a14 Classification of metamorphic rocks

< confining pressure, directed pressure, grade, facies >

> Much of the mystery about the jade trade concerns just how a trader judges the quality of something encased in a rust-like oxidation skin so dense it hides all traces of color. Traders will often wet the surface of a boulder to better see the color lurking within. They also utilize small metal plates and penlights. The plate is placed on the surface at a likely spot and a penlight shone through from the side furthest from the eye. This reveals color in the absence of glare from the light. Traders and miners look for something they call *pyat kyet* (literally ‘show points’), which are areas where the skin is thin enough to see through. ... how do miners separate the quite occasional jade boulder from the thousands of others they also dig up that look so completely similar? ... The diggers examine the boulders, give each a sharp rap with a hammer, then discard the unworthy. Patience, patience, clank, clunk, hammer against stone, patience, patience, hurry, hurry, discard, discard, and so it goes, hundreds of times.
>
> —Richard W. Hughes & Fred Ward.[1]

Minerals that make up a rock are stable only within certain bounds of temperature, pressure, and chemical environment variations. Outside of these ranges, minerals will recrystallized, or react with each other, and so become replaced by other minerals. Such adjustment below Earth’s surface is called *metamorphism*. (Adjustment at Earth’s surface is called *weathering*.) Metamorphic reactions at lithospheric pressures less than 1.2 GPa (which exists at a depth of ~100 km) require the presence of a mediating fluid (usually water or carbon dioxide) and will not occur if the rock is dry.

Metamorphic means *changed in form*. A metamorphic rock is so recrystallized that any original rock fabric is no more. If not, the prefix *meta*- is applied to the rock’s original name.

When an increase or decrease in ambient temperature is solely responsible for the recrystallization of a rock, the metamorphism is called *contact metamorphism* (because the country rock shows progressive alteration in mineralogy and texture towards its contact with an intrusive igneous rock). Fluids released from a cooling magma can also promote metamorphism. Recrystallization occurs under conditions of lithostatic (non-directed, confining) pressure. The texture of a contact-metamorphic rock is typically *non-foliated* and can look like that of a crystalline igneous rock, but minerals uncommon in igneous rocks can be present and be diagnostic of metamorphism.

When deformation due to directed pressure accompanies or causes the recrystallization of a rock, the metamorphism is called *regional metamorphism* (because the country rock shows alteration in mineralogy and texture in “regions” of present or past fold-mountain building). The texture of a regional-metamorphic rock is typically *foliated* and can look like that of a layered sedimentary rock but with the noticeable difference that its grains are interlocking crystals. Deformation grades from dynamic to dynamothermal, that is, from brittle breakage or crushing (mylonitization) at shallow depths, to ductile recrystallization at high pressures and temperatures (***Figure a14.1***).

Shale is a sedimentary rock made of clay. This mineral, stable (being the product of weathering) at surface temperature and pressures, is replaced by its recrystallization to other minerals at higher temperature. In 1893, George Barrow (1853-1932) discovered that shale traced to where granite has intruded it, changes in its texture and mineral content toward the contact with the igneous rock. He reasoned that the temperature under which the “contact” metamorphic change occurred would have increased in the direction of the igneous rock. Going toward the igneous rock contact, Barrow mapped zones of distinctive minerals in the sequence: chlorite, biotite, garnet, staurolite, kyanite, and sillimanite. All seemed well, but association not proof and the granites in the region of Scotland he studied are now known to be younger than the metamorphism. However, these readily identifiable minerals do in fact record increasing temperature of crystallization (grade) of metamorphism for each zone. The outer part of a zone where an index mineral first appears also marks where a certain temperature was reached. For each index mineral, a line drawn on a map joining such points is called an *isograd* (same grade).[2] To include pressure variation, in addition to temperature variation (***Figure a14.2***), Pentii Elias Eskola (1883-1964) in 1929 defined a metamorphic mineral *facies* as comprising all the rocks that have originated under temperature and pressure conditions so similar that a definite chemical composition results in the same set of minerals.[3] ❑

Figure a14.1

Fold-mountain metamorphic facies and styles of deformation (*after* W. R. Church)[4]

Prograde metamorphism results in water being lost. Retrograde metamorphism or metasomatism of dry rocks can occur when a fluid as H_2O or CO_2 passes through as a catalyst or enters to be a chemically bonded component of recrystallizing minerals.

Historical note: Folds are easily understood to record crustal shortening but boudinage, which results from stretching of the same, was ignored until a physical theory was devised for how strata of different competences deform as a sandwich under general conditions of stress (illustrating the wry adage that you should never trust a fact until it's been confirmed by theory).

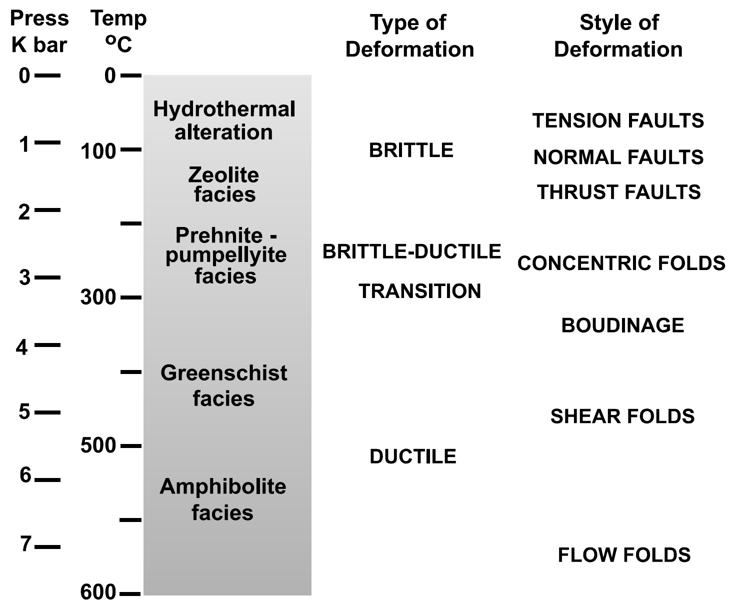

Figure a14.2 **P-T diagram of metamorphic facies** [5]

The wet-granite melting curve is the edge of the dark gray area (*Note*: an ascending wet-granite magma can decompression freeze). Mineral fields outlined are for when load and water pressures are equal. Metamorphic facies shift to lower temperatures when water pressure lessens. Pressure and depth is for a 2.8 gm/cc crust.

Three common prograde series are:

1) From moderate to high temperatures at low pressures (the albite-epidote hornfels, hornblende hornfels, pyroxene hornfels, and sanidinite facies) which is so of contact-metamorphic aureoles, or of xenoliths in mafic igneous rocks.

2) Increasing temperature and pressure (the zeolite, greenschist, amphibolite, and granulite facies) typical of regionally metamorphosed orogenic belts.

3) Very little increase of temperature despite a marked rise in pressure (the prehnite-pumpellyite, blueschist, and eclogite facies) that results from subduction.

Exceeding Nature at low pressure, a potter's kiln fires (recrystallizes) common clays to earthenware at 900-1150 ºC, to stoneware at 1,250 ºC, and higher again, at about 1280-1300 ºC, causes the clay kaolinite, $Al_2Si_2O_5[OH]_4.2H_2O$ (named after the locality in China called *Kauling*, meaning "high ridge" where it was originally found), to recrystallize as the quartz and andalusite of white china. Higher temperatures cause partial melting and, thereby, upon rapid cooling, porcelain.