20.3 Igneous Rocks

The formation of igneous rocks begins when rock melts below Earth's surface. In this section, you will review how rock melts. Then, you will learn that the length of time for magma or lava to cool affects the size of the crystals in the rock. By the end of this section, you will be able to tell a lot about the history of an igneous rock.

Melted rock

Plastic mantle rock

A good way to describe hot, solid mantle rock is that it is like stiff putty that takes millions of years to move. Material like this is described as being plastic, or able to change shape without breaking.

Pressure and water

You learned in section 20.2 that although mantle rock is very hot, it only melts under certain conditions of pressure and water content. For example, mantle rock melts when it is carried toward the surface at mid-ocean ridges. As the mantle rock rises, the pressure drops and the rock melts, becoming a liquid. Mantle rock also melts near a subducting plate where water is carried into the mantle. Both decreased pressure and the addition of water lower the melting temperature of mantle rock so that it melts (Figure 20.20).

Why is the mantle so hot?

As you learned in Chapter 18, Earth is 4.6 billion years old. As materials came together to form Earth, the collisions from these extraterrestrial impacts generated heat. The interior of Earth is extremely hot because Earth is still cooling from when it formed so long ago. Also, as the denser components of Earth—iron and nickel—sank to Earth's core, there was a conversion of potential energy to heat. In addition, some of the heat inside of Earth is caused by the decay of radioactive elements.

From melted to solid rock

Each of the rocks below is an igneous rock. They are all formed from melted rock; however, they differ in appearance. Why? You will learn the answer to this question in the next few pages.

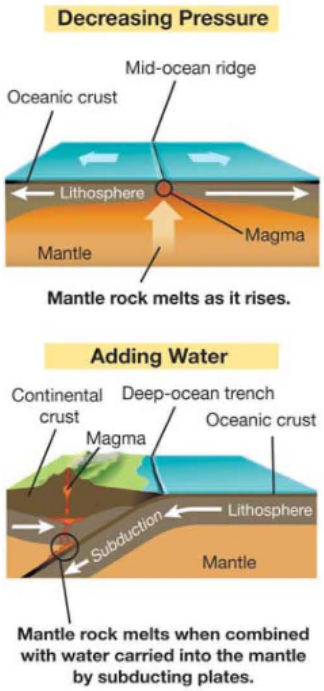


Figure 20.20: *Changes in pressure and the addition of water cause the hot rock in the mantle to melt.*

How are igneous rocks formed?

Where did igneous rocks come from?

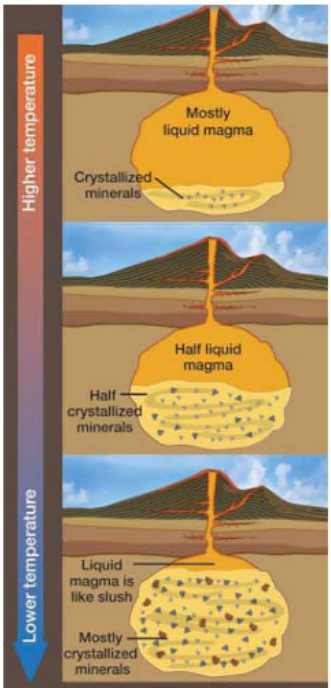
Originally Earth was a ball of material that increased in size as the early planet gathered an ever-larger mass of particles from the gas and dust that formed our solar system. Today Earth's crust, mantle, and core are distinctly different from one another even though each layer was formed from the Earth's original material.What happened to cause similar particles to become the different materials that we find today?

Magma is a complex substance

These different materials and the wide variety of igneous rocks result from changes that take place after magma forms. In the case of a simple substance such as water, the temperature at which it melts is equal to the temperature at which it freezes, or crystallizes; in water's case, 0°C. Magma, however, is a complex blend of many elements and compounds, each with a different melting point. The melting points vary over a large temperature range.

What happens as magma gradually cools?

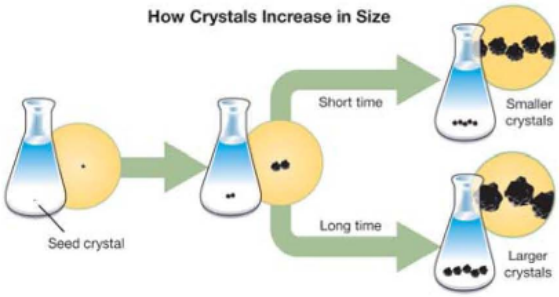
Imagine a magma chamber below Earth's surface. The graphic at right shows a magma chamber at high temperature, but cooling. In the top panel, high-melting-point minerals begin to form crystals. In the middle panel, the magma continues to cool slowly, more of the original minerals crystallize, and new minerals with slightly lower melting points begin to crystallize also. In the bottom panel, the temperature has fallen significantly, the first and second mineral crystals are plentiful, and a third new mineral is beginning to crystallize. At this point, the magma is slushy because there are more solid crystals present than liquid melt. Convection currents within the still-hot magma slowly swirl the crystal slush. It is important to realize that the chemistry of the remaining melt changes as each mineral is removed by crystallization. Toward the end of this process, the remaining melt will produce granite rock. But other rocks might be produced if the crystallization process is interrupted earlier, by the magma erupting, for example.



As minerals are removed from the original magma by crystallization, the remaining liquid changes from a basalt-like, low-silica magma to a more granite-like, high-silica magma.

Crystals in igneous rocks

Crystallization As melted rock cools, minerals in magma or lava form crystals that can be large, small, or microscopic depending on the rate at which cooling takes place. **Crystallization** is the process by which crystals form and increase in size. Crystallization begins when atoms in a liquid begin to collect on the surface of a solid particle called the seed crystal. When there is a long time for atoms to attach to the seed crystal and for the liquid to crystallize, large crystals form. If there is less time, only small crystals form.



Large and small crystals Igneous rocks formed from underground magma have larger crystals and a coarse texture because magma tends to cool slowly. This is because the surrounding ground acts as an insulator, keeping magma warm for a long time. Lava, flowing out of a volcano, tends to cool quickly when it is exposed to the air, cold water, or glaciers. Cooling lava forms igneous rocks with smaller crystals.

Obsidian lacks crystals As you saw on the first page of this section, obsidian is an igneous rock that has no visible crystals. Obsidian, also called volcanic glass, is formed when extruded lava cools so quickly that crystals do not have time to form. The large amount of silica in the lava that produces obsidian forms silica chains that effectively prevent mineral crystals from forming. As a glassy substance, obsidian has sharp edges (as thin as 3 nanometers wide) and has been used to make surgical scalpels (Figure 20.21).

VOCABULARY

crystallization - the process by which crystals form and grow in size.

Figure 20.21: *Often called volcanic glass, obsidian is an igneous rock that lacks crystals.*

SCIENCE FACT

The Big Obsidian Flow

The Newberry Volcano in central Oregon last erupted 1,300 years ago and produced a huge amount of obsidian called the Big Obsidian Flow.

Read more about the Newberry Volcano and write a short report on one of its interesting features.

Interpreting igneous rocks

Igneous rocks tell stories Having read about volcanoes and magma and how igneous rocks are formed, you might be surprised to learn that you can now figure out the story that an igneous rock has to tell. Two characteristics that can be used to interpret the history of an igneous rock are its color and crystal size.

Color One of the most obvious characteristics of an igneous rock is how light or dark it is. The general color of igneous rocks is a measure of the kinds of minerals present. Dark minerals are high in iron and magnesium and have higher melting points than light-colored silicate minerals. Look at the image at the right. The swirl of dark minerals probably formed early in the cooling of a magma chamber, whereas the light-colored feldspar crystals formed from the remaining magma.

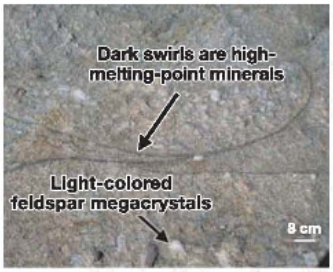


Photo courtesy of Jim Sammons, Sammons' INK

Crystal size As you learned on the previous page, an igneous rock forms when minerals in magma or lava crystallize. Depending on the rate of cooling, the crystals might be invisible, small, or large. Large crystals form when magma cools slowly over a long time. Small to invisible crystals form when magma or lava cools quickly. Pegmatite, featured at the right, is an example of a rock that cooled slowly and formed large, visible crystals.

Pegmatite

CHALLENGE

Interpreting Igneous Rocks

Read the following text, then answer the questions below.

- When you grind up a piece of pegmatite, the powder is light in color.
- Pegmatite forms from mature magma (high silica). High-melting-point minerals are removed from the melt by crystallization as indicated by pegmatite's light color.
- The large crystals indicate slow cooling.

1. In which location listed below would pegmatite be likely to form?
   (a) At a mid-ocean ridge (where pillow lava commonly forms).
   (b) From the lava of a shield volcano.
   (c) Within a sub-surface magma chamber.
2. Describe the color and crystal size of a rock formed from young magma (low silica) that crystallizes slowly.
3. Andesite (a significant component of continents) is midway between granite and basalt in composition. What do you think andesite looks like in terms of color and crystal size?

Comparing igneous rocks

Extrusive and intrusive rocks

On the previous page, you had to determine where pegmatite forms. The correct answer was underground in a magma chamber. Because of where it cooled, pegmatite is an **intrusive rock**, an igneous rock that forms within Earth's crust. Another example of an intrusive rock is granite. An **extrusive rock** is an igneous rock that cools and crystallizes above Earth's surface. Basalt is an extrusive rock. As you might suspect, intrusive rocks are more likely to have large crystals than extrusive rocks (Figure 20.22).

Low-silica rocks: basalt and gabbro

Basalt and gabbro are formed from magma or lava of similar composition. They are silica poor but rich in magnesium and iron. Basalt is formed from low-silica, runny lava. Remember that oceanic crust is made of basalt. When you compare the two silica-poor rocks, you see shiny, angular crystals in the gabbro, but no crystals are visible in the basalt. This tells you that the basalt cooled much faster than the gabbro.

High-silica rocks: granite and obsidian

Both granite and obsidian are igneous rocks formed from silica-rich magma. Granite is made from magma that cooled slowly within Earth. It cooled so slowly that it has large visible crystals. Granite forms much of the continental crust. In contrast, obsidian, formed from lava, is so smooth that it is called volcanic glass. Obsidian contains almost no crystals. Crystals don't have enough time to form in obsidian because the lava cools so quickly.

	No Visible Crystals	Visible Crystals
Low Silica	Basalt 	Gabbro 
High Silica	Obsidian 	Granite 

VOCABULARY

intrusive rock - an igneous rock that cools inside Earth's crust; an example is granite.

extrusive rock - an igneous rock that cools outside of Earth's crust; an example is basalt.

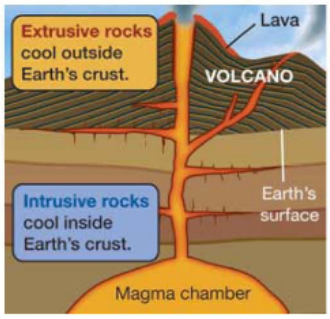


Figure 20.22: *Extrusive and intrusive rocks.*

SCIENCE FACT

Granite for Your Kitchen

Granite is commonly used for kitchen counters. Find out why.

Section 20.3 Review

1. The rock of the mantle is described as being plastic. Why?
2. List two factors that cause mantle rock to melt.
3. The interior of Earth is extremely hot. Explain why.
4. Is magma a simple or a complex substance? Provide a piece of evidence that supports your answer.
5. Multiple choice: The melting point of iron is 1,535°C. What happens when iron reaches this temperature?
   a. Solid iron melts.
   b. Liquid iron freezes.
   c. Liquid iron evaporates.
   d. All of the above.
   e. Only (a) and (b) are correct.
   f. Only (a) and (c) are correct.
6. What is crystallization? Explain why the rate of cooling affects the size of the crystals that form.
7. Why is obsidian called volcanic glass?
8. An igneous rock has very large crystals. Describe a possible history of this rock: Where was it formed? How was it formed?
9. An igneous rock sample has light-colored minerals and a few dark-colored minerals. Which of these minerals formed first? Why?
10. What is the difference between an intrusive and an extrusive igneous rock?
11. Compare and contrast gabbro and granite.
12. Design and fill in a table that compares and contrasts basalt and granite. To design your table, first decide on the properties you will use to compare the rocks. For example, one property might be "density."
13. Iceland is located on the Mid-Atlantic Ridge. Would you expect to find igneous rocks in Iceland? What kinds of igneous rocks might you find? Explain your answer.

SCIENCE FACT

Magma vs. Lava

You might be wondering why there are two different names for molten rock. Do they have different names just because they are in different locations? Not exactly.

You know that magma is present below Earth's surface, and lava refers to magma that has reached Earth's surface.

Although lava is derived from magma, it does differ in its composition because it has less dissolved gas, including water vapor.

So, in fact, magma and lava *are* different and not just because they are in different locations.

One of the methods that scientists use to study volcanoes is lava sampling, which can be dangerous. Find out about this method and what kind of information is learned from it.

Photo courtesy of USGS