GY 111 Lecture Notes
Metamorphism 3: Contact Metamorphism

Lecture Goals:
A) Metamorphic Aureoles
B) Isograds
C) Index minerals and metamorphic grade

Reference: Press et al., 2004, Chapter 9; Grotzinger et al., 2007, Chapter 6;
GY 111 Lab manual Chapter 4

A) Metamorphic Aureoles
Contact metamorphism is induced by plutons as they pass upward through the lithosphere
and crust toward the surface of the Earth, or by other magma-filled intrusions like dikes
and sills. These bodies all contain molten rock (magma) which heats the enclosing parent
rock to high temperatures and therefore induces heat only metamorphism. As previously
discussed, heat only metamorphism is called contact metamorphism.

Unlike regional metamorphism, contact metamorphism is generally localized to the immediate vicinity of
the intrusion. In fact, there is a zone of metamorphism that
surrounds the intrusion like a halo or an envelop which
is officially called a metamorphic aureole (see cartoon
at the top of the next page and the image to the left
from http://newterra.chemeketa.edu). Within the
aureole, metamorphic grade of the parent rock varies
from high nearest the intrusion, to low someway from
the contact. The width of the metamorphic aureole (or
the width of the zone of contact metamorphism)
depends on several factors such as the size and
temperature of the intrusion (dikes and sills are small and therefore induce “thin” aureoles whereas large bodies like plutons and batholiths induce “thick” aureoles), the amount of time the parent rocks were in contact with the intrusion and the type of parent rock. Some rocks conduct heat more readily or are more susceptible to heat than others.

Contact metamorphism is relatively easy to understand because it is heat only driven. However, the rocks that are produced via this process are not so easy to identify. Because there is no pressure involved in this type of metamorphism, no foliation can develop, even in rocks that initially contained a lot of clays and platy minerals like the micas. Instead, the rocks just get “cooked”. A slightly cooked shale or a slightly cooked sandstone look pretty much the same as their uncooked equivalents, but if the temperature was high enough (say equivalent to med-high grade metamorphism), then metamorphic minerals like chlorite, muscovite, biotite and even garnet might form in the metamorphic aureole. They just won’t develop a foliation.

There are a couple of things that we must address at this point. The first is how do we classify (or name) non-foliated “cooked” rocks. Fortunately, you don’t need to remember a separate name for a cooked sandstone or a cooked shale or a cooked anything. Instead, we will group them all together and refer to them collectively as hornfels. In my humble opinion, the hornfels are ugly rocks and while you will see one in the lab component of GY 111, you are permitted to not like it.

The other item that we have to consider is the mineral assemblages that develop within the metamorphic aureole. It is obvious that the highest metamorphic grade occurs nearest the intrusion and that the lowest metamorphic grade occurs away from the intrusion. Doesn’t it stand to reason that the minerals that form under the highest grade conditions will grow nearest the intrusion and that the minerals that form under the lowest grade conditions will grow farthest from the intrusion?

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1 In an upcoming lecture, you will learn that the term hornfels is actually a metamorphic facies. Facies are to metamorphic rocks what groups are to minerals. They both allow us to cluster similar things (rocks and minerals) into groups thereby making classification just a bit easier. There are potentially hundreds of different types of metamorphic rocks, most of which can be grouped into 7 distinct clusters (or facies) that are related to pressure and temperature. The metamorphic facies will comprise an upcoming lecture.
conditions will grow well away from the contact? If you predict that there will be zones of different minerals within the metamorphic aureole, pat yourself on the back. There are and they are called **isograds** (see figure at the bottom of the previous page).

**B) Isograds**

Isograds are defined as lines that represent the same pressure/temperature conditions (think of them as being combinations of isotherm and isobars). And with this definition, I need to stress that isograds are not restricted to contact metamorphism. Isograds, as you will see shortly, are also associated with regional metamorphism. However, discussing the isograds for contact metamorphism first is desirable because it is easier to envision a heat-only situation than one involving heat and pressure.

Consider a close up view of a metamorphic aureole (i.e., the cartoon below). In this situation, the highest grade metamorphism (where the heat is the greatest) that occurs in direct contact with the pluton is forming biotite. The red band in the diagram below is called the biotite isograd because these are the perfect conditions for biotite to grow. The next band (orange) is the interval where muscovite is most likely to form (medium grade metamorphism) and is called the muscovite isograd. The yellow band is the chlorite isograd and it marks the other edge of the metamorphic aureole where the metamorphic grad was the lowest.

Regional metamorphism is more complex because there are many more minerals that form when pressure and heat are affecting rocks. The diagram at the top of the next page which comes from the 2004 version of your textbook shows you what I’m talking about. Here you see isograds for minerals like kyanite, staurolite, sillimanite (a mineral that you do not see in GY 111) and garnet (all formed under conditions of high pressure but
variable temperature). The region defined by the sillimanite is the highest metamorphic grade of the figure.

C) Index Minerals and Metamorphic Grade
Okay, we are just about done for today’s lecture. All that is left is relate minerals to metamorphic grade. By now you should understand that there are some minerals like chlorite that only form under minimal metamorphism (i.e., low grade) and some minerals like garnet that only form during high grade metamorphism. Geologists use this knowledge to map out the extent of metamorphism around intrusions (contact metamorphism), across faults (cataclastic metamorphism) and throughout mountain belts (regional metamorphism). There are many different index minerals that indicate the grade of metamorphism that parent rocks have experienced. The figure below that comes from the GY 111 lab manual relates those index minerals to metamorphic grade and metamorphic rock types. It is important for you to remember that the minerals that form during metamorphism are dependant on the starting composition of the rock. The diagram below shows the index minerals that form from a shale or a felsic igneous rock like rhyolite. You get a substantially different set of index minerals if you metamorphose a mafic igneous rock like basalt (see the book figure on the next page; it’s also from the 2004 edition of your textbook).
Important terms/concepts from today’s lecture

(Google any terms that you are not familiar with)

- Contact metamorphism
- Metamorphic aureoles
- Hornfels
- Isograds
- Index minerals