EENS 2120	Petrology
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Contact Metamorphism	

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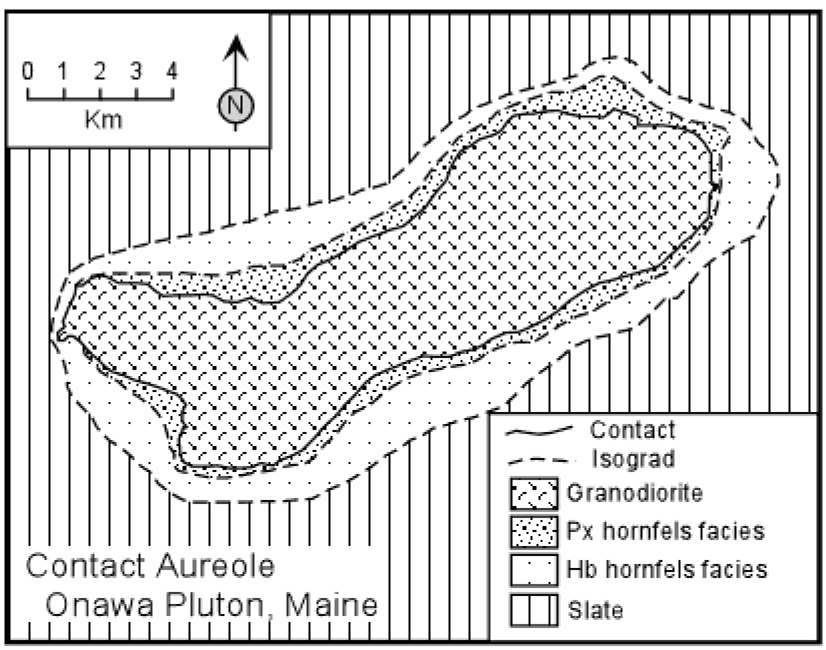
As discussed previously, contact metamorphism occurs as a result of a high geothermal gradient produced locally around intruding magma. Contact metamorphism is usually restricted to relatively shallow depths (low pressure) in the Earth because it is only at shallow depths where there will be a large contrast in temperature between the intruding magma and the surrounding country rock. Also, since intrusion of magma does not usually involve high differential stress, contact metamorphic rocks do not often show foliation. Instead, the common rocks types produced are fine grained idioblastic or hypidioblastic rocks called hornfels. The area surrounding an igneous intrusion that has been metamorphosed as a result of the heat released by the magma is called a contact aureole. We will here first discuss contact aureoles, then look at the facies produced by contact metamorphism.

Contact Aureoles

Within a contact metamorphic aureole the grade of metamorphism increases toward the contact with the igneous intrusion.

An example of a contact aureole surrounding the Onawa Pluton in Maine is shown here. The granodiorite pluton was intruded into slates produced by a prior regional metamorphic event. The aureole is a zone ranging in width from about 0.5 to 2.5 km around the intrusion. Two zones representing different contact metamorphic facies are seen within the aureole. The outer zone contains metapelites in the Hornblende Hornfels Facies, and the zone adjacent to the pluton contains metapelites in the Pyroxene Hornfels Facies. The zones are marked by an ***isograd***, which represents a surface along which the grade of metamorphism is equal.



After Philbrick (1936) & Moore, 1960)

The size of a contact aureole depends on a number of factors that control the rate at which heat can move out of the pluton and into the surrounding country rock. Among these factors are:

- The size and temperature of the intrusion. This will control how much heat is available to heat the surrounding country rocks.
- The thermal conductivity of the surrounding rocks. This will control the rate at which heat can be transferred by conduction into the surrounding rocks. In general, the rate of heat flow Q, depends on the thermal conductivity, K, and the temperature gradient, $(\partial T/\partial x)$

$$Q = K(\partial T/\partial x)$$

  Thus, the rate at which heat moves by conduction increases if the thermal conductivity and temperature gradient are higher.

- The initial temperature within the country rock. This, in combination with the temperature of the intrusion, will determine the initial temperature gradient, and thus the rate at which heat can flow into the surrounding country rocks.

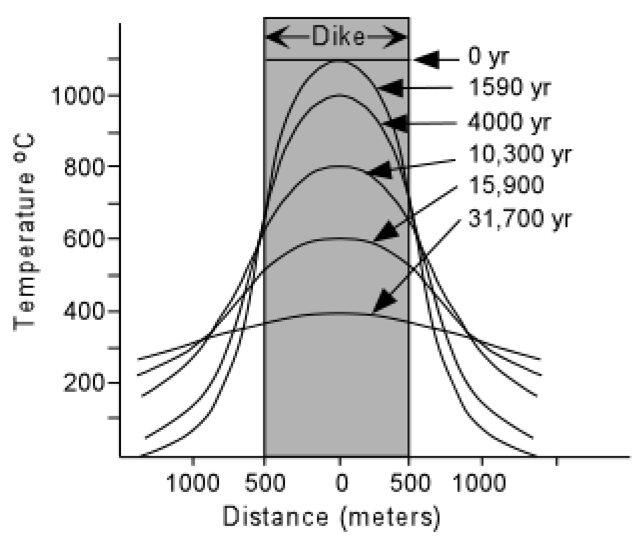
- The latent heat of crystallization of the magma. As you recall, the total amount of heat available in a liquid is not only dependent on the temperature, but also involves the heat released due to crystallization. Thus, if the latent heat of crystallization is large, their will be more heat available to heat the surrounding country rocks.

- The heat of metamorphic reactions. In order for a metamorphic reaction to take place some heat is necessary and this heat will be absorbed by the reactions without increasing the temperature in the intrusion.

- The amount of water in and the permeability of the surrounding country rock. If the country rock is permeable and contains groundwater, heat will be able to move by convection.

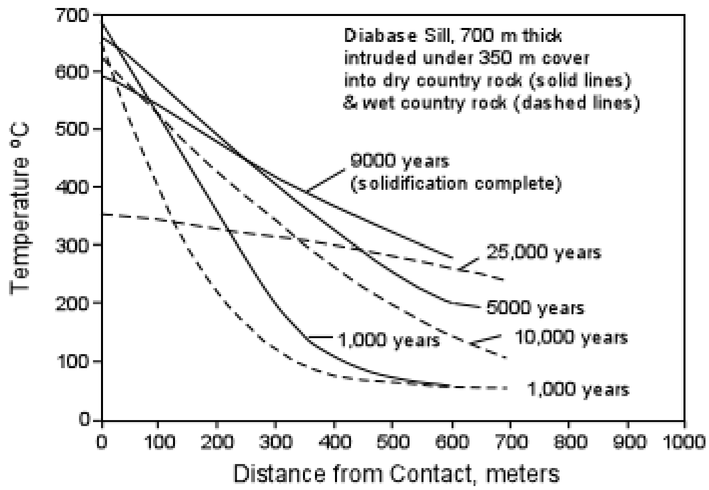
Solutions to the heat equation given above are complicated because most the terms in the equation are functions of temperature, time, and position. Solutions for a simple case are shown below.

In this simple case a basaltic dike is assumed to have intruded at temperature of 1100^{o}C, into dry country rock at a temperature of 0^{o}C. The width of dike is assumed to be 1000 m, and the latent heat of crystallization is assumed to be released between 1100^{o} and 800^{o}. Solidification of the intrusion is thus complete at 800^{o}, after 10,300 years. Note how the temperature of the country rock near the contact reaches a maximum of about 600^{o} after about 1600 years, and how the temperature in the country rock at distances greater than about 700 m from the center of the dike continues to rise, while temperatures near the contact drops.



The model above assumes that all heat moves by conduction. If the country rock is saturated with water or the pluton expels water, and if the country rock is permeable, then the heat will move into the country rock by convection. Water will be heated near the contact and carry heat outward and away where it will eventually cool to return to the contact to carry more heat away.

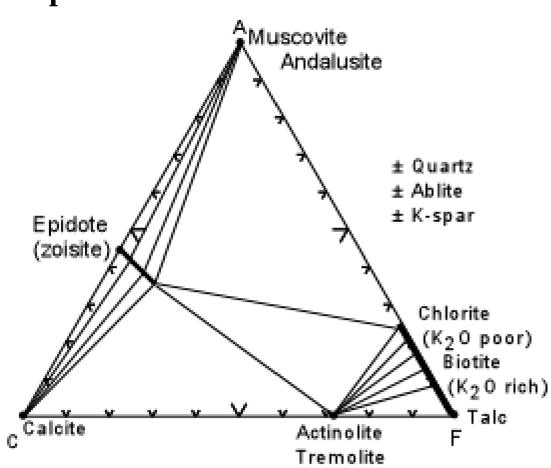
To show these effects, a model was developed for a diabase sill 700 m thick, intruded under 350 m of cover into both dry and wet country rock. The results show that the temperature gradient developed in the country rock will be higher under dry country rock conditions, and the actual temperature attained in the country rock at any position will be slightly less under wet conditions than under dry conditions. Thus, the size of the aureole will be smaller if the heat is removed and distributed by convection.



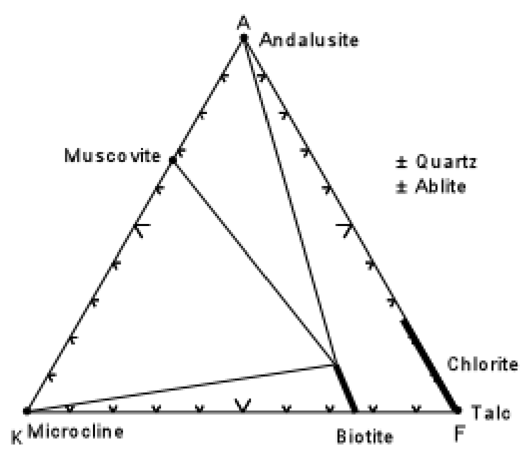
Facies of Contact Metamorphism

The facies of contact metamorphism progress in temperature at relatively low pressure from the Albite-Epidote Hornfels Facies to the Hornblende Hornfels Facies, to the Pyroxene Hornfels Facies. Xenoliths picked up by the magma may be metamorphosed to the Sanidinite Facies, but such rocks are relatively rare. In this lecture we will look at the mineral assemblages that develop in these contact metamorphic facies.

Albite - Epidote Hornfels Facies



Albite-Epidote Hornfels Facies



Albite-Epidote Hornfels Facies

Pelitic rocks will be characterized by an assemblage of

- quartz, albite, epidote, muscovite or andalusite, chlorite, biotite

Quartzo-feldspathic rocks will be characterized by an assemblage of

- microcline, quartz, muscovite, albite, and biotite.

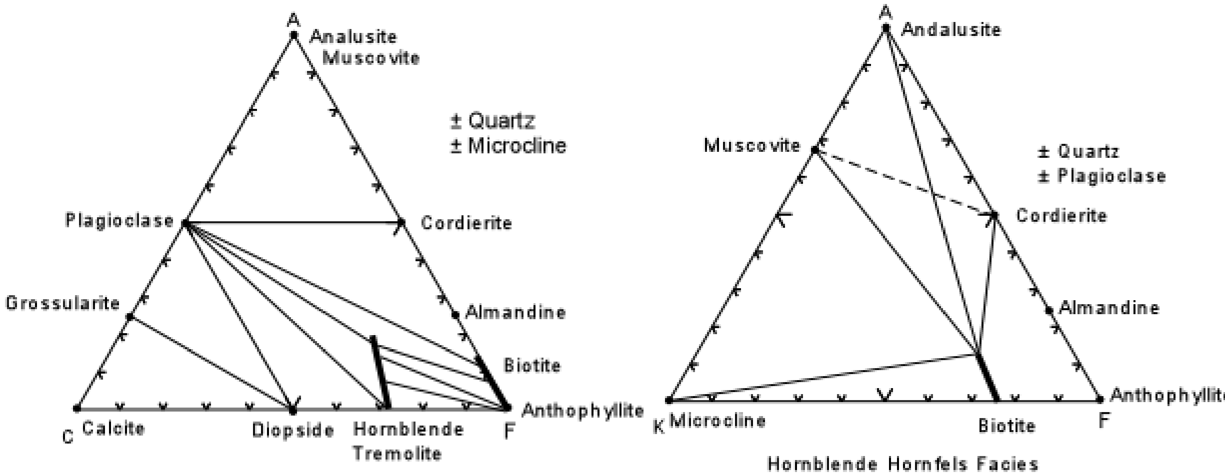
Basic rocks will contain

- actinolite, epidote, chlorite, and/or biotite, and possibly talc, and may contain quartz and albite.

Calcareous rocks will consist of

- calcite, epidote and tremolite, with possibly quartz.

Hornblende-Hornfels Facies



Pelitic rocks will be characterized by an assemblage of

- quartz, plagioclase, muscovite or andalusite, cordierite, or
- quartz, plagioclase cordierite, muscovite, and biotite

  Note the absence of epidote and chlorite in these assemblages.

Quartzo-feldspathic rocks will be characterized by an assemblage of

- microcline, quartz, muscovite, plagioclase and biotite and possibly almandine.

Basic rocks will likely contain

- plagioclase, biotite, and possibly almandine, and may contain quartz, anthophyllite & cordierite

  Note the absence of epidote and actinolite.

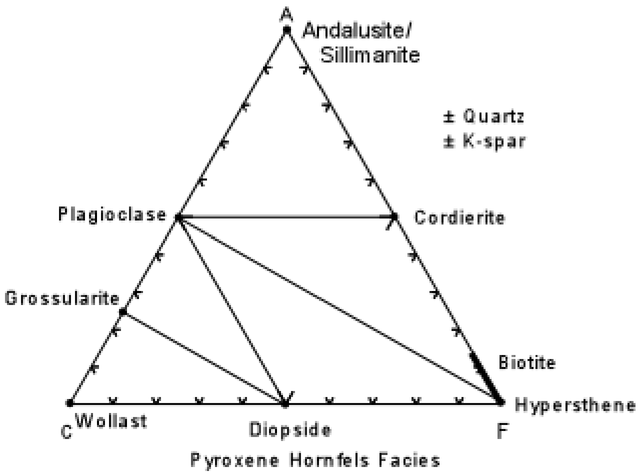
Calcareous rocks will consist of

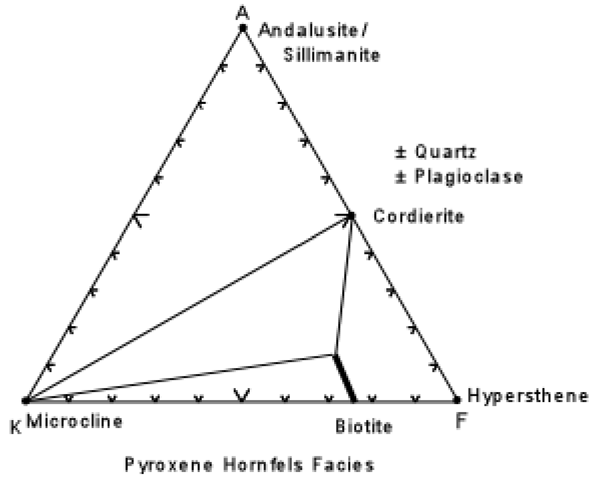
- plagioclase, grossularite, and tremolite and possibly quartz, or

- calcite, diopside, and grossularite with possibly quartz.

  Note the absence of epidote.

Pyroxene-Hornfels Facies





Pelitic rocks will be characterized by an assemblage of

- quartz, plagioclase, K-spar, andalusite or sillimanite, and cordierite

  Note the absence of muscovite.

Quartzo-feldspathic rocks will be characterized by an assemblage of

- K-spar, quartz, plagioclase and biotite

  Again note the absence of muscovite

Basic rocks will likely contain

- plagioclase, cordierite, and biotite and possibly quartz, or
- plagioclase, hypersthene, biotite, and diopside, and possibly quartz.

  Note the absence of hornblende in the these assemblages.

Calcareous rocks will consist of

- plagioclase, grossularite, and diopside and possibly quartz, or
- wollastonite, diopside, and grossularite with possibly quartz.

  Note the absence of calcite and tremolite in these assemblages.

Sanidinite Facies

The sanidinite facies is relatively rare in contact metamorphic aureoles, although it is somewhat more common in rocks found as xenoliths in igneous rocks. It represents the highest conditions of temperature. The facies is characterized by the absence of hydrous minerals, particularly micas.

- Pelitic and quartzo-feldspathic rocks contain unusual phases like mullite ($3Al_2O_3 \cdot 2SiO_2$), along with sanidine, cordierite, anorthite, hypersthene, and sillimanite or corundum. Sometimes tridymite is present in place of quartz.
- Basic rocks of the sanidinite facies are more common, and are often found along the conduit walls of dikes. Several assemblages have been reported.

  augite, hypersthene, calcic plagioclase, brookite, and tridymite

  olivine, augite, plagioclase, magnetite, and ilmenite (similar to an igneous mineral assemblage)

  hypersthene, plagioclase, magnetite, ilmenite, psuedobrookite

  cordierite, plagioclase, magnetite, hematite, psuedobrookite

  some rare aluminous basic rocks have also been found with corundum and hematite

  corundum, mullite, and hematite, sometimes with cristobalite or tridymite

  corundum, mullite, hercynite ($FeAl_2O_4$), sometimes with cordierite and cristobalite or tridymite

- Calcareous rocks contain various assemblages with rare minerals. Among the assemblages observed are:

  wollastonite, anorthite, and diopside

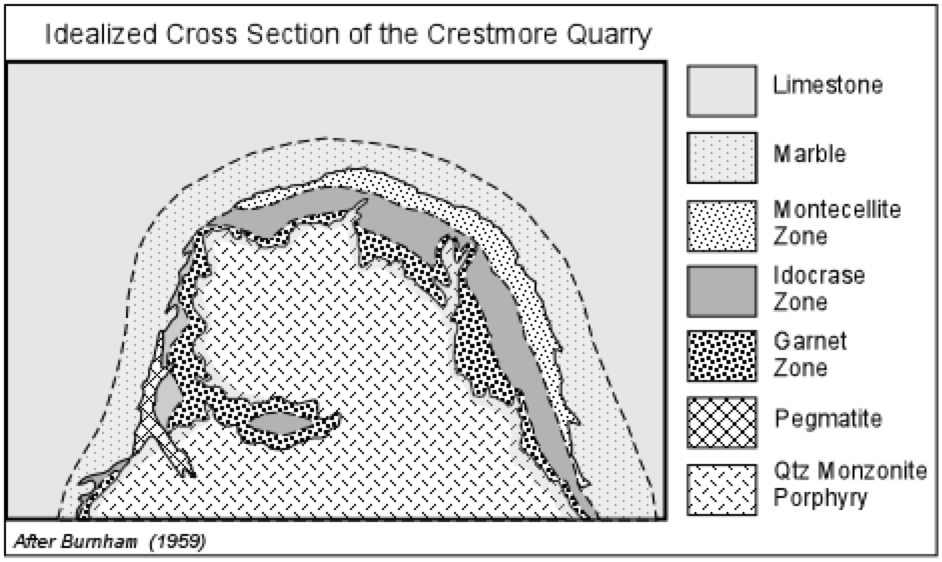
  wollastonite, mellilite ($[Ca,Na]_2[Mg,Fe,Al,Si]_3O_7$), and

  calcite, larnite (Ca_2SiO_4), along with the rare minerals brownmillerite ($Ca_2[Al,Fe]_2O_5$) and mayenite ($Ca_{12}Al_{14}O_{33}$)

Skarns

Sometimes when a siliceous magma intrudes carbonate rocks like limestone and dolostone, significant chemical exchange (metasomatism) takes place between the magma and the carbonate rock. Such a metasomatized rock is refered to as skarn. An excellent example of a skarn occurs in the Crestmore quarry near San Diego, California.

Here, quartz monzonite intruded an Mg-rich limestone. Metamorphism and metasomatism produced four zones near the contact three ranging in size from 3 cm to 15 m in width. The outer zone consists of calcite marble or calcite - brucite [$MgOH_2$] marble, showing little metasomatism.



Closer to the contact is the montecellite zone. This zone consists of calcite, montecellite [$Ca(Mg,Fe)SiO_4$] and one or more of the minerals clinohumite [$Mg(OH,F)_2 \cdot 4Mg_2SiO_4$], forsterite, mellilite, spurrite [$2Ca_2SiO_4.CaCO_3$], tilleyite [$Ca_3Si_2O_7 \cdot 2CaCO_3$], and merwinite [$Ca_3MgSi_2O_8$]

Interior to the montecellite zone is the idocrase zone, consisting of idocrase [$Ca_{19}(Al,Fe)_{10}(Mg,Fe)_3Si_{18}O_{68}(OH,F)_{10}$] in association with calcite, diopside, wollastonite, phlogopite (Mg-rich biotite), montecellite, and xanthophyllite [$Ca_2(Mg,Fe)_{4.6}Al_{6.9}Si_{2.5}O_{20}(OH)_4$].

Next to the contact is the garnet zone consisting of grossularite garnet, diopside, wollastonite, and miner calcite and quartz.

A thin zone along the contact shows evidence of assimilation of the limestone by the magma.

The ratio of Si to Ca and the concentration of Al all increase toward the contact, indicating that the limestone received these components from the magma.

Examples of questions on this material that could be asked on an exam

1. What is contact metamorphism, why does it occur and why is it generally restricted to relatively shallow depths in the earth's crust?
2. What are the characteristics of a contact metamorphic aureole?
3. What factors control the size of a contact metamorphic aureole?
4. What are the contact metamorphic facies in order from lowest grade to highest grade?
5. What is a skarn and how do skarns form?

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