May 17, 2021

Clay Minerals

Figure 1 - Ming Vase

Credit: Gary Todd, Creative Commons CC0 1.0 Universal Public Domain Dedication

You might be thinking: What does a Ming Vase have to do with a blog on geology? The simple answer is that while clay minerals are complex and fascinating, they are often dull and not very pretty. However, clay can be made into beautiful things.

Weathering - Where Clay Minerals Come From

Unlike the other rock forming minerals that I've discussed in this blog, clay minerals were not created in the heat and pressure that gave us the minerals in igneous and metamorphic rocks. Clay minerals, along with sand and carbonate minerals, are the result of weathering processes that took place under the temperatures and pressures we have at the Earth's surface. Burial and compression of clay deposits create mudstones and shales, however the clay minerals themselves are the product of surficial weathering.

Weathering of rocks can be broken down into two main processes: physical weathering and chemical weathering. Physical weathering is the breakdown of rocks by forces such as water erosion, wind erosion, biological action, frost fracturing, and heat stress fracturing. Chemical erosion begins with the simple fact that carbon dioxide dissolved in rain water is slightly acidic. this slight acidity, a pH just under the neutral pH of 7, will gradually dissolve minerals. the chemical excretions of living things can also cause chemical weathering.

Some minerals are more susceptible to weathering than others. The relative chemical stability of minerals was discovered by Norman Bowen when he investigated the melting and crystallization of igneous rocks. Originally published in 1928, as The Evolution of the Igneous Rocks (Anniversary Edition, 1956, Dover Publications, New York) Bowen's work showed a definite pattern of crystallization of minerals out of a magma now called the Bowen Reaction Series. Research by Samuel S. Goldich, originally published in The Journal of Geology, Vol. 46, No. 1, Jan. - Feb. 1938 (behind a pay wall), showed a pattern in the weathering of the minerals that mirrored Bowen Reaction Series, this weathering pattern is now called the Goldich Dissolution Series. In the Goldich Dissolution Series, the minerals at the top of the Bowen's Reaction Series, such as olivine and calcium rich plagioclase, are the first to weather whereas the minerals near the bottom, the minerals with the lowest melting point, are the most resilient to weathering. The explanation is due to their chemistry: the ionic bonds in the minerals most likely to weather are weaker than those in the more resilient minerals. Combining the two series, we get the diagram shown in Figure 2.

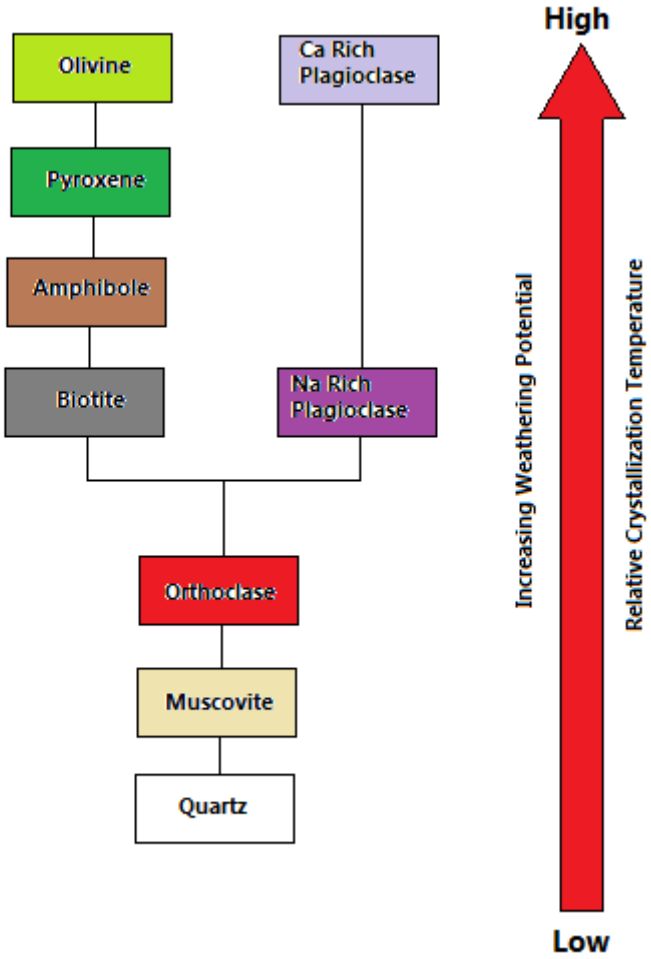

Figure 2 - Combined Bowen Reaction Series & Goldich Dissolution Series (by author)

Clay Mineral Structure

Clay minerals are similar to mica in that they are sheet silicates. In case of clay minerals, they are made up of hydrous aluminium sheet silicates containing variable amounts of iron, magnesium, alkali metals, alkaline earths, and other cations. The key is the water (the hydrous bit), clay minerals bind up water in their crystal matrix, as in Figure 3.

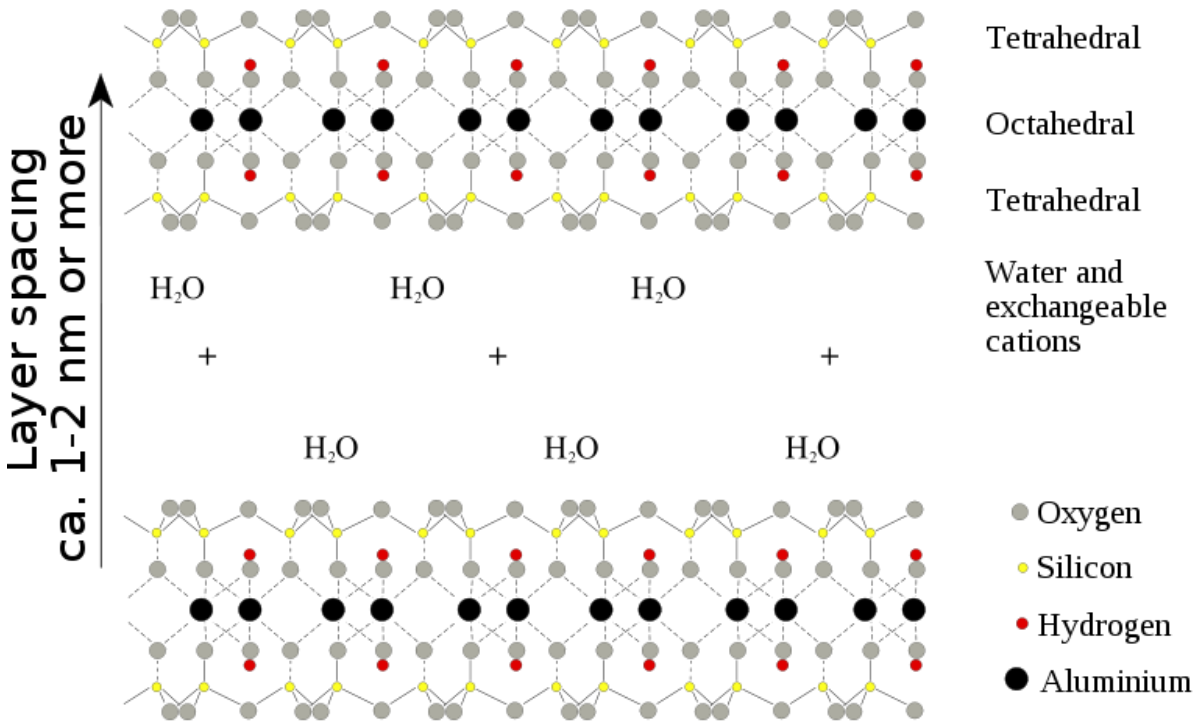

Figure 3 - Atomic Structure of Montmorillonite Clay

Credit: Andreas Trepte, Creative Commons Attribution-Share Alike 2.5 Generic

Common Clay Minerals

Kaolinite

Figure 4 - Kaolinite

Credit: USGS Minerals and Materials Photo Gallery, public domain

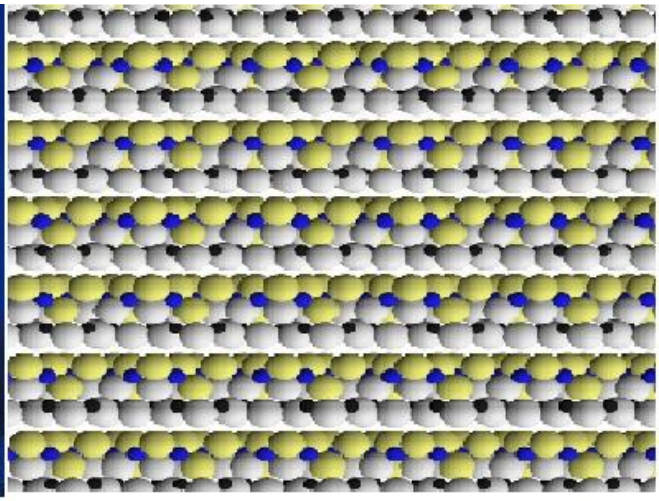

Figure 5 - Kaolinite Atomic Structure

Credit: Kent G. Budge, Creative Commons CC0 1.0 Universal Public Domain Dedication

Named after the type locality, Gaoling Mine in China, Kaolinite, $Al_2(Si_2O_5)(OH)_4$, is generally white, but can also have red, brown or bluish tints. Kaolinite is formed from the hydrothermal alteration of feldspars, feldspathoids and other silicates under slightly acidic conditions. Kaolinite is usually found in massive deposits of the mineral. Kaolinite is one of the most important clay minerals for pottery production, especially for white coloured pottery such as fine china.

Illite

Figure 6 - Illite

Credit: Mindat.org, Creative Commons Attribution 3.0 Unported

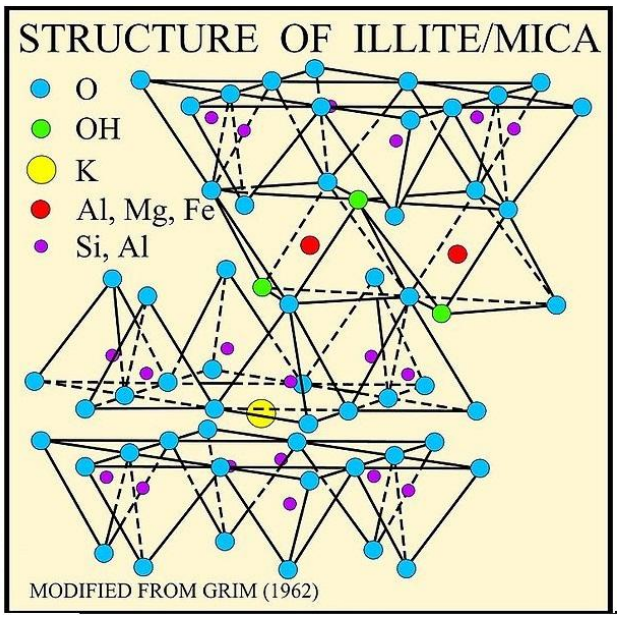

Figure 7 - Illite Structure

Credit: USGS, public domain

Illite, $K_{0.65}Al_{2.0}[Al_{0.65}Si_{3.35}O_{10}](OH)_2$, is a pale coloured mineral, varying from gray-white to silvery-white to greenish-gray. It is the dominant mineral in shales and mudstones. Illite is derived from the weathering of feldspars and other silicates under alkaline conditions. The structure of illite resembles that of mica and is considered a variety of muscovite for that reason.

Illite is named after Illinois, where the type locality, the Maquoketa Shale is found.

Montmorillonite

Figure 8 - Brushite-Montmorillonite

Credit: Leon Hupperichs, Creative Commons Attribution-Share Alike 3.0 Unported

Also called smectite, montmorillonite, $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$, varies in colour from white to buff to yellow to green and sometimes pale pink to red. It is formed by the alteration of volcanic rocks such as tuff and volcanic ash. Montmorillonite is the principle component of bentonite. Montmorillonite was named after the type locality in Montmorillon, France.

Vermiculite

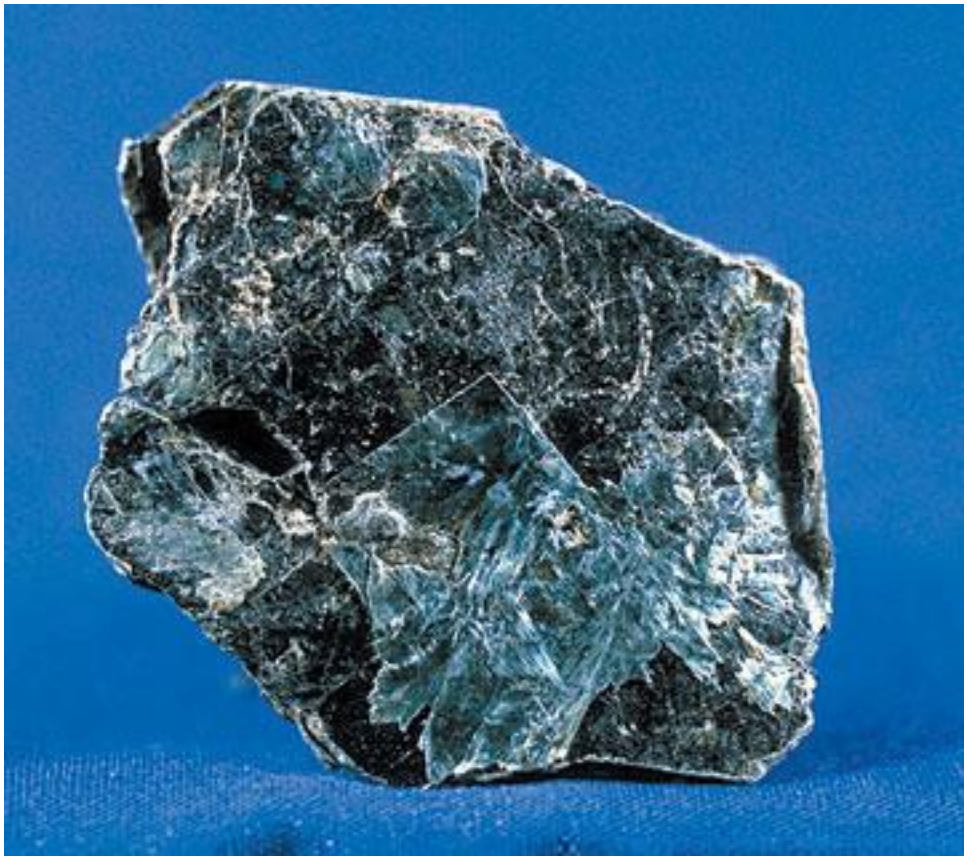

Figure 9 - Vermiculite

USGS Minerals and Materials Photo Gallery, public domain

Vermiculite, $Mg_{0.7}(Mg,Fe,Al)_6(Si,Al)_8O_{20}(OH)_4 \cdot 8H_2O$, can occur in the contact between felsic intrusive rocks and mafic or ultramafic rocks or it can be formed by the hydrothermal alteration or weathering of biotite. Yellow, green and/or brown in colour, it forms worm-like structures when heated up, hence the name.

Uses of Clay

The United States Geological Survey Mineral Commodity Summaries 2020 lists the following kinds of clay produced or imported into the United States:

- Ball clay
- Common clay
- Bentonite
- Fuller's earth
- Fire clay
- Kaolin

Ball clay and common clay are used to make such items as porcelain, floor and wall tiles and sanitary-ware (toilets, urinals and sinks). Bentonite is used mostly for kitty litter and drilling mud. Fuller's earth is a form of montmorillonite clay used in textile production, decontamination, food production (look for aluminum silicate on the ingredients label) and cosmetic clay. Fire clay is used to make cement and refractory brick. Kaolin is used in the production of fine porcelain and to make glossy white paper.

Vermiculite, noted above, is best known for its use as insulation. Natural occurrences of vermiculite in nature usually have a small amount of asbestos. Inhaling asbestos fibres can lead to mesothelioma, usually around 30 years after the initial exposure. If you have vermiculite insulation in your attic, **don't mess around with it** unless you are wearing the proper personal protective equipment (PPE).

Further Studies

I have barely scratched the surface in discussing clay minerals; there is an immense body of knowledge on the subject of clay minerals. Some geologists spend their whole career studying them.

If the subject interests you, Internet searches alone into clay and clay minerals can lead you deep into a rabbit hole of published scientific investigations. There is also *The Clay Mineral Society* with an accompanying *Clays and Clay Minerals* journal.

Or you can just be a child again, and play in the mud.

Standard Caveat

The purpose of my weblog postings is to spark people's curiosity in geology. Don't entirely believe me until you've done your own research and checked the evidence. If I have sparked your curiosity in the subject of this posting, follow up with some of the links provided here. If you want to, go out into the field and examine some rocks on your own with the help of a good field guide. Follow the evidence and make up your own mind.

In science, the only authority is the evidence.