

Mineralogy Boot Camp Session #11

Crystal Growth

This session of Mineralogy Boot Camp deviates from our ongoing descriptions of mineral groups to discuss a basic feature of mineralogy, as well as other sciences: How and why do solid substances like minerals form in the first place? To begin with, it's important to understand that the term *crystal* applies to any relatively homogeneous solid with an ordered internal (atomic) structure. The term applies to all such materials, not just those with a visible crystal face. *Amorphous* solids are those that lack this internal order, such as glass. By definition, a mineral must have an ordered atomic structure, thus amorphous solids like obsidian and amber are not considered true minerals.

Studies of crystal growth developed rapidly during the first half of the 20th century, when the electronics industries (particularly radio) created high demand for quartz oscillator plates. Suitable quartz needed to be of high purity, and natural sources were unable to meet the demand. Laboratory-grown quartz became a critically important source, and understanding crystal growth moved from being theoretical to quite practical.

Atoms in liquids and vapors occur in a random arrangement, and have the ability to easily move within the substance. Changes in the temperature, pressure, and atomic abundance (concentration) may cause atoms to join together in an organized solid because this crystalline state actually represents a lower energy state, which is a more stable situation.

The first stage of crystal growth is *nucleation*. A nucleus (or *seed*) forms when the atoms join together to form an initial structure pattern. Many of these nuclei will dissociate back into solution because heat causes atoms to vibrate and they will push away from each other. Attraction forces on a nuclear level (like between positive- and negative-charged ions) will bring these atoms back together again, and as the temperature drops these attraction forces will dominate over the vibration forces. As a result, tiny seed crystals will form and remain stable at particular favorable sites. Crystals will enlarge in size because it's easier for atoms to attach to an existing crystalline structure rather than form a new seed crystal. Figure 1 is an explanation of how atoms can join an existing crystalline framework. Crystallization will not necessarily start at the same temperature, because a site of nucleation is required before a crystal will grow. See Figures 2A and 2B for an example of the importance of nucleation sites (and the rate of temperature drop) in the growth of the mineral ice.

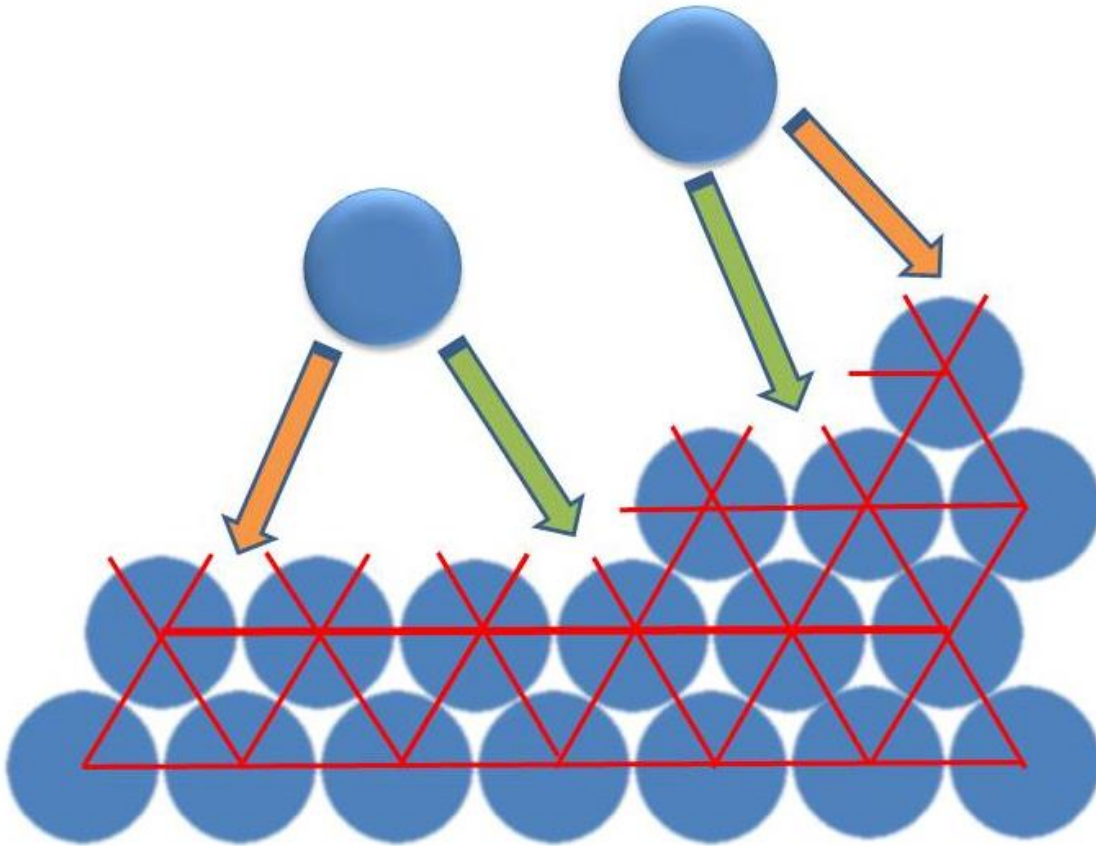


Figure 1. This is a simplified example of how crystals grow by the addition of atoms dissolved in a solution. The blue circles represent atoms. The red lines indicate atomic bonds holding the crystalline structure together. Short red lines projecting out of the crystalline structure represent available bonds that can attract passing free ions. Two atoms are approaching the structure and will join it, but most likely at particular sites. In both cases the atoms will tend to attach at the site shown by the green arrow because there are three bonds available, creating a stronger structure. The orange arrows indicate less likely sites, because only two bonds are available to hold the new atom in place. The “step” position shown by the green arrow sites allows the crystal to grow faster than might otherwise be expected when having atoms just randomly join any location. In three-dimensions, this “step” growth pattern results in crystal faces growing in a corkscrew or spiral fashion rather than simply adding flat atomic layers one on top of another.



Figure 2A. The wiper streaks on this windshield provided the proper nucleation sites for ice to form once the temperature got cold enough to precipitate water vapor out of the atmosphere and form ice. This pattern of mineral growth most likely was the result of a very slow drop in atmospheric temperature.



Figure 2B. A close-up view of the windshield in Figure 2A showing how ice prefers growing outward from the initial sites of nucleation along the streaks, rather than starting new nucleation sites scattered randomly all over the glass surface. This pattern of mineral growth is referred to as a *dendritic* habit.

Common changes in environmental conditions resulting in crystallization include removal of the fluid (such as evaporation of water), lowering of the temperature (resulting in freezing), and decreasing the pressure (such as eruption of magma). Probably the most common cause of mineral formation is a temperature decrease. A rapid drop in temperature, as shown in Figure 3, often results in a finer-grained texture because the atoms in solution must rapidly find a place to join a crystalline framework.



Figure 3. Very fine-grained ice crystals (frost) formed on this windshield because the atmospheric temperature dropped rapidly during the night. Parts of the glass are covered with larger ice crystals (lower left) creating a design above the wiper during earlier parts of the evening, but as the temperature dropped rapidly toward dawn, the ice formed a multitude of nucleation sites leading to a more uniform appearance of tiny crystals. Compare this with Figure 2B, where the atmospheric temperature likely dropped at a much slower rate, resulting in far fewer nucleation sites with larger crystals.

Figure 4 is a geologic example of two rates of cooling for a particular magma. The large pink crystals grew very slowly while the magma was at great depth and cooling very slowly. The dark surrounding groundmass crystallized when the magma moved upward into a much shallower position, where both the temperature and pressure dropped rapidly. Numerous nucleation sites were created, resulting in a fine-grained texture of tiny crystals.



Figure 4. This igneous rock experienced two separate periods of cooling, resulting in two completely different sizes of crystals. Large pink crystals are potassium feldspar, and the fine-grained groundmass is a mixture of potassium feldspar, plagioclase feldspar, and quartz. Note the clip of a mechanical pencil along the top of the photograph for scale.

The continued growth of a crystal is strongly influenced by various environmental factors and the space provided for these crystalline structures to enlarge. Eventual shapes and sizes of crystals are controlled by processes during the growth history, not just the configuration of the atomic structure. Figure 5 is an example of a situation where the direction of fluid flow carrying dissolved constituents can have a large influence on the overall final shape of the crystal.

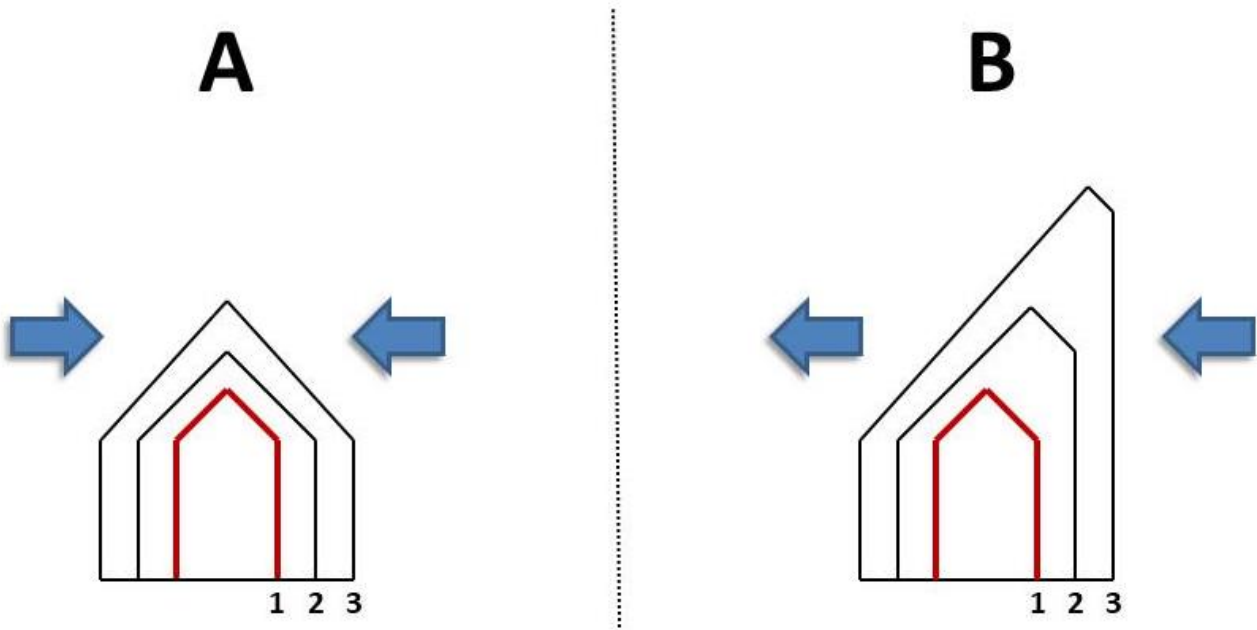


Figure 5. Different crystal faces may grow at different rates depending on the direction of fluid flow (shown by the blue arrows) relative to the position of the crystal. In both situations **A** and **B**, the original crystal at time 1 is shown by the red outline. In situation **A**, fluids are flowing in all directions so that at time 2 and time 3 the various faces grow at the same rate and the crystal maintains its overall original shape. In situation **B**, fluids are flowing consistently from right to left after time 1, resulting in some crystal faces growing faster than others. By time 2, the upper right face has grown faster, resulting in a thicker layer but smaller exposed surface. By time 3, this same face appears even smaller. One counter-intuitive feature of crystal growth is that the fastest growing crystal faces tend to grow themselves out of existence.