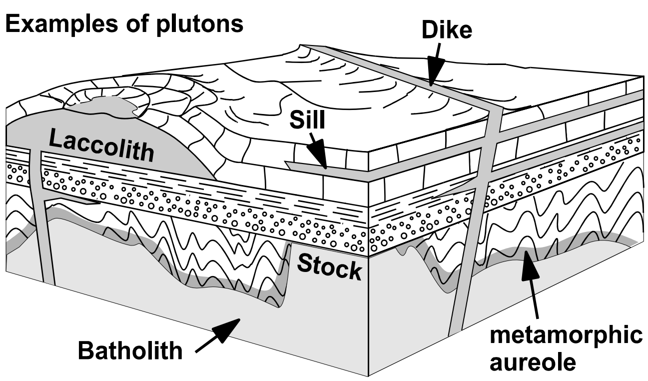
a12 Classification of igneous rocks < L. *ignis*, fire >

To prove his 1939 theory that the eruption of Mount Thera brought about the end of the Minoan Civilisation, Professor Spyridion Marinatos started excavations in Akrotiri in 1967 and uncovered an abundance of well-preserved architecture, pottery and murals.[1]

Igneous rocks if crystalline are classified (***Figure a12.1***) according to the dual-criterion of color (mineral composition) and texture (volcanic or plutonic).

The color of a crystalline igneous rock can indicate the proportions in it of one or more of the eight *essential minerals* (quartz, orthoclase, plagioclase, muscovite, biotite, amphibole, pyroxene, and olivine) for its classification. Usually present, at less than one percent and often too small to be noticed in a hand specimen are *accessory minerals* such as apatite, garnet, ilmenite, magnetite, rutile, sphene, and zircon.

Textural varieties of igneous rocks range from natural glasses to those more commonly composed of an interlocking mosaic of crystals. Field and laboratory observations find the size of igneous-rock crystals is determined by a lava's or a magma's rate of cooling, composition (which determines viscosity at given temperatures), and volatile (water, carbon dioxide, sulfur, chlorine, and fluorine) content. The word *lava*, by general usage, can refer to a molten extrusive or the rock that is solidified from it. Sometimes, the retronyms *molten lava* or *lava rock* need to be used for clarity of meaning. Glasses (with a liquid's disordered molecular structure and a solid's rigidity)[2] are volcanics or country-rock contact margins of an intrusive that were chilled (quenched) too fast for amorphous-to-crystalline state transitions to occur.[3] Crystalline volcanic rocks are typically *aphanitic* (fine grained) but thick flows of molten lava can solidify as lava rock with coarse-grained interiors. Intrusive igneous rocks are typically *phaneritic* (coarse grained) as the total surface energy (vapor pressure) of a crystal, which decreases with size, and diffusion, given time, lets the larger grow at the expense of the smaller (the "capitalistic principle!" or, more correctly, by an Ostwald ripening mechanism).[4]



Volcanic igneous rocks have been seen to originate from volcanoes as lava (extrusive magma) and tephra (eruptive pyroclastics), and so their origin is not in doubt. Field relationships can sometimes show that an igneous rock was formed from the cooling of an intrusive magma.[5] Such are called *plutonic igneous rocks*. They are phaneritic rocks (which look granular, either sugary or crystalline, everywhere). As a result they look different from aphanitic rocks (which look dull or earthy in their parts between any visible crystals).

Most igneous rock were named long before their origin was known. Thus, igneous rocks of the same composition, but markedly dissimilar appearance, usually have different names (***Figure a12.2***). For example, basalt and gabbro have the same composition (both are dark (melanocratic) in color, 20% > CaO + MgO > 12%) but have a different texture (aphanitic and phaneritic respectively). Rhyolite and granite are such a pair but they are light in color (in thin section the predominant minerals: quartz and feldspar, are seen to be leucocratic). Should decisive field relationships be absent, aphanitic and phaneritic igneous rocks are deemed to be volcanic and plutonic respectively. This is not a hard and fast rule. For example, an igneous rock of the composition and texture of basalt is correctly called "basalt" be it an extrusive flow *or* an intrusive dike or sill. Plutonic igneous rocks can be named after estimation in the hand inspection of the proportions of quartz or feldspathoids if quartz is not present, plagioclase (Ca-Na feldspar), and syenite (K-feldspar) (***Figure a12.3***).

Igneous rocks in all their variety are derived, although most are many steps removed, from peridotite. Partial melting during heating, or fractional crystallization during cooling, results in magmas between the crystalline solids that are more siliceous than the whole. Magma can either exit when it more than interstitially wets crystals or it can separated out as crystals immersed in it sink or float. These processes are collectively called *magmatic differentiation*. The derived magma and the residual rock will differ in composition from the original rock. Magmatic differentiation can operate again on either a residual rock or a derived magma. Each time, igneous rocks result with compositions different from what was before. This was first, convincingly, explained in terms of crystal-melt reactions by **Norman Levi Bowen** in his book *The Evolution of the Igneous Rocks*, 1928.[6]

Norman Levi Bowen (1887-1956)[7] Geophysical Laboratory, Washington, D.C., policy mandated that Bowen retire at 65 years of age. Depressed, although invited back as a Research Associate, Bowen to the distress of his wife committed suicide.[8]

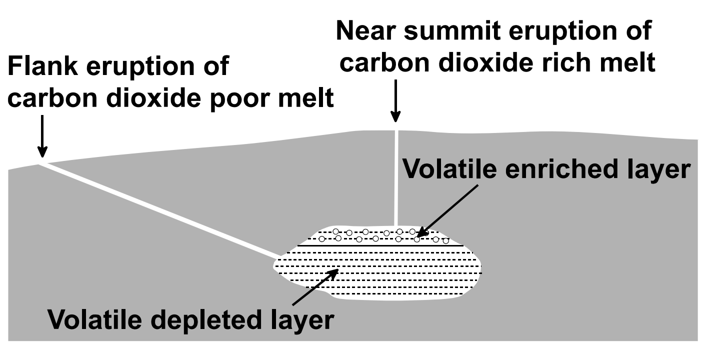
Bowen's reaction principle is that in a cooling magma, changing equilibrium conditions allow:

(1) some minerals to appear and disappear in a *discontinuous reaction series*. For example, olivine that crystallizes at a high temperature dissolves in the magma at a lower temperature when at the same time pyroxene crystallizes. This, in turn, at a lower temperature dissolves and amphibole crystallizes, and this, at a lower temperature, dissolves and biotite crystallizes.

(2) some solid-solution minerals, upon crystallizing, change their composition in a *continuous reaction series*. For example, calcium-rich plagioclase feldspar changes by a continuous diffusion of cations between magma and mineral to become sodium-rich plagioclase feldspar.

(3) some minerals after crystallizing not change in their overall composition. Examples are: alkali (K, Na) feldspar (which crystallizes at moderately high temperature and restructures to become a perthitic [orthoclase and exsolved albite] feldspar at lower temperature), and muscovite and quartz (both of which crystallize at relatively low temperatures). ❑

Figure a12.1 Magmas can hold in solution significant volumes (up to 10 %) of dissolved volatiles: predominantly water in acidic and intermediate magmas and with a large component of carbon dioxide in basaltic magmas. Pressure in a subterranean magma chamber remains at that imposed by the overburden as the magma cools except under circumstances that gas exsolves (comes out of solution) to increase the pressure on the magma and trigger an eruption.



"First boiling" is when decompression allows volatiles to exsolve (bubble free) in a magma risen from greater and hotter depths where its source rock melted or partially melted or when cracking of its magma chamber roof allows venting. A process called "second boiling" is when, cooling and crystallization of a magma causes it to boil. This latter can happen at depths of as much as ten kilometers because the high-temperature silicate crystals which first form even under high confining pressure in a cooling magma do not incorporate volatile chemical species in their structures. Either boilings can occur and recur at different times. The roof of a magma chamber is at the height to which the magma can rise buoyantly.[9]

Figure a12.2 [10] Compositions and textures of some common volcanic and plutonic igneous rock

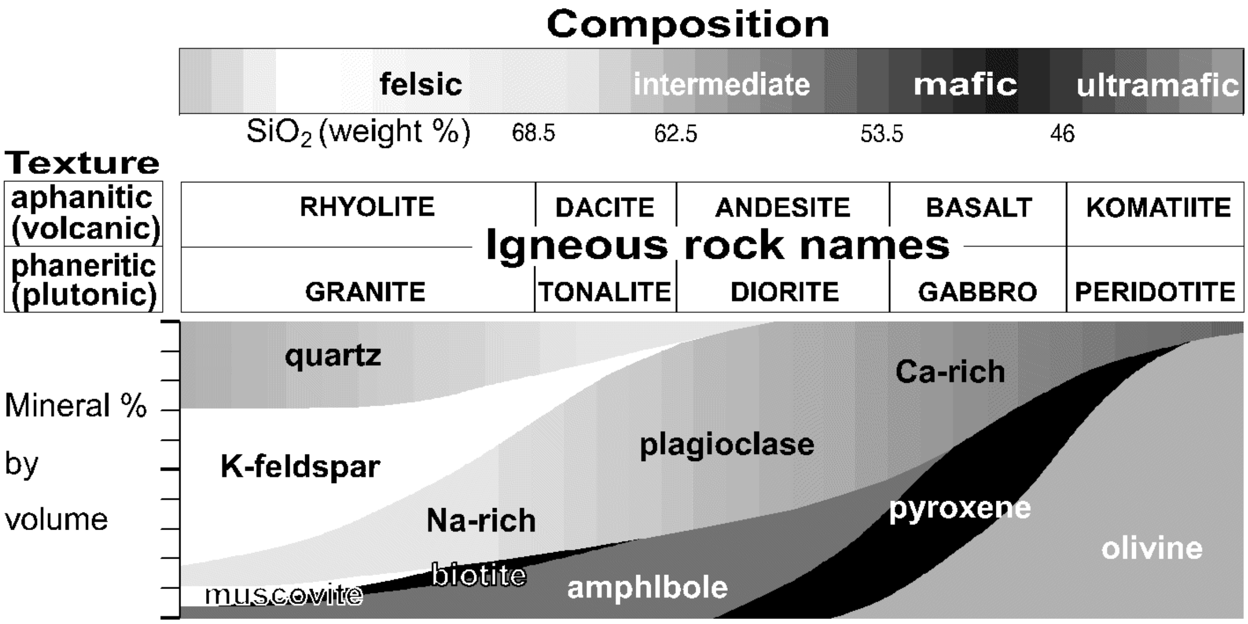


Figure a12.3 [11] Mineral compositions of some common plutonic igneous rocks