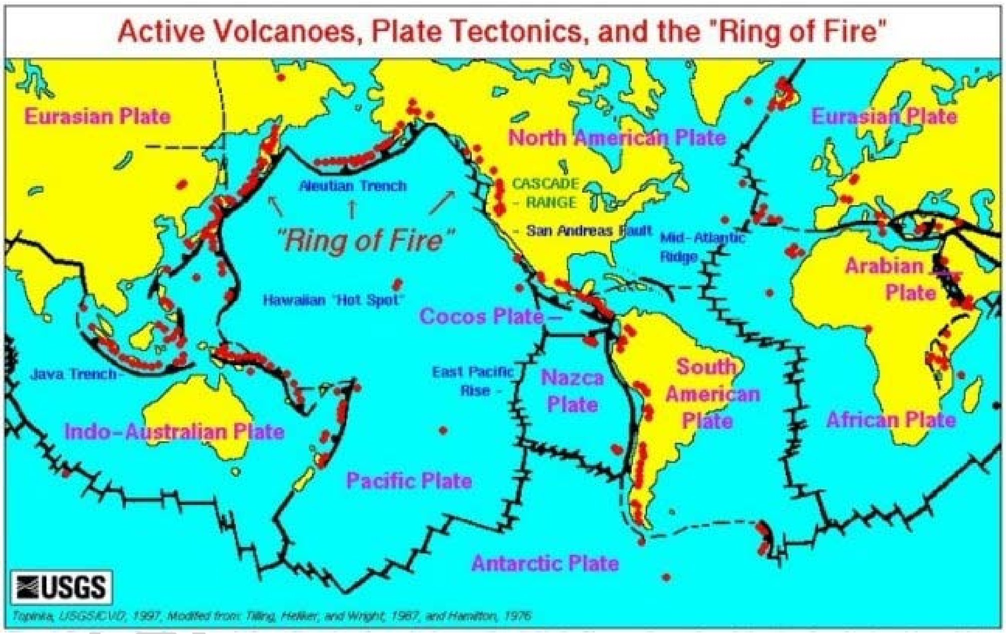

Figure 1. Earth's surface is composed of a small number of tectonic plates (outlines in black). Plate margins are the main locations for volcanic activity (red dots), although magma produced by mantle plumes (or hot spots) can feed volcanoes through plate interiors, such as the Hawaiian Islands in the Pacific Ocean. Note also the so-called "Ring of Fire" that marks the rim of the Pacific. (Courtesy of the US Geological Survey.)

The view of Earth as a self-organizing planet has become increasingly popular since the surge of interest in how nonlinear dynamic systems can spontaneously produce complex structures characterized by a fractal geometry. A fractal geometry describes hierarchies of shapes that show the same relation to each other independent of their actual size.

Such geometry is well known in geology. For example, patterns of folds or arrangements of fractures often appear to be similar whether the structures occur over square centimeters or hundreds of square kilometers. Indeed, almost the first lesson in field geology is to declare the scale of an object; this is why geological photographs are littered with common objects of known size, such as coins or geological hammers.

The notion of scale independence suggests that the pattern being studied is the result of a particular balance among governing factors, rather than on a factor's absolute size. Among dynamical systems, preferred balances often reflect conditions for which rates of energy loss are minimized. For instance, it is common for viscous surface flows (such as mudflows and volcanic lava flows) to approach steady rates of advance, since this condition corresponds to minimum rates of energy loss against friction. Similar arguments also apply to styles of fracturing, which reflect how a brittle rock tries to minimize the amount of energy it loses while breaking. Rather than summarize the range of geological processes that show clear signs of self-organization, this chapter will complement the topics from related contributions and focus on examples that embrace volcanism, seismicity, and tectonic behavior.

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Biographical Sketch

Christopher Kilburn is a research fellow in the Department of Geological Sciences at University College London. His main research interests include the dynamics of surface flows, principally lava flows and landslides, and the use of fracture mechanics for improving forecasts of volcanic eruptions.

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