

## LECTURE 7

### 7.0 NATURE AND CLASSIFICATION OF METAMORPHIC ROCKS

#### 7.1 INTRODUCTION

Welcome to lecture 7. In the previous two lectures we covered the nature and classification of igneous and sedimentary rocks. In the present lecture, we shall go through another, but equally important class of rocks - metamorphic rocks - that are formed when sedimentary or igneous rocks are subjected to heat and pressure. The heat and pressure cause the rocks to “metamorphose” or change to another form. Some of the interesting things we are going to learn about these rocks are their many and varied textures. Like in igneous and sedimentary rocks, there will be some new terms that may be a little bit confusing but these will be adequately explained. In this lecture we shall start by defining and explaining the various processes and types of metamorphism. Thereafter we shall look at the mode of occurrences and characteristic textures of these rocks.



### OBJECTIVES

By the end of this lecture you should be able to:

- a). Define what metamorphism is.
- b). Explain what an open and closed metamorphic system is.
- c). Describe the main agents of metamorphism.
- d). Outline the role of volatiles in metamorphic processes.
- e). Discuss the mode of occurrence and characteristic textures common in metamorphic rocks.
- f). Summarize the progression of different rock types produced by regional metamorphism.
- g). Relate common metamorphic rocks to different types of metamorphism.
- h). Illustrate the time relations between metamorphic minerals and deformation.

## 7.2 METAMORPHISM DEFINED

**Metamorphism** is the process of mineralogical and structural changes of rocks in their solid state in response to physical and chemical conditions (pressure, temperature and chemistry). Metamorphism occurs at higher pressure and temperature than weathering and diagenetic processes. Metamorphism encompasses all solid-state changes in the fabric and composition of a rock body occurring well beneath the surface of the earth, but without the production of a melted stage (i.e., silicate melt).

**Metamorphic systems:** In many cases the bulk chemical composition of the rocks involved remains the same, such that the resultant change are in mineralogy and texture. This is referred to as **Isochemical** metamorphism, and the metamorphic system in this case has remained closed. However, if there is loss or gain, the bulk chemistry varies and this may cause changes in mineralogy, texture and chemistry. This process is referred to as **Allochemical** metamorphism and in this case the metamorphic system is said to be open, allowing exchange of material.

**Prograde Metamorphism** – this is the transformation of lower grade metamorphic rocks to higher grade ones due to an increase in temperature and pressure. Prograde reactions liberate H<sub>2</sub>O and CO<sub>2</sub> from the metamorphic body.

**Retrograde Metamorphism** – This is the transformation of higher grade metamorphic rocks to lower grade ones e.g., amphibolite into greenschist generally due to decreasing temperature.

## 7.3 AGENTS OF METAMORPHISM

### 7.3.1 HEAT

Increased temperature (T) agitates the atoms in a crystal lattice and eventually causes that lattice to break down and reform to a structure that is stable at the higher temperature (T). This is **Prograde** metamorphism i.e. it occurs at increasing temperature (T) and or pressure (P). As the new lattice cools, it is able and has time to change back to a structure

stable at a lower temperature (T). This is **Retrograde** metamorphism. The same applies for changing pressure regimes (environment).

Heat sources for metamorphisms are:

- The increase of temperature with increasing depth (thermal gradient) within the earth. Below 30 m temperature increases at approximately 30°C per km depth
- Heat production due to earth's movements particularly those of very large size.
- Heat coming from large bodies of intrusive magma. Probably the most important of the three sources.

### 7.3.2 PRESSURE

Pressure can be divided into two types:

- **Hydraulic Pressure**

This is purely a function of depth within the earth i.e. at deeper levels the overlying load increases and in consequence the pressure increases. This increase is not linear as the mantle, the crust, and the core are of different densities. Hydrostatic pressure (P) tends to produce minerals with more compact atomic structures i.e. of greater densities.

- **Shear Stress**

Whereas hydrostatic pressure (P) is equal in all directions shear stress is directed pressure that is greatest in a single direction. It is associated with large scale movements within the crust and upper mantle. It causes changes in the form and orientation of minerals and promotes mechanical breakdown.

### 7.3.3 VOLATILES

These are liquids and gases and during metamorphism they act as:

- **Solvents**

These dissolve material and aid re-crystallization, chemical reaction and general movement of material.

- **Catalysts**

These accelerate the rate of metamorphic reactions i.e. without them some reactions would proceed so slowly as to in effect not react at all. Gases involved in metamorphism are mainly CO<sub>2</sub>, F<sub>2</sub> and B<sub>2</sub> . which are associated with acid magmas- and Cl<sub>2</sub>, which is associated with basic magmas. Water (H<sub>2</sub>O) is the most important liquid and may be derived from one or more of the following:

- Meteoric water i.e. rain or connate water i.e. that trapped in sediments during deposition
- Water from hydrous minerals
- Juvenile water from intrusive magmas.

#### **7.4 MOVEMENT AND ACTION OF FLUIDS**

The chemically active gases and liquids move forward through the spaces between the grains of the rock so that the metamorphic changes take place along an advancing front. It is only necessary for the fluids to be present in small quantities at the front. Water for example, acts as a medium in which different ions are mixed together and as well as a transporting medium of the ions i.e., material through the solid rock. The water may not necessarily enter into any of the newly formed minerals but where conditions allow, hydrous minerals e.g. **Micas, Chlorites** and **Amphiboles** can be formed.

#### **7.5 THE TYPES OF METAMORPHISM**

There are four main types of metamorphism, namely dynamic or dislocation metamorphism, contact metamorphism, burial metamorphism and regional metamorphism. A brief summary of their pressure and temperature regime occurrence is summarised here below:

##### **7.5.1 Dynamic or Dislocation Metamorphism**

This occurs in areas of intense local deformation e.g. in faults and thrust zones. It is essentially a destructive process but some new mineral growth may occur. Temperature and Pressure are usually low but the fault movements can produce frictional heating.

### 7.5.2 Contact Metamorphism

This is high Temperature low Pressure metamorphism and occurs near intrusive igneous bodies. The zone of metamorphism around an intrusion is referred to as metamorphic **aureole**. Metamorphic effects are obviously greatest nearest to the intrusion.

### 7.5.3 Burial Metamorphism

These are changes simply due to Temperature and Pressure increases resulting from depth of burial or overburden stress.

### 7.5.4 Regional Metamorphism

This is a very large-scale phenomenon that occurs at depth owing to the regional thermal gradient. The effects cover very large areas. It is due to combination of temperature, hydrostatic and directed stress and to fluids such that intensity of effects varies laterally as well as vertically. There is no simple relationship to depth or to proximity of igneous bodies. At its highest levels partial melting of rocks occurs and granitic melts are produced.

## 7.6 DYNAMIC METAMORPHISM

In dynamic metamorphism environment, the characteristic rock types range from fault breccias to mylonites and pseudotachylytes. A brief discussion on their mode of formation is given here below.

### 7.6.1 Fault Breccias

The rocks along the fault or thrust zone i.e. the fracture zone will be subjected to shearing or shear stresses. They will be shattered, broken up and grounded against each other and against the sides of the zone. The resulting zone of broken or crushed rocks is called a **Fault Breccia** with angular clasts like a sedimentary breccia. This is the first stage of dynamic metamorphism.

### 7.6.2 Mylonites

In major fault zones where movements have been continuous for long periods, the rocks in the zone are crushed to a very fine grain size. This resultant rock is referred to as a **Mylonite**. During mylonitization the quartz and feldspar grains are broken and stripped out. The quartz grains in particular shows the **wavey** or **undulose extinction** that is characteristic of highly stained crystals.

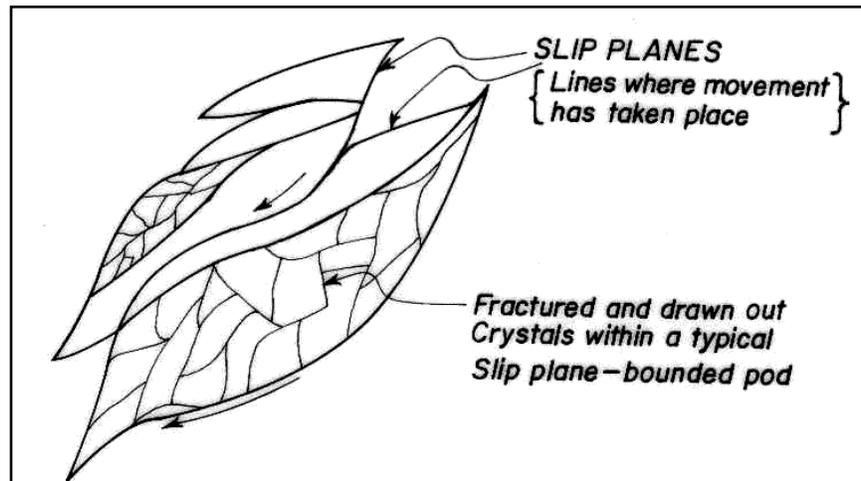


Figure 7.1 Broken and stripped-out quartz grains in a fault zone.

This type of grinding down of minerals in shear zones is called **cataclasis** and the resultant rocks are commonly referred to as **cataclastic rocks**. Similar rocks are also produced by tectonic processes i.e. movements of the earth's crust and mantle.

### 7.6.3 Pseudotachylytes

If the movements in the fault zone are fairly rapid e.g. 5 cm/sec. the temperature rise due to frictional heating may be sufficient to locally melt the rocks along the zone. This produces a black fine-grained **pseudotachylite** rock along the fault zone. This liquid rock also intrudes the rocks adjacent to the zones in small irregular dykes and veins.

## 7.7 CONTACT METAMORPHISM

The characteristic contact metamorphic effects produced around an igneous intrusion, the formation of metamorphic zones and associated rock types that are formed in contact metamorphism environment will be discussed here below:

### 7.7.1 Contact Metamorphic effects

Contact metamorphism is found around igneous intrusions and the factors affecting heat around these intrusions are illustrated in the temperature versus distance diagram in Figure 7.2.

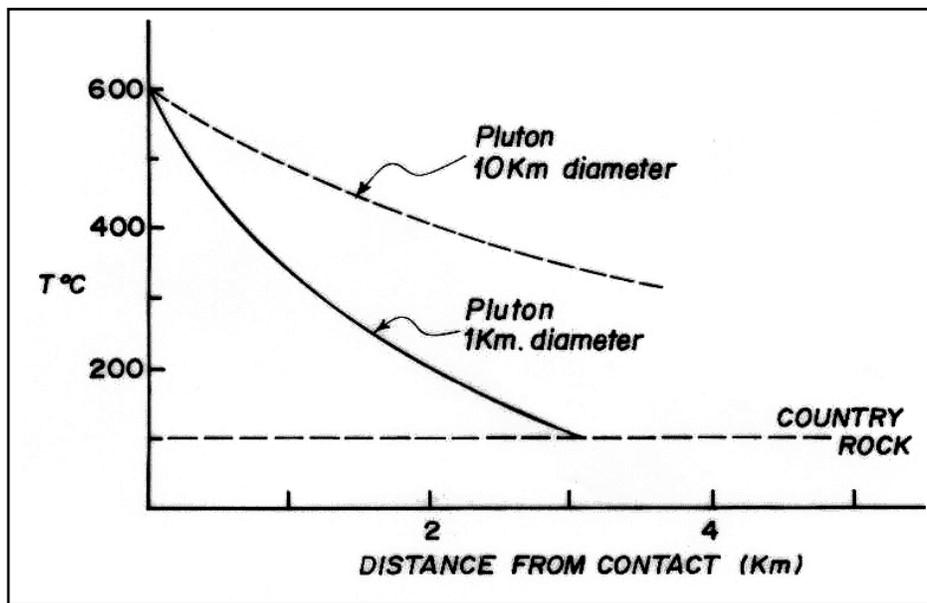


Figure 7.2 Temperature versus distance diagram for two igneous intrusions of varying sizes.

With reference to Figure 7.2, note the difference due to the size of the igneous body. The temperature at any point outside the igneous body depends not only on **distance** from the body but also on the **size** of the body. The larger the size of the igneous body (e.g. the 10 km diameter pluton), the higher the temperature it maintains away from its contact relative to the smaller size igneous body (e.g. the 1 km diameter pluton).

Let us now consider the observed effects on the temperature – time variation for two igneous intrusions of different sizes as exemplified in Figure 7.3. Note from Figure 7.3 that the Temperature (T) at any given point e.g. at 800m from the 4km pluton will rise gradually to a maximum and then decline. Note the difference in time it takes for the temperature (T) of the country rock to rise around the two plutons. For the 4 km pluton the adjacent rocks warm up and cool down relatively quickly, e.g.  $2 \times 10^5$ . For the 10 km pluton, the surrounding temperature (T) rise and fall are much slower e.g.  $1.2 \times 10^6$ .

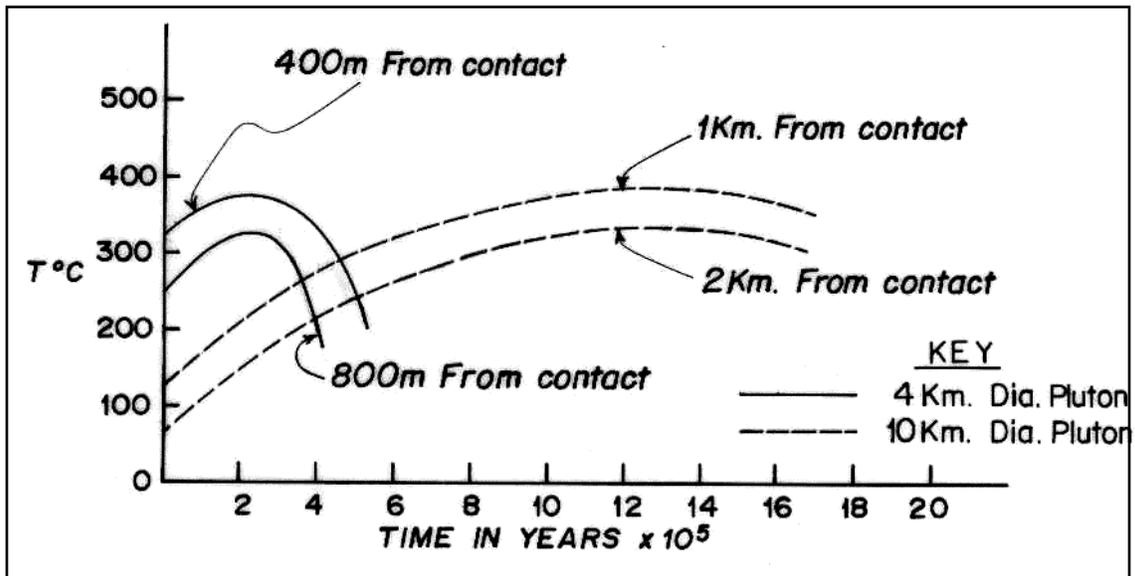


Figure 7.3 Temperature versus Time diagram for two igneous intrusions of varying sizes.

Therefore a small hot body will produce little metamorphic effect since the surrounding rock will have relatively little time to warm up. The material immediately adjacent to the hot body will become baked or hardened and this usually occurs around small intrusions such as dykes and sills and also below some lava flows. But for the larger intrusions, the heat output lasts longer and there is more time for the country rocks to heat up and for chemical reactions to occur and produce new metamorphic minerals.

Based on the aforementioned illustrations, the temperature at any point around a pluton will be influenced by:

- Temperature of the pluton
- The distance of the point from the edge of the pluton
- The size of the pluton
- The time that has passed since the intrusion of the pluton

Therefore any point away from the pluton will reach a maximum temperature well after the intrusion of the pluton and the length of time for which this maximum temperature will be maintained will be controlled by the size of the pluton.

### 7.7.2 METAMORPHIC ZONES



What is a metamorphic zone?

The minerals that grow at any point in a metamorphic aureole will be controlled by the temperature prevailing at that point. It is possible to map the occurrence of a certain mineral around a pluton. Everywhere that this mineral occurs will roughly be at the same temperature. This area of uniform maximum temperature is referred to as a **metamorphic zone** and the mineral that characterizes this zone i.e. the temperature conditions for this zone is an **index mineral**. It indicates a specific temperature grade. Metamorphic effects thus decreases away from the intrusions; and each intrusion will be surrounded by a series of metamorphic zones each with its own temperature dependent index mineral or minerals.

For example, granites in S.W. England have **andalusite** close to the contact such that mapping this mineral defines the Andalusite zone. Further away from the granites, temperature T was not higher enough for andalusite growth. However there are other new minerals (e.g., **sillimanite**, **biotite** etc.) stable at those lower temperatures. Therefore this relative mineral stability sequence produces a series of zones.

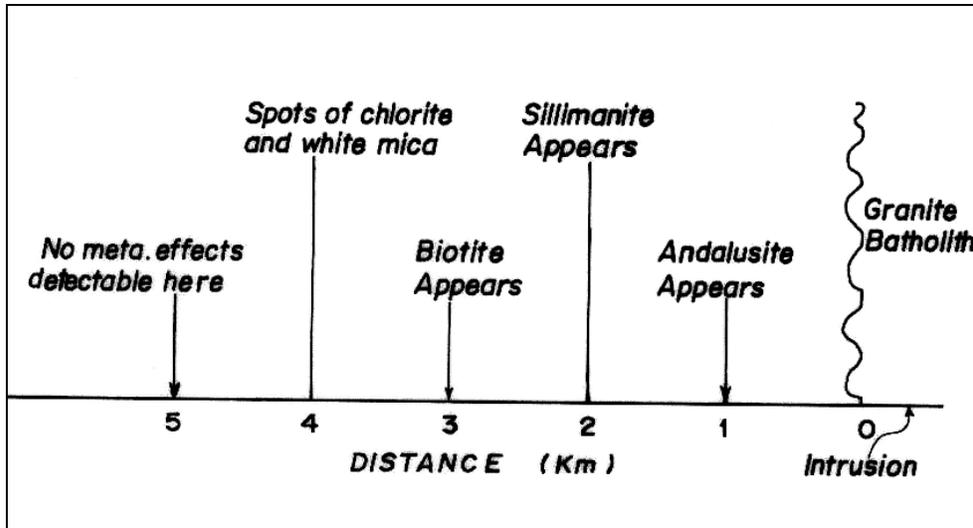


Figure 7.4 Metamorphic zones around an igneous intrusion.

### 7.7.3 HORNFELS

The **hornfels** rocks are typically produced by contact metamorphism. These rocks are hard, compact and splinterly. They consist of fine-grained equi-dimensional crystals that have been re-crystallized by heat into a non-directional texture.

### 7.7.4 MARBLE

Marble is a metamorphosed limestone in which the individual calcite grains have re-crystallized and become tightly interlocking to form a **Granoblastic texture** i.e. a mosaic of equi-dimensional grains, in this case calcite.

### 7.7.5 QUARTZITE

Quartzite is a quartz-rich metamorphic rock, often formed from a quartz-rich sandstone. The quartz crystals are typically much more tightly interlocked in the quartzite, and the quartzite is a more compact, denser, and stronger rock than the original sandstone.

### 7.7.6 METASOMATISM

Calcareous ( $\text{CaCO}_3$ ) rocks that are near to igneous contacts are often replaced by Ca and Mg silicates, iron oxides and sulfides. These altered rocks are called **Skarns** and their formation involves the movement of large amounts of material to and from the pluton.

Processes which involves such large-scale chemical change are **metasomatic** i.e. they are open chemical systems.

## 7.8 BURIAL METAMORPHISM

This defines the changes produced in rocks by unusually deep burial in areas of relatively low heat flow. By this definition it overlaps with diagenesis in sediments and with the lower grades of regional metamorphism. But the latter is more usually associated with areas of higher heat flow.

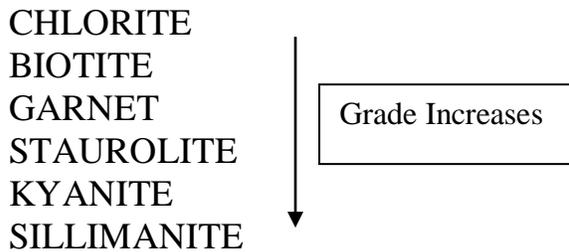
Burial metamorphism was discovered by a geologist named Coombs in New Zealand when he found **zeolites** (hydrated CaAl silicates) in a 10 km thick sedimentary sequence. Previously these minerals had only been found in altered lavas and were thought to be igneous. Coombs also found a depth zonation in these zeolites such that different levels within the 10 km sequence were characterized by completely different zeolites assemblages i.e. a series of metamorphic zones that were changing with increasing pressure and depth.

Burial metamorphic rocks have since been found in many parts of the world and the deepest i.e. highest pressure levels usually contain the mineral **Glaucophane** which is an Amphibole with a distinctive deep blue colour. Hence these rocks are called **glaucophane or Blue schists**. Their distribution on the earth appears to coincide with ancient or modern subduction zones, associated with margins of continental plates. Thus the very high pressure necessary for glaucophane formation probably results from partial subduction of rocks.

## 7.9 REGIONAL METAMORPHISM

Dynamic and burial metamorphism mainly reflect the effects of pressure increase, while contact metamorphism results from Temperature rise. Regional metamorphism results from temperature and pressure increases and usually occur over very large areas. The phenomenon occurs at depth owing to the regional thermal gradient.

Barrow (1893) was the first to map regional metamorphic zones in the south of Scotland and since then these zones are known as the **Barrovian zones** of regional metamorphism. As in contact metamorphism, he used **index minerals**. Obviously metamorphism would affect all the minerals in a rock but the progress of the metamorphism can best be recorded by the first appearance of the most easily recognized index minerals. In his case, he used six minerals, namely:



As before these produces a series of metamorphic zones on the map and lines drawn through the area of occurrence of each index mineral define lines of equal Temperature and Pressure called **Isograds**.

### 7.10 EFFECTS OF COMPOSITION IN METAMORPHIC MINEROLOGY

For a given metamorphic grade, different mineralogical assemblages will be produced by different chemical compositions. The **Barrovian zones** were constructed by using **pelitic rocks** (metamorphosed clay grain-size sediments). Hence metamorphosed calcareous or igneous rocks can be in one of the barrows zone and yet not contain the index mineral since their chemistry does not permit its formation.

### 7.11 COMMON METAMORPHIC ROCKS AND TEXTURES

#### FOLIATION

This is the texture developed when planar minerals e.g. mica flakes show orientation parallel to each other. Such a rock is said to be foliated e.g. **SCHIST**.

#### LINEATION

This is the texture shown by the parallel orientation of needle-shaped or prismatic crystals e.g. **Hornblende**. Such a rock is said to be lineated. The orientation of foliation

and lineation in the field is measured with a compass, and such data is usually important in structural geology studies.

### PORPHYROBLAST (IC)

**Porphyroblast** (or porphyroblastic texture) is term that defines large crystals of a mineral e.g. garnet or andalusite that have grown in the solid medium of a metamorphic rock. Such crystals are surrounded by a mass of smaller grains. Note that igneous **phenocrysts** grow in the liquid medium.

### POIKILOBLAST (IC)

This is a porphyroblast which contains numerous **inclusions** of one or more of the groundmass mineral which have been enveloped during the growth of the larger crystal.



Arrange the following four metamorphic rocks in increasing order of metamorphic grade.

**Gneiss, phyllite, schist, slate**

### SHALE – MICA SCHIST SERIES

This is a series of rocks resulting from regional metamorphism of sedimentary rocks such as MUD, **SHALE** and SILT. The latter are unmetamorphosed sediments which have fine grain-size and which may show sedimentary bedding or lamination. Temperature and pressure affect these rocks and cause new micaceous metamorphic minerals to grow at right angles to the maximum stress. This orientated growth of plate-like crystals produces very well-defined planes of parting or splitting in the rock. This process produces a well-developed **slaty cleavage** and the rock itself is said to be a **slate** (a metamorphosed shale that has developed foliation under stress. The rock tends to break along the foliation planes, parallel to the alignment of those minerals. A slate is still very fine-grained and its component crystals are not visible.

With further metamorphism of this slate, the rock **Phyllite** is produced. Here the metamorphic micas and chlorites grow larger and the cleavage surfaces have a distinct lustrous sheen due to these shiny new crystals, but the rock is still relatively fine grained.

Further metamorphism of the phyllite produces **mica schist** (a coarser-grained, mica-rich metamorphic rock in which the mica flakes are oriented). The crystals of mica have grown larger and are now easily identifiable in a hand specimen i.e. the rock is coarse grained. The rock is now said to be **schistose**, i.e. a schist due to the parallel orientation of the large metamorphic micas. Any parallel orientation of tabular minerals will produce a more or less **planar fissility** i.e. direction of splitting or **schistosity** in a rock.

#### SPOTTED SLATE PHYLLITE

Slate or phyllite with dark spots is usually due to contact metamorphism and the spots are the beginnings of **porphyroblasts**.

#### GNEISS

This is a medium to coarse grained irregularly banded rock where the bands may consist for example of layers rich in mica alternating with layers rich in quartz and feldspar. It has a poor schistosity due to the abundance of non-tabular quartz and feldspar, but it does have **Gneissosity** which is an alternation of lighter and darker layers (see Figure 7.5.) Its metamorphic grade is equivalent to or higher than schist.

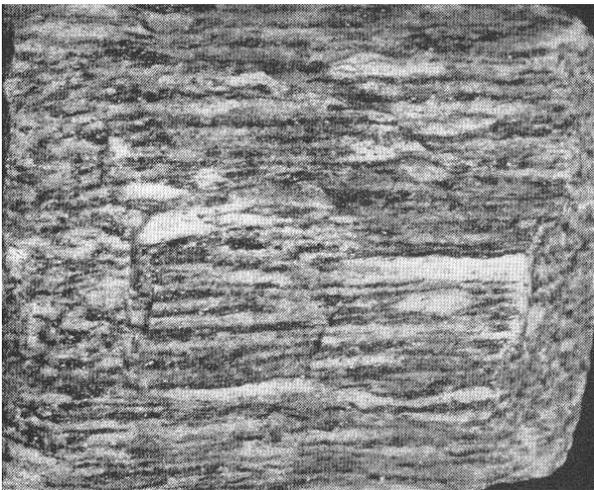


Figure 7.5. Biotite gneiss

## AMPHIBOLITE

It is a medium to coarse grained hornblende (i.e., amphibole) plagioclase rock. Parallel orientation of prismatic hornblende crystals often form a lineation.

## MIGMATITE

These are gneisses that contain veins and/or layers of granitic material i.e. acid material that was originally liquid. Theories for the formation of migmatites vary but most probably they represent the upper extremes of metamorphism where metamorphic rocks are melted and thus grade into igneous melts.

## FLASER TEXTURE

This is a **cataclastic** texture where undestroyed eyes of the original rock are surrounded by a mass of deformed streaks and laminae. This type of texture is illustrated in Fig. 7.6.

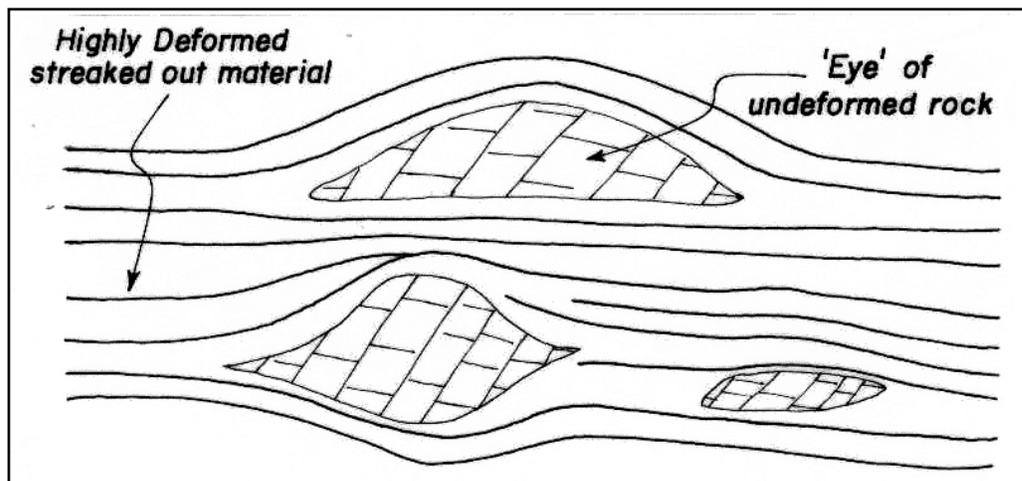


Figure 7.6. The flaser texture in metamorphic rocks.

## 7.12 NATURE OF METAMORPHIC TEXTURES

### 7.12.1 ORIGINAL TEXTURE

The retention of relict original textures often occurs in metamorphic rocks. The chances of textural preservation vary with the type of metamorphism e.g. in dynamic

metamorphism the original textures are usually destroyed by the intense shearing and high-grade regional metamorphism also tends to destroy **RELICT** textures. Thermally metamorphosed **hornfels** often retain **relict** texture in good preservation as do burial metamorphosed rocks. Types of **relict** textures include:

- **Sedimentary Bedding**

This is often preserved particularly where there is a material of compositional difference between adjacent beds. Such metamorphosed rocks are always very different in appearance from the original sediments.

- **Igneous Textures**

Metamorphosed igneous rocks are often very similar in appearance to un-metamorphosed ones except that a new foliation may have developed. Coarse grained igneous rocks in particular often look unchanged when metamorphosed.

### 7.12.2 DEVELOPMENT OF NEW TEXTURE

Whether or not a new metamorphic mineral will form euhedral crystals is expressed by the **BECKE force of crystallization** scale. Some minerals tend to form euhedral crystals and some do not. This scale begins with minerals that crystallize euhedrally and goes down to minerals that crystallize anhedrally.

MAGNETITE, GARNET, PYRITE,  
PHROXENE, HORNBLende } Usually form well-defined crystals

MICA,  
CALCITE  
QUARTZ, PLAGIOCLASE  
ALKALI FELDSPAR

↓  
Increasingly anhedral

The theory of this scale is as follows:

The higher members of the scale are all more dense than the lower ones. This higher density is a result of tighter ionic packing. Since metamorphic minerals must crystallize with the minimum expenditure of energy, they form the simplest possible crystals. Since the simplest crystal faces have the lower surface energies. The denser minerals have lower surface area and therefore lower surface energy per unit mass, and thus are more easily able to form good crystal faces i.e. more easily than the ion dense minerals. Hence the denser minerals are at the top of the scale.

### 7.13 TECTONIC HISTORY

- **Single Events**

All the metamorphic examples so far considered have been single events i.e. one period of heating or deformation or both. This single event has been illustrated in Fig. 7.7.

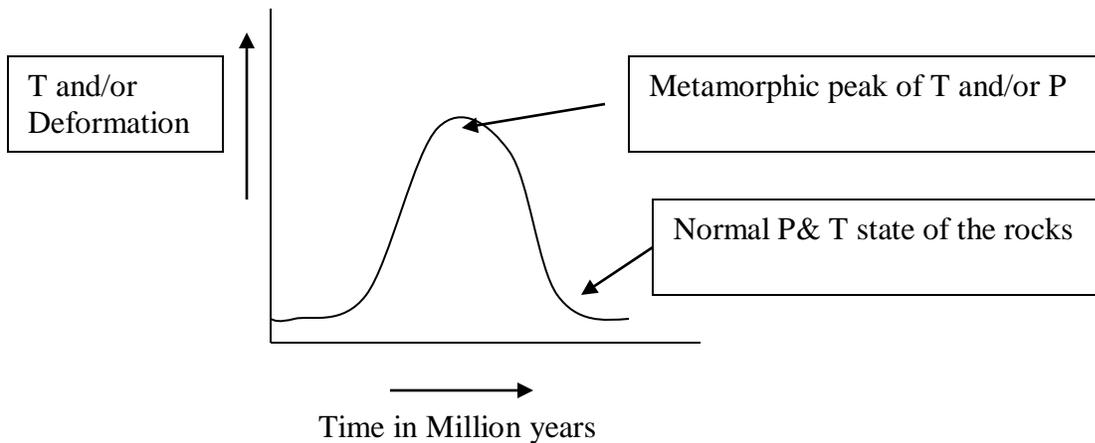


Figure 7.7 Temperature and/or deformation versus time.

Therefore in this example, there is one set of metamorphic products i.e. minerals or deformational textures or both that have been formed during one metamorphic event.

- **Multiple Events**

As an example of multiple events, let's take a metamorphic event from the DALRADIAN geological period of Scotland as presented in Figure 7.8.

In this example illustrated in Figure 7.8, a metamorphic thermal high occurred around 510 million years, followed by temperature decrease around 500 million years. A further higher temperature heating occurred at about 440 My followed by rapid temperature decrease at around 420 My.

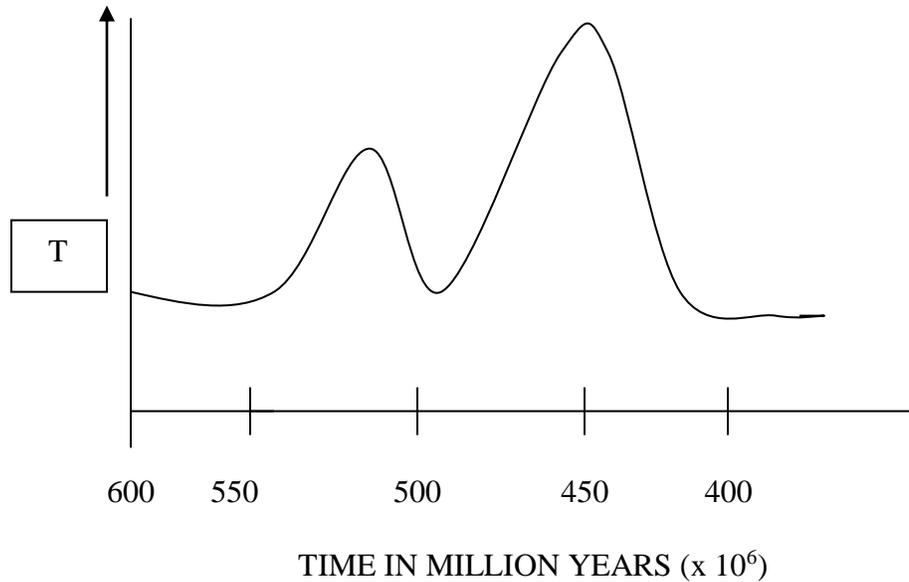


Figure 7.8 Temperature versus time (million years).

Therefore in the Dalradian period, there were two distinct thermal highs i.e. two metamorphic events. Each of these thermal highs may be mapped by the growth of new metamorphic minerals and the minerals formed during the second event may or may not destroy those that grew in the 1<sup>st</sup> event. In addition, distinct periods of deformations may accompany each thermal high such that the textures e.g., lineations, foliations etc. of the first deformation may be altered or modified by the second.

Lastly, the thermal highs may not correspond exactly in time with the deformation, such that, for example, thermally formed minerals may be later deformed. Thus by examining metamorphic rocks, it is often possible to detect a series of metamorphic events that provide the metamorphic history of the rock sample or of the outcrop or of the area.

## 7.14 TIME RELATIONS BETWEEN METAMORPHIC MINERALS AND DEFORMATION

Logically there are three possible times of mineral deformation i.e. before, during and after deformation.

- **PRE-DEFORMATION TEXTURE:**

These are also called **PRE-KINEMATIC TEXTURES**, where **KINEMATIC** is another term for the movements that occurred during the deformation. In this case taking the mineral garnet as an example, the crystals formed before the rock was deformed (see Figure 7.9).

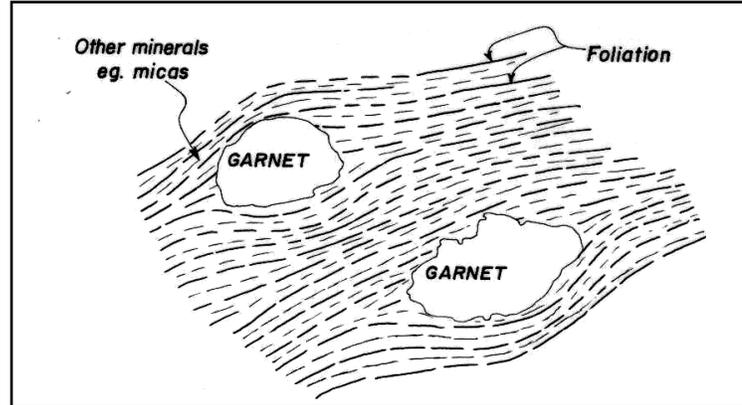


Figure 7.9 Pre-kinematic texture in metamorphic rock.

Note in Figure 7.9 how the micas and other tabular minerals appear to flow around the garnet. The parallel orientation of the micas and other tabular minerals has been produced by the deformation. This orientation is schistose texture and it flows around i.e. is tangential to the garnets that were present before it was produced.

- **POST-KINEMATIC GARNET**

In post-kinematic deformation, the garnet is formed **after** the deformation has taken place (see Figure 7.10).

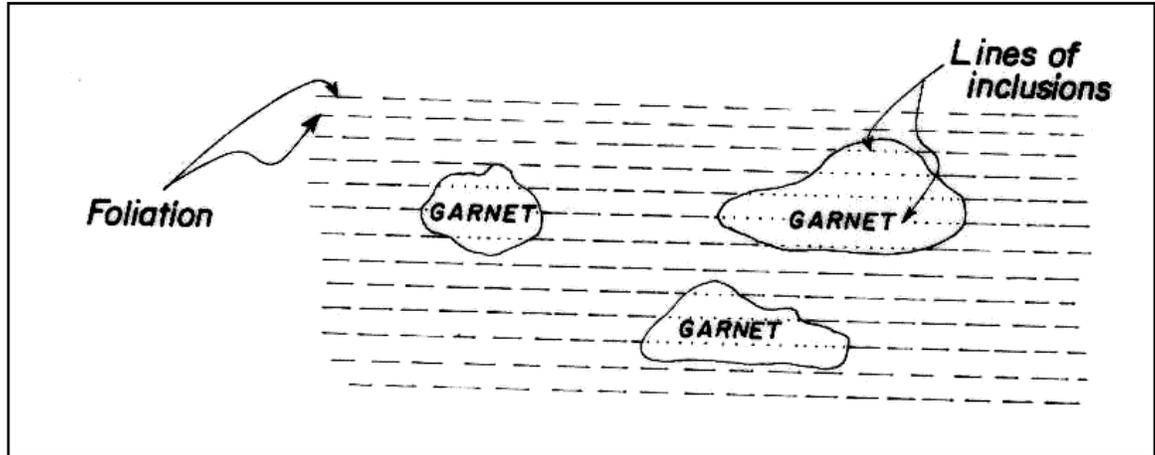


Figure 7.10. Post-kinematic texture in metamorphic rock.

The foliation has formed and then the garnets have grown across it causing no disturbs. There is no flowage of the foliation around the garnet. The original foliation in the areas of the rock where the garnets have grown over can be traced within the garnets as lines of inclusions - which are small particles of other minerals incorporated within the garnet as they grew in the solid state.

- SYN-KINEMATIC GARNET

This type of garnet grows while the deformation is taking place.

The characteristic texture exemplified by syn-kinematic deformation is illustrated in Figure 7.11. The foliation around the garnet can still be traced into the crystal as lines of inclusions, but these lines are curved and folded showing the garnet to have been rotating clockwise i.e. in response to the deformation as it was growing. This rotation could be produced by deformational shear stress as indicated in Figure 7.11.

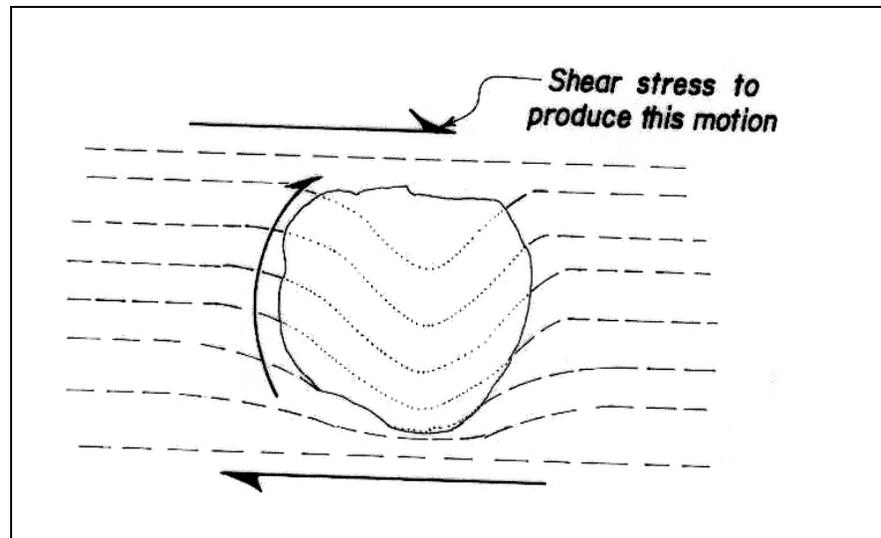


Figure 7.11. Syn-kinematic texture in metamorphic rocks.



### ACTIVITY

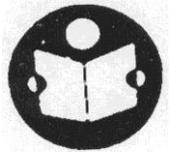
Match each of the following rock types (1-4) with one of the sets of conditions in the key (A-D).

#### Rocks

1. Mylonite
2. Phyllite
3. Hornfels
4. Gneiss

#### KEY

- |   |                                  |
|---|----------------------------------|
| A | Contact metamorphism             |
| B | High grade regional metamorphism |
| C | Dynamic metamorphism             |
| D | Low grade regional metamorphism. |



## Summary

1. Contact metamorphism occurs when hot magma affects the rocks that are directly in contact with it. Regional metamorphism is a larger-scale phenomenon that occurs at depth owing to the regional thermal gradient.
2. New minerals grow in rocks as a result of metamorphic processes; when directional pressure is involved, platy minerals in particular develop at right angles to the direction of pressure and so impart cleavage to the entire rock.
3. As mud rocks e.g. shale, are metamorphosed, they pass through a metamorphic sequence from slate to phyllite to schist. As they do so, the size and complexity of the metamorphic fabric and mineralogy increases.
4. At the highest temperatures and pressures (high-grade metamorphism), the melting point of granitic rocks is exceeded and igneous magmas are formed.



## REFERENCES

Gillen, C. (1982). *Metamorphic Geology*. George Allen & Unwin, London.

Best, M.G. (1982). *Igneous and Metamorphic Petrology*. W.H. Freeman and Company, 630p.