7.1: Controls Over Metamorphic Processes

The main factors that control metamorphic processes are:

- the mineral composition of the parent rock,
- the temperature at which metamorphism takes place,
- the amount and type of pressure during metamorphism,
- the types of fluids (mostly water) that are present during metamorphism, and
- the amount of time available for metamorphism.

Parent Rock

The parent rock is the rock that exists before metamorphism starts. Sedimentary or igneous rocks can be considered the parent rocks for metamorphic rocks. Although an existing metamorphic rock can be further metamorphosed or re-metamorphosed, metamorphic rock doesn’t normally qualify as a “parent rock”. For example, if a mudstone is metamorphosed to slate and then buried deeper where it is metamorphosed to schist, the parent rock of the schist is mudstone, not slate. The critical feature of the parent rock is its mineral composition because it is the stability of minerals that counts when metamorphism takes place. In other words, when a rock is subjected to increased temperatures, certain minerals may become unstable and start to recrystallize into new minerals.
Temperature

The temperature that the rock is subjected to is a key variable in controlling the type of metamorphism that takes place. As we learned in the context of igneous rocks, mineral stability is a function of temperature, pressure, and the presence of fluids (especially water). All minerals are stable over a specific range of temperatures. For example, quartz is stable from environmental temperatures (whatever the weather can throw at it) all the way up to about 1800°C. If the pressure is higher, that upper limit will be even higher. If there is water present, it will be lower. On the other hand, most clay minerals are only stable up to about 150° or 200°C; above that, they transform into micas. Most feldspars are stable up to between 1000°C and 1200°C. Most other common minerals have upper limits between 150°C and 1000°C.

Some minerals will crystallize into different polymorphs (same composition, but different crystalline structure) depending on the temperature and pressure. The minerals kyanite, andalusite, and sillimanite are polymorphs with the composition Al$_2$SiO$_5$. They are stable at different pressures and temperatures, and, as we will see later, they are important indicators of the pressures and temperatures that existed during the formation of metamorphic rocks (Figure \(\PageIndex{1}\)).

![Temperature and pressure stability fields of the three polymorphs of Al$_2$SiO$_5$](image)

Pressure

Pressure is important in metamorphic processes for two main reasons. First, it has implications for mineral stability (Figure \(\PageIndex{1}\)). Second, it has implications for the texture of metamorphic rocks. Rocks that are subjected to very high confining pressures are typically denser than others because the mineral grains are squeezed together (Figure \(\PageIndex{2}\)a), and also because they may contain minerals that have greater density because the atoms are more closely packed.

Because of plate tectonics, pressures within the crust are typically not applied equally in all directions. In areas of plate convergence, for example, the pressure in one direction (perpendicular to the direction of convergence) is typically greater
than in the other directions (Figure \(\PageIndex{2}\)b). In situations where different blocks of the crust are being pushed in different directions, the rocks will likely be subjected to shear stress (Figure \(\PageIndex{2}\)c).

One of the results of directed pressure and shear stress is that rocks become foliated—meaning that they’ll have a directional fabric. Foliation a very important aspect of metamorphic rocks, and is described in more detail later in this chapter.

![Figure \(\PageIndex{2}\) An illustration of different types of pressure on rocks. (a) confining pressure, where the pressure is essentially equal in all directions, (b) directed pressure, where the pressure from the sides is greater than that from the top and bottom, and (c) shear stress caused by different blocks of rock being pushed in different directions. (In a and b there is also pressure in and out of the page.)](image)

### Fluids

Water is the main fluid present within rocks of the crust, and the only one that we’ll consider here. The presence of water is important for two main reasons. First, water facilitates the transfer of ions between minerals and within minerals, and therefore increases the rates at which metamorphic reactions take place. So, while the water doesn’t necessarily change the outcome of a metamorphic process, it speeds the process up so metamorphism might take place over a shorter time period, or metamorphic processes that might not otherwise have had time to be completed are completed.

Secondly, water, especially hot water, can have elevated concentrations of dissolved elements (ions), and therefore it is an important medium for moving certain elements around within the crust. So not only does water facilitate metamorphic reactions on a grain-to-grain basis, it also allows for the transportation of elements from one place to another. This is very important in hydrothermal processes, which are discussed toward the end of this chapter, and in the formation of mineral deposits.

### Time

Most metamorphic reactions take place at very slow rates. For example, the growth of new minerals within a rock during metamorphism has been estimated to be about 1 millimetre per million years. For this reason, it is very difficult to study metamorphic processes in a lab.

While the rate of metamorphism is slow, the tectonic processes that lead to metamorphism are also very slow, so in most cases, the chance for metamorphic reactions to be completed is high. For example, one important metamorphic setting is many kilometers deep within the roots of mountain ranges. A mountain range takes tens of millions of years to form, and tens of millions of years more to be eroded to the extent that we can see the rocks that were metamorphosed deep beneath it.
Exercise 7.1

![Garnets in a rock. Euro coin (23 mm) is for scale.](image)

This photo shows a sample of garnet-mica schist from the Greek island of Syros. The large reddish crystals are garnet, and the surrounding light colored rock is dominated by muscovite mica. The Euro coin is 23 millimeters in diameter. Assume that the diameters of the garnets increased at a rate of 1 millimetre per million years.

Based on the approximate average diameter of the garnets visible, estimate how long this metamorphic process might have taken.

See Appendix 3 for Exercise 7.1 answers.

**Image Descriptions**

Figure 1 image description: The temperature ranges that polymorphs of $\text{Al}_2\text{SiO}_5$ are stable at at various depths.

<table>
<thead>
<tr>
<th>Depth (kilometers)</th>
<th>Kyanite</th>
<th>Andalusite</th>
<th>Sillimanite</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Less than 300°C</td>
<td>300 to 650°C</td>
<td>Greater than 670°C</td>
</tr>
<tr>
<td>10</td>
<td>Less than 400°C</td>
<td>410 to 580°C</td>
<td>Greater than 590°C</td>
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<tr>
<td>15</td>
<td>Less than 500°C</td>
<td>Not stable</td>
<td>Greater than 500°C</td>
</tr>
<tr>
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<td>Greater than 620°C</td>
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<tr>
<td>30</td>
<td>Less than 700°C</td>
<td>Not stable</td>
<td>Greater than 700°C</td>
</tr>
</tbody>
</table>

[Return to Figure 1]
Media Attributions

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