Metamorphism and Metamorphic Rocks

Two weeks ago we examined igneous rocks—rocks which were formed from melted material (high temperature).

Last week we examined what happens to rocks exposed at the Earth's surface (low temperature, low pressure).

Through weathering, erosion, transportation and lithification these may eventually become sedimentary rocks.

This week we will examine what happens to rocks if they are subjected to high temperature and/or high pressure.

For example, as rocks become deeply buried.

However, temperature cannot be too high: if they melt we eventually get what?

Why do rocks and minerals change as the pressure and temperature increases?

Recall that minerals which formed nearest to the temperature and pressure seen at the Earth's surface are the most resistant to weathering.

Rocks and minerals are most stable in environments similar to that in which they formed.

Change the environment and minerals may change to ones most suited to the new environment.

Example?

Factors which increase metamorphic activity:

1. Heat

2. Pressure

3. Chemically active Fluids

1. Heat

Recall that high temperatures promote chemical weathering at the Earth's surface—hot environments weather more quickly.

Occurs because the high temperature increases the rate of chemical reactions.

Same factor is operative in metamorphism.

High temperatures provide the energy needed to drive many of the chemical reactions we see in metamorphic processes.

Metamorphosing rocks generally require temperatures greater than about 200°C.

Where does the heat come from?

2. Pressure

Increasing pressure on a rock also can change a rock in a number of ways.

Tends to close up pore spaces within a rock.

Pressure also closes up fractures within a rock.

Intense pressure at contact points may dissolve minerals which migrate to lower pressure regions:

Rocks under pressure tend to deform plastically rather than fracture (ductile vs. brittle behavior).

Increasing pressure will favor new minerals over existing ones.

Types of Pressure

Burial of material increases the pressure on it.

Burial results in even pressure on all sides and is called *lithostatic* or *hydrostatic* pressure.

However, sometimes the pressure does not act equally in all directions.

For example where plates collide the rocks are compressed in the direction the plates are moving.

In this case the rock is said to be under a *compressive* (or tensional) *stress*.

Foliation

Directed stresses result in a layered or banded texture to rocks called *foliation*.

3. Chemically Active Fluids

Just as with chemical weathering at the Earth's surface, chemical activity is greatly facilitated by fluids within a rock at depth.

Fluids can act as a transport medium for ions.

They can dissolve ions in regions of high pressure and transport them to regions of low pressure.

Water's facilitation of such reactions greatly increases with depth.

At depth water can be superheated to higher temperatures than at the Earth's surface.

Can dissolve more matter.

e.g. water can dissolve quartz fairly easily at depth while quartz is quite resistant at the Earth's surface.

Where do the fluids come from?

The fluids to facilitate such reactions can come from a variety of sources.

Sometimes water is trapped in pore spaces of sedimentary rocks.

Water may percolate down from the surface.

Water may be driven from hydrated minerals (e.g. clays, micas, amphiboles).

CO_2 may be derived from carbonates placed under high pressure and temperature.

Types of Metamorphism

Metamorphism can occur in a variety of geologic settings:

1. Regional Metamorphism

The most widely seen form of metamorphism.

It occurs over large areas.

Two types of regional metamorphism:

1. Dynamothermal Metamorphism

Metamorphism of this kind can occur as plates collide producing compressive stresses.

Occurs in regions of current mountain-building or *orogenic* zones.

Heat and fluids provided by rising magma associated with convergent plate boundaries.

Would you expect metamorphism of this type to result in foliated or unfoliated rocks?

Such rocks form the cores of many mountain ranges.

2. Burial Metamorphism

As rocks are buried further to a depth of more than ~10 km the confining pressure and temperatures become high enough to metamorphose the rocks.

Usually associated with deep sedimentary basins and not plate tectonics.

Would you expect burial metamorphism to result in foliated or unfoliated rocks?

In some sense this type of metamorphism is just a continuation of the lithification of sedimentary rocks as they get further buried.

3. Contact Metamorphism

As magma moves up through surrounding rock it may modify the rocks near it.

It may melt some rock (assimilation).

However, even if the magma doesn't melt the rock, it may subject rock to high temperatures.

This type of metamorphism occurs at high temperature but not necessarily high pressure.

Effect is largest nearest the magma and tails off away from it.

Occurs on a small scale: seen in rock a few cm to meters around magma.

4. Other Types of Metamorphism

In addition, there are other metamorphic processes that occur, but not as frequently:

Hydrothermal Metamorphism

Occurs when hot water heated by magma or otherwise chemically alters preexisting rocks.

This type of metamorphism is most important at the mid-ocean ridges.

Sea water is heated to steam by the rising magma which then rises up through the overlying rock.

Can modify the fractured and porous basalts seen at the mid-ocean ridges.

Many valuable ores may also be deposited from material dissolved in hot water when it cools.

Shear Metamorphism (fault-zone metamorphism)

Near faults, rocks can be subjected to large directed stresses.

Frictional heat generated can be sufficient to allow metamorphism.

Movement along faults tends to pulverize rocks and roll and rotate rock fragments.

Shock metamorphism

Meteorite impacts can result in extreme pressures and heating of rocks.

Extreme pressures and temperature leads to shattering and recrystallization of the rocks.

Some minerals, such as stishovite, are only seen naturally in such settings.

Review for Test

Test will be similar to the quizzes (though unlike the quiz you will have some choice in questions to answer). It will consist of:

37-39 multiple choice questions of which you need to answer 35.

4 short answer questions of which you need to answer 3.

Remember that you can bring 1 4×6 index card, written on both sides, to the test.

Questions will be similar to the quizzes—in fact I will copy a few straight off old quizzes.

What to Study

In the multiple choice questions I will ask some factual/definitional type questions.

However, in the short answer questions I have tried to ask questions that require you to synthesize the material in the chapters.

On the test I'll likely ask a question which asks you to synthesize material across chapters.

In studying I wouldn't necessarily read the whole book again—rather read over the chapter summaries.

Look over your (my) notes—if I talked about it I think it's important.

Try, *without referring to your notes or the book,* to answer the questions at the end of the chapters and especially off the review sheets.

If you can, great, if not, review those areas where you are fuzzy.

After a couple hours or so then try to answer the questions again.

If you can, great, if not, review that material further.