METAMORPHISM – Tutorial Script

Metamorphic rocks are rocks that have undergone metamorphism, or change. When rocks are subjected to temperatures, pressures, or chemically active fluids higher than what is normally found at Earth's surface or within about the first kilometer of Earth's surface, these rocks will undergo physical and chemical changes and create new metamorphic rocks. How much pressure and temperature? What kind of changes? If a rock is subjected to so much heat that it fully melts, it becomes a magma and is igneous – so metamorphic temperatures have to be lower than that. If surface sediments are subjected to a little heat or pressure or cool fluids, just enough to compact or cement sediments, or leave crystals in pockets or holes, it's sedimentary. So metamorphic rocks sit in the zone between these two environments.

The metamorphic rocks that form under these changed conditions depend on the original parent rock chemistry the exact pressures and temperatures to which the rock was subjected, and the amount of water available for chemical reactions.

Where do we find metamorphism happening on our planet?

When we bury surface rocks beneath layers of sediment or lavas, those rocks will sink deeper in the crust. The deeper they go, the higher the pressures and temperatures and hence the higher the grade or intensity of change or metamorphism. These temperature and pressure gradients will vary in particular geologic settings such as subduction zones or between converging continents, but where rocks outside these areas are gradually buried over time, their temperatures and pressures will rise steadily together. There's usually no large source of water in burial, just whatever water happens to be inside the mineral formulas or is trapped in holes in the rocks..

Not surprisingly, pressures get quite high where two plates collide. When the two colliding plates are made of continental crust, there will be no subduction, and the crust will be folded and faulted. Pressures will be most extreme deep in the middle of these two plates. Temperatures will also increase especially the deeper we move into the center of the convergence zone and beneath the crust under the plate boundary. Like with burial metamorphism, any water that's available comes from water trapped in the rocks or in the mineral formulas.

What happens at subduction zones? Pressures are also quite high here – and get higher the deeper the plate sinks into the mantle. But the temperatures do not rise at the same rate because the subducting plate is cold and insulated and sinks faster than temperatures can equilibrate. So subduction zone metamorphic settings are characterized by high pressures but low to moderate temperatures. Water content can be quite high because of the high amount of water absorbed by sediment and rocks in contact with the ocean water for the potentially hundreds of millions of years that the subducting plate was being pushed across the oceans.

What happens around volcanic centers? These areas of course have high amounts of heat and also water, water that comes from surface fluids (rains and groundwater) or coming off the magma chamber. So temperatures can get quite high, while there is no added pressure, so pressures remain low. The major changes that occur in the rocks around volcanic centers are chemical changes facilitated by hot chemically active fluids interacting with the original rock material. Rocks around the edges of a magma chamber undergo what we call contact metamorphism. Rocks further away can be metamorphosed by hot fluids that migrate upward and outward from the volcanic zones. We call that metamorphism hydrothermal metamorphism.

What are the physical changes that can occur during increasing metamorphism? With increased pressure, we get increased density. Also, any minerals that have a long or flat axis will align themselves to equalize the pressure, a process called foliation, which we will describe more in the next video tutorial. Additionally, under increased temperatures, crystals can actually grow larger. How? Adding heat to a rock will make atoms vibrate at greater and greater energies or speeds. This increased energy can allow the atoms to migrate across the solid without melting. Atoms will use this added energy to seek out new bonding partners, if nearby. For example, atoms in two side-by-side crystals of the same material will migrate across the boundaries, obliterating them and growing into a new larger crystal.

In addition to physical changes, there are chemical changes that can result from added heat. As the atoms increase their energy and migrate, they can react with atoms in nearby minerals and create new minerals that are more stable at the new temperatures (and pressures). If chemically active fluids are present, these fluids can bring in new atoms and make those available during the process. They can also take some away. If the new minerals that form are stable under narrow temperatures and pressures, they become valuable clues to the story of the rock. Such minerals are referred to as **index minerals**. For example, quartz is stable under all pressures and temperatures in the metamorphic realm, so finding quartz in a metamorphic rock doesn't tell us much. However, the mineral garnet is stable only at higher pressures and temperatures, so if we find garnet in a rock, we know that it had to be subjected to those higher pressures and temperatures. As discussed in the Inside Minerals video, these three minerals, kyanite, andalusite, and sillimanite are polymorphs – different crystalline structures, but same chemical formulas, so three different minerals. These minerals are excellent index minerals because when the pressure and temperatures change in a metamorphic setting where one of these minerals exists in the rocks, the mineral will transform one into one of the others. Finding kyanite in a rock, for example, indicates that pressures could have gotten quite high, but temperatures not. We know from earlier in this video tutorial that such a situation exists in subduction zones. So kyanite minerals are good clues that a particular rock metamorphosed in a subduction zone.

For more information and more detail in regard to the wide range of metamorphic rocks found across the planet, continue on to the next video in this series.

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