OCCURRENCE, TEXTURE, AND CLASSIFICATION OF IGNEOUS ROCKS

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Contents

Summary

In this article, the manner in which igneous rocks occur in nature is introduced, followed by a discussion of the general textural features and appearance of these rocks. The classification and nomenclature of igneous rocks are treated in the final section.

Igneous rocks are formed when magma cools, either on Earth's surface or beneath it, though some may form by fragmentation of solidifying magma. Typical occurrences of igneous rock bodies on the surface include lava flows, lava domes, necks and spines, and pyroclastic deposits. Plutonic bodies with different dimensions and geometry form by cooling of magma beneath the earth surface, and are exposed at the surface by post-emplacement geological processes and erosion.

The term "texture" is used in the conventional geological meaning for features such as grain shape and size, and spatial relationships between mineral grains in a rock. The subject is discussed in terms of recent research on the nature of crystallization.

The recommendations of the International Union of Geological Sciences (IUGS) subcommission for igneous rock terminology and classification are illustrated. For the sake of completeness, and in order to provide a general picture of the whole spectrum of igneous rocks, also included are a number of types that are either rare or difficult to identify without the use of advanced techniques.

1. Introduction

For centuries people living near volcanoes have noticed that the red-hot molten material that erupted onto Earth's surface as lava cooled and solidified to give solid rocks. Lava (from the Italian *lavare*: to wash) was originally applied to streams of water, and in the eighteenth century in Neapolitan dialect to streams of molten rock from the Vesuvius volcano. The term is now used for the molten material that erupts from volcanoes as well as for the rock that forms on solidification of this material. Rocks resulting from volcanic eruption represent only a small proportion of those rocks formed by the cooling and crystallization of magma, most of which occurs at depths beneath the Earth's surface.

All rocks represent the final products of a multitude of physical and chemical processes (see *Igneous and Metamorphic Petrology; Processes of Magma Evolution, Magmatic Suites and Consequences for the Composition of Continental Crust*). Throughout their cooling history all magmatic rocks try to achieve mechanical and chemical equilibrium, but rarely succeed. As a result, they leave behind trails consisting of wide chemical and mineralogical variations, disequilibrium mineral assemblages, disequilibrium textures, fluid inclusions, and so on, which when taken together, permit us to reconstruct the history of the magmatic rock.

This article attempts to cover the description, mode of occurrence, and classification of igneous rocks. The article follows a purely descriptive approach, providing factual data and attaching names to igneous rocks. This is not an end in itself, but rather one step toward understanding how rock bodies form and how magmatic eruptions behave.

2. Mode of Occurrence of Igneous Rocks

Magmas erupted from volcanoes are either poured out as coherent fluidal lava flows or blown out as fragments of various sizes. A body of magma may also be emplaced and cool beneath the surface of the Earth. Igneous rocks result from the final solidification of magma at the surface or at variable depths within the Earth, as well as from the eventual consolidation of fragmented debris.

Igneous rocks thus occur in two ways, either as “extrusive” (on the surface) rocks or as “intrusive” (below the surface) bodies. Intrusive rocks are also called “plutonic” (Pluto, the Greek god of infernal regions, therefore deep-seated) and extrusive rocks “volcanic.” The terms intrusive and extrusive only refer to the place where the rock solidified. Extrusive rocks cool rapidly because they have erupted at the Earth’s surface, but intrusive rocks cool more slowly within an insulating blanket of surrounding rocks into which they have been emplaced. The rapid cooling of magma gives a fine-grained rock, which may even be glassy, whereas slower cooling gives coarse-grained rock with large crystals.

2.1. Lava Flows and Domes

In its upward movement, magma may be erupted at the surface from fissures or volcanic vents. Fundamentally, differences in magma composition and volatile content are responsible for all variations between the extremes of quiet lava effusion and catastrophic explosion. Some volcanic eruptions are short and sharp, whereas others drag on for months through various phases with different eruptive styles.

Effusive activity is dominated by passive emission of “lavas.” Lavas may be emitted from fissures or central vents. Several central eruptions may line up along a great fracture or fissure zone.

Lava flows extruded on the earth’s surface range from a few centimeters to a few hundred meters in thickness. The area may be a few square meters or many square kilometers. Extrusions display a wide range of forms, depending upon their mobility or apparent viscosity.

Lava flows are tabular igneous bodies, generally thin compared with their horizontal extent. The attitude corresponds in a general way to that of the surface upon which they are erupted. On flat plains, the lava flows are more or less horizontal; but on the slopes of volcanoes, they may consolidate with a considerable inclination. Relatively low-viscosity or fluid flows (basaltic magmas) spread out from the vent as thin extensive sheets, whereas viscous rhyolite lavas are thick and short. At the largest scale, there is a clear separation between effusive and explosive styles by composition. Large-volume basaltic eruptions are almost exclusively effusive; large-volume silicic eruptions are exclusively explosive.

In general terms, if a volcano is built up by a single eruption, it is called “monogenetic.” If there are repeated episodes of activity from the vent, a bigger “polygenetic” volcano results.

“Fissure” eruptions result when magma-filled dykes intersect the surface. When a dyke of mafic lava breaks through to the surface, huge-volume basaltic flows may be formed. In historic times, the largest example of this phenomenon took place between June 1783 and February 1784, when 14 cubic kilometers of lava flooded from the 25 km length of the Laki Fissure in southern Iceland.

Central eruption forms various types of volcanic edifices, among which “shield volcanoes” and “stratovolcanoes” are the largest. Shield volcanoes are broad cones with low angles of slope, built chiefly of fluid basaltic lava emitted prevailingly from a central area. Stratovolcanoes are formed by mixed effusive and explosive activity, and consist of alternating lava flows and pyroclastic deposits. In central volcanoes, variable amounts of lava and tephra erupt from vents or fissures on the side of the cone. Very symmetrical volcanic cones (for example, Mayon in the Philippines, or Fuji in Japan) are built up by lavas and pyroclastic deposits emitted almost exclusively from a central vent. Other asymmetrical large volcanoes are more complex, and result from eruptions that took place both from the summit vent, and from various craters along the flanks.

In volcanic complexes resulting from fissure eruptions accompanied by swarms of feeders, areas of several hundred square kilometers may be flooded by lava flows amounting to thousands of meters in total thickness. These are known as large igneous provinces (LIPs). Most LIPs, such as the Deccan Plateau of western India, the Parana of South America, and the high plateaus of Ethiopia and East Africa, have been constructed primarily by fissure eruptions. Basalts constitute more than 90 percent of the lavas participating in the eruptions.

The surface of lava flows is generally covered by irregularities of different magnitude and shape, which depend on the magma viscosity. *Pahoehoe* lava has a smooth billowy or ropy surface, and is typical of very fluid basaltic magmas. *Aa* lava is typical of slightly more viscous basaltic magmas and consists of irregular blocks that are commonly covered with small spines. *Blocky* lava is composed of irregular blocks that lack spines, and are typical of intermediate and salic magmas. Subaqueous basaltic volcanic eruptions have characteristic “pillow” structures. Pillows are elongated, bulbous, tube or sac-like bodies of lava that form by repeated budding and extrusion of fluid lava at the fronts of underwater flows.

Very viscous acid lava flows are less mobile and are commonly extruded either as tongue-like lava flows, or as thick, bulbous masses called “domes,” which pile up over and around their vents. The ratio of horizontal diameter to thickness of lava domes can be near unity. Some domes are emplaced as nearly consolidated masses, and are simply thrust slowly out of the vent as a “spine” without much lateral expansion, like a cork withdrawn from a wine bottle.

2.2. Pyroclastic Deposits

When magmas are rich in volatiles (especially H_2O and CO_2), they erupt explosively and become fragmented. Explosive eruptions and magma fragmentation can vary from a continuous slow process to the devastating process of gigantic eruptions. Eruptions eject large varieties of pyroclastic material, including large blobs of magma that are still molten or plastic, intensely fragmented fine ashes, and blocks of solid rocks. As the eruption continues, ejected material piles up partly around the vent, and partly at a considerable distance from the vent, depending on the energy of the explosive eruption and on the dimensions of pyroclasts.

Scoria cones are small, rarely more than 200 to 300 meters high, monogenic volcanic features with a distinctive morphology and side slopes close to 33°. They result from minor moderately explosive basaltic eruptions. *Maar craters* are simple circular depressions excavated into the substrate, surrounded by low rims of ejected debris; they are commonly filled with water and are manifested as lakes. *Maars* are formed when basaltic magmas interact with water at shallow depths. *Tuff rings* are accumulations of highly fragmented basaltic tephra, with a characteristic broad and flat circular geometry. *Tuff cones* are smaller, steeper versions of tuff rings, composed of similar fragmented tephra, and have a morphologic resemblance to scoria cones.

2.3. Intrusive Bodies

Intrusive rock bodies, formed by slow crystallization beneath the surface of the earth, can be seen only where they are uncovered by erosion. The existence of an intrusion demands a mass of older, solid or semisolid country, wall, or host rock. Intrusions are described as "concordant" if their contacts are more or less parallel to the structures (bedding or schistosity) of the intruded host rocks, and "discordant" if the intrusive body cuts across the host rock structures.

Bodies of intrusive rocks vary greatly in form and extent. The smallest are dikes and veins a few centimeters wide; the larger masses outcrop continuously over areas measured in thousands of square kilometers. The most important role in the emplacement of intrusive bodies is played by gravity. Their mode of intrusion is largely determined by the difference in density between the magma and its country rocks; other factors, such as the viscosity of the magma or the stress regime in the country rocks, have only a modifying influence. Some of the commoner intrusive types, classified according to form and relation to invaded rocks, are described briefly below.

2.3.1. Plutons

Pluton is a term that embraces all intrusive bodies of igneous rock produced by solidification of large bodies of magma at depths of several km or even tens of km. Plutons believed to have been emplaced at shallower levels in the crust (< 10 km) can usually be seen to be discordant, whereas deeper plutons tend to be concordant with the structure of their country rock. Several types of plutons have been identified on the basis of their size and geometry (Figure 1).

- *Laccoliths* (Greek: *lakkos*, a cistern; *lithos*, stone) are sheet-like bodies with a flat base and domed roof, above which the invaded strata have been arched concordantly at the time of intrusion.
- *Phacoliths* (meaning lens rocks) are curved, lensoid masses injected along and concordant with the arches and troughs of folded strata. They may be described as saddle-shaped laccoliths.

- *Lopoliths* (Greek: *lopos*, basin) are roughly sheet-like or funnel-shaped bodies with upper and lower surfaces that are concave upwards, the general configuration being connected with sagging of the floor rocks under the load of the thickening intrusions.
- *Batholiths* (Greek: b*athos*, depth) are intrusions with surface outcrop areas in excess of 100 km^2; they are discordant, usually composite, with steeply inclined walls and without any visible floor. They are very large features, the size of mountain ranges, and are typically composed of felsic rocks (granite, granodiorite, and related rocks).
- *Stocks*: These are similar in form and composition to batholiths but are smaller in size (with outcrops less than about 100 km^2.).

2.3.2. Minor Intrusions

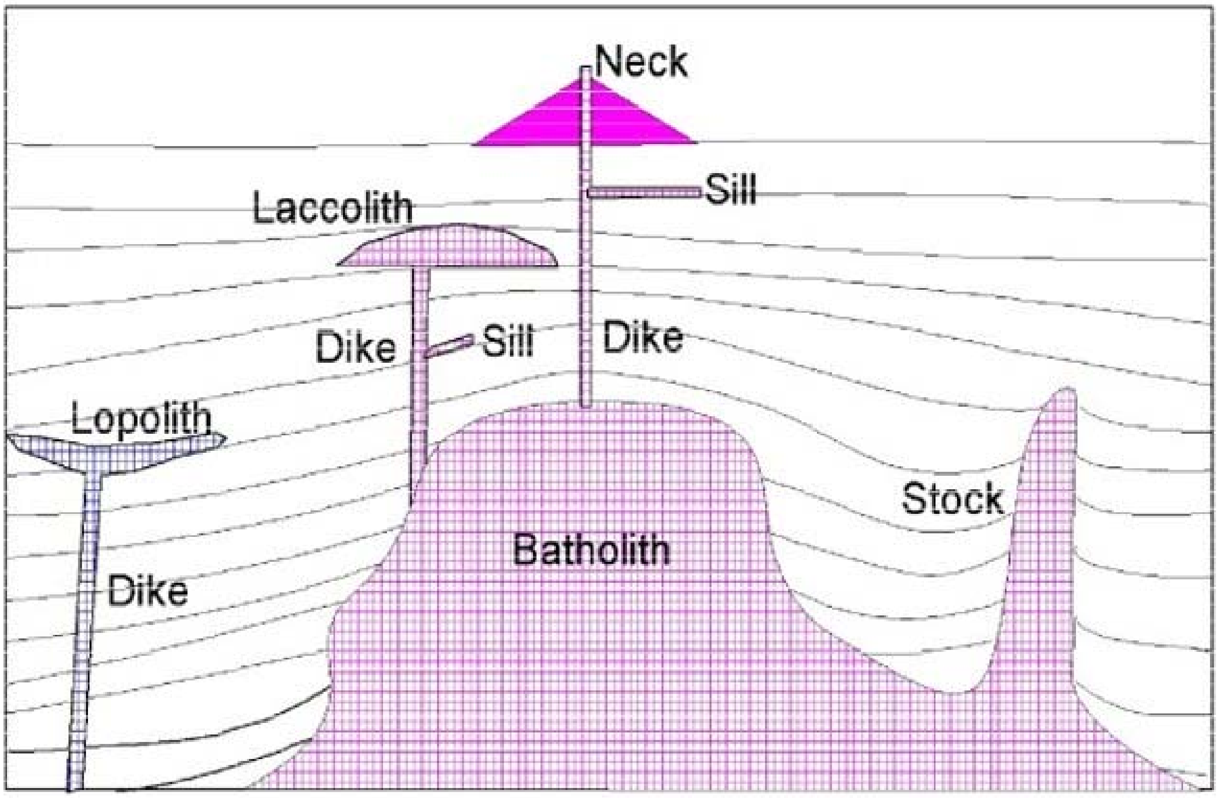

Figure 1. Cartoon showing occurrence of major types of intrusive body

A minor intrusion is any intrusion too small to be classified as a pluton. Many of these are emplaced at shallow depth, within a few kilometers of the surface, and very often reveal links between plutonic and volcanic activity. A number of types are distinguished on the basis of their geometrical form.

- *Dikes*: These are tabular, often vertical or steeply inclined sheets that cut across the trend of structure (for example, bedding planes, cleavage planes) of the invaded rocks. Dikes tend to occur in swarms, in parallel mode or radiating from a common center.

- *Ring dikes*: These are steeply inclined dikes of arcuate outcrop, formed by the uprise of magma along major steeply conical or cylindrical fractures bounding central collapsed blocks.
- *Plugs or necks*: These are steep pipe-like bodies with relatively small cross-sections, less than 100 m in diameter; many are conduits of volcanic vents.
- *Sills*: These are generally horizontal tabular or sheet-like intrusions that are mostly concordant with and thus injected along the major structure (for example, bedding or foliation) of the invaded rocks. They can measure hundreds of meters in thickness and extend laterally for many kilometers.

2.3.3. Layered Intrusions

These are usually large plutonic rock bodies characterized by prominent phase layering. The name is traditionally applied to mafic and ultramafic intrusions. These bodies are commonly funnel-shaped, and characteristically show pervasive mineral layering that is discordant with the walls of the funnel.

Single layers range from millimeters to hundreds of meters in thickness, and from meters to tens of kilometers in lateral extent.

Layering is most conspicuously defined by variations in relative proportions of minerals. Gradational variations within a single layer, from top to bottom, may be obvious. Sorting of minerals by mineralogy or by grain size may show layering. Other types of layers show no sorting and are essentially isomodal throughout, standing out by virtue of their contrast with adjacent layers.

The rhythmic alternation of sorted or isomodal layers is the most visible aspect of layered intrusions. The Bushveld complex in South Africa is a typical layered intrusion, exposed over an area of 65 000 km^2 with a thickness of up to 7 km.

3. Texture of Igneous Rocks

By “texture” is meant the general physical appearance of a rock, especially the size, shape, and arrangement of constituent mineral grains. It is generally defined as the geometrical relationship among the component minerals of a rock and any amorphous materials (glass or gas in cavities) that may be present.

Understanding igneous textures involves understanding crystals; what they are, how they form and what controls their numbers, shapes, and sizes. Thus crystals may be *euhedral*, *subhedral*, or *anhedral*; they may be relatively large or small, and they may exhibit a great diversity of form ranging from regular forms with planar faces to skeletal crystals, and from highly *inequidimensional* to *equant* forms.

In addition, crystals may be *twinned* or *zoned*, and one mineral may be *intergrown* with another. The reason for such diversity is in part found in the variety of circumstances that lead to crystallization, including the cooling of magma, devitrification of glass, production of new stable phases concomitant with the breakdown of unstable material, and precipitation from solution.

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Biographical Sketch

Dr. Gezahegn Yirgu, born in Addis Ababa in 1951, is currently Associate Professor of Igneous Petrology and Geochemistry at the Department of Earth Sciences, Addis Ababa University. He obtained his B.Sc. in 1977, his M.Sc. in 1980 in Geology from Addis Ababa University, and his Ph.D. in Igneous

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