Metamorphic Rocks

- Metamorphic rocks are formed from pre-existing rocks of any type that undergo **recrystallization** without melting in response to changed physical conditions.

- The mineralogical and textural changes are stable at the new conditions. There are three principal factors that affect the specifics of a metamorphic rock:
- what the **parent rock** was, what the **temperature** is, and what the **pressure** is.

- Metamorphic temperatures are greater than those required for diagenesis (i.e. changes during lithification - compaction, cementation, recrystallization in sedimentary rocks) and less than those required to melt the rock.

- Temperature and pressure increase with depth. Temperature increases at a steady rate called the **geothermal gradient**.
- Other temperature sources can include local plutonic activity. Other pressure sources can include regional directed stress associated with tectonic activity.

The average geothermal gradient is 25°C/km

- Chemical conditions may also facilitate metamorphic changes if fluids pass through the rocks during metamorphism.

- The effects of metamorphism include changes in **mineralogy** and **textures** of the initial rocks.

- Parent minerals might not be stable at higher temperatures. They will break down to form new minerals stable at higher temperatures.
- With increasing pressure, **denser** (higher pressure crystals) minerals may form in metamorphic rocks.

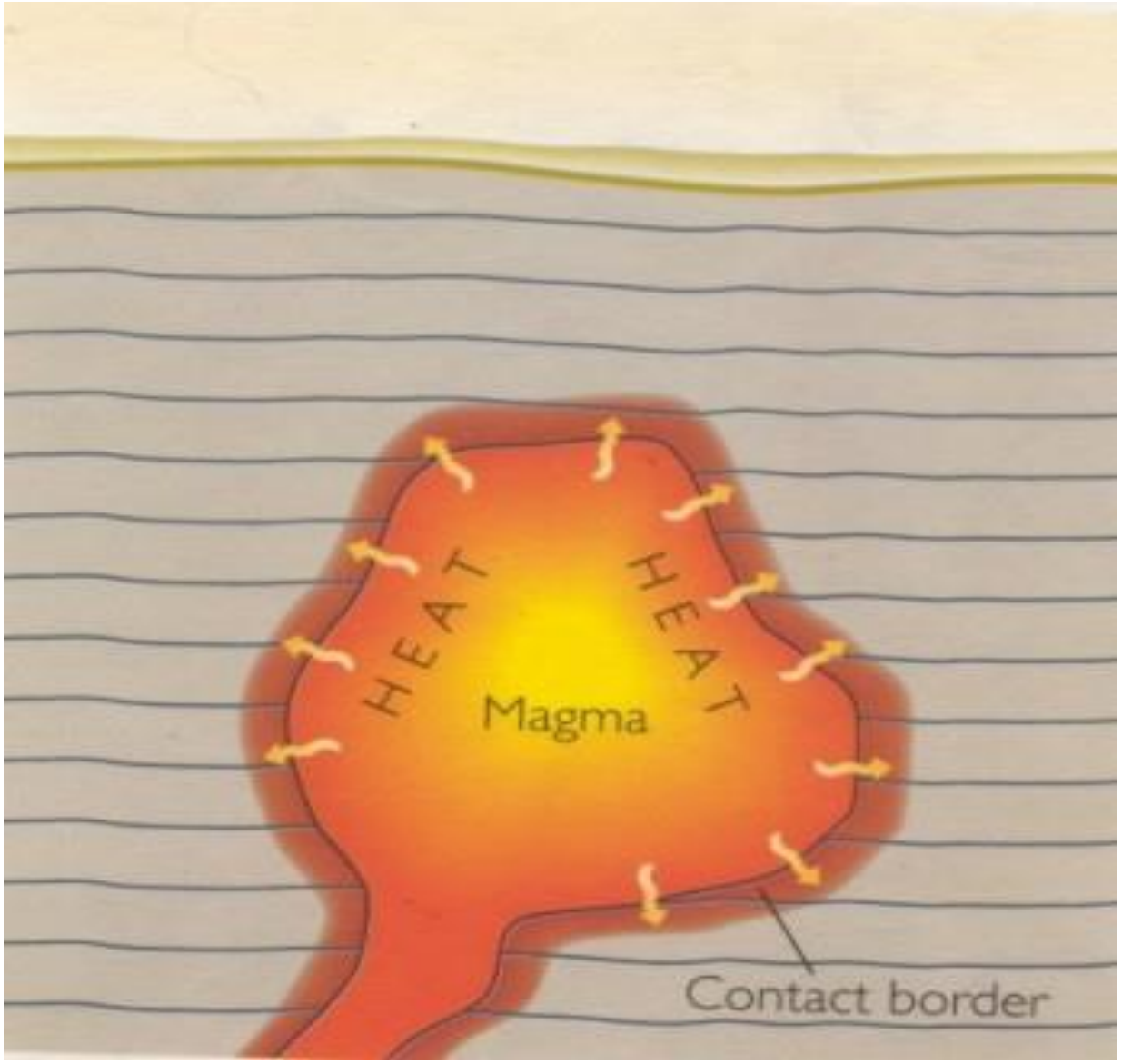
- With increases in **directed** stress, compositional or textural **banding** or layering may develop in metamorphic rocks. (aka foliation)
- Chemical changes are more difficult to generalize, but also play an important role during metamorphism.

Types of Metamorphism:

- Rocks are changed when they are subject to physical or chemical conditions which differ from those under which they were formed.

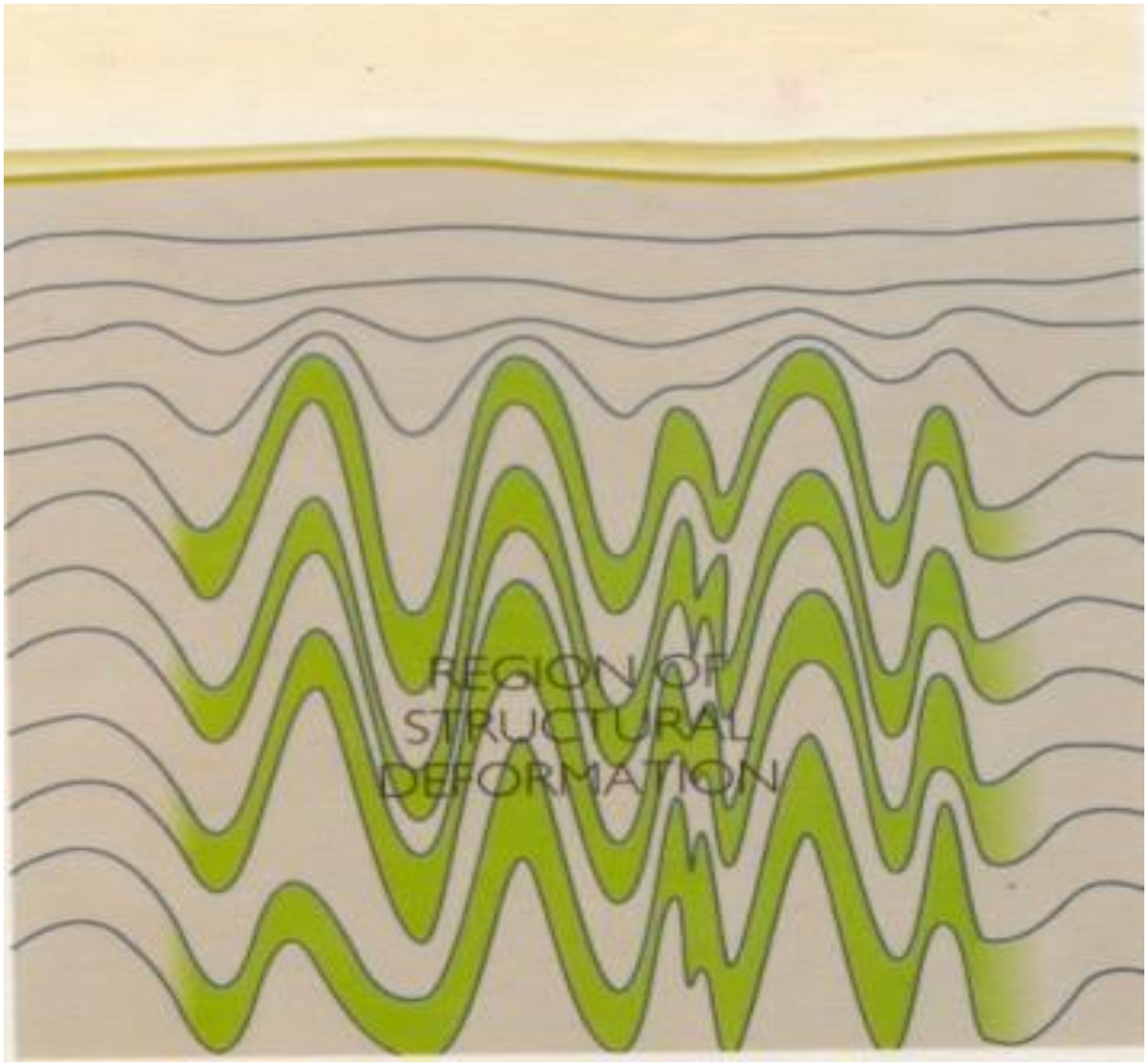
Contact Metamorphism

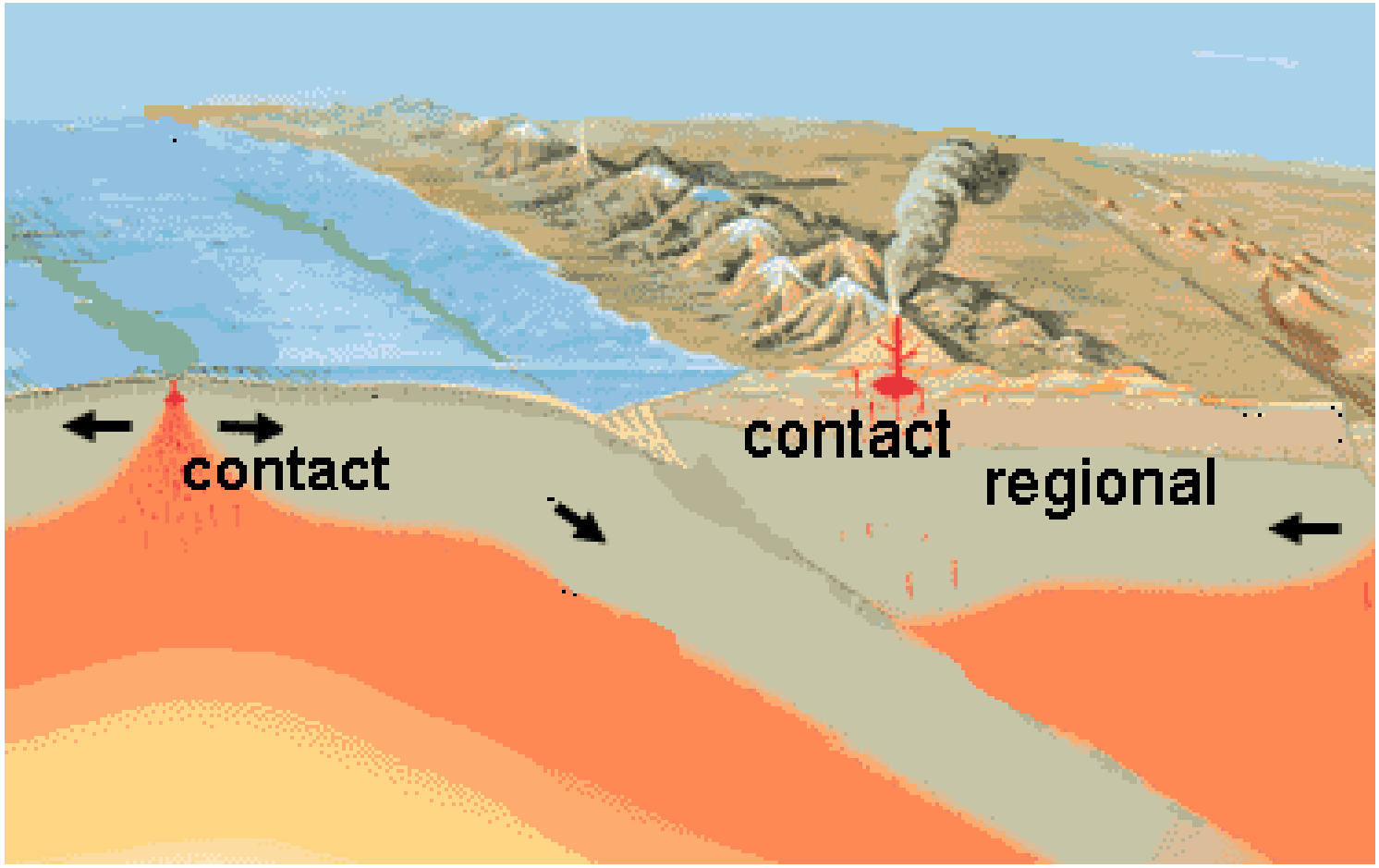
- **localized**, relatively **shallow** depth
- zone of metamorphic rock around a pluton in country rock
- known as a contact aureole


HEAT
HEAT
Magma
Contact border

Regional Metamorphism

- occurs over a **large region**, and often occurs during **mountain building**
- extreme pressure and heat associated with deep burial
- can also be associated with major igneous intrusions-
- widespread migration of hot fluids throughout the region. These fluid reactions are called hydrothermal alteration.


REGION OF
STRUCTURAL
DEFORMATION


contact
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Metamorphic Textures

- Metamorphic rocks are commonly divided into two main types based on their texture. These textures are **foliated** and **unfoliated**.

- **Foliated** – A **banded** rock split more or less evenly into layers. It usually forms from a combination of both heat and pressure. The pressure was perpendicular to the banding.

- **Unfoliated** – A rock with **no definite layers** or bands. It will break randomly. It forms primarily due to temperature.

FOLIATED ROCKS

- Foliated rocks are named based on the texture and how well they break.
- The property of splitting is often referred to as **cleavage**.
- If a rock splits easily, it has a good cleavage plane. They are generally formed by a combination of both heat and pressure.

Slate

- A rock derived from shale. These are **low grade** metamorphic rocks.
- It shows **slaty cleavage**. It is **fissile**, splitting into thin, parallel sheets with smooth flat surfaces.
- It is microcrystalline, meaning the minerals can only be seen under high magnification. It can be used for roofing tiles.

Phyllite

- These are also a **low grade** metamorphic rocks, but higher than slate. Phyllite is tough and microcrystalline like slate, but does not have such clean cleavage.
- Some minerals are large enough to be seen. The presence of mica can give it a noticeable **silky/shiny lustre**.

Schist

- Schists are a medium grade metamorphic rock, and have a **medium** cleavage. They break into uneven surfaces.
- The crystals are visibly flattened and deformed, and can usually be seen with the naked eye. Frequently, schist splits and flakes easily.


3 cm

Gneiss

- Gneiss is a **high** grade metamorphic rock. It has **poor cleavage** and very rough surfaces. The readily visible crystal structure is noticeably banded from pressure effects.
- Gneiss commonly forms from granite or syenite, or from clay-rich sedimentary rocks. Sometimes garnets are visible in the layers of the gneiss.

Acasta Gneiss

From the NWT, approximately 4 billion years old

Amphibolite

- Amphibolite is a hard, dark, fine-grained rock which is **slightly** foliated. It is generally, formed from the metamorphism of mafic volcanic rocks such as basalt.


1
EURO
CENT

UNFOLIATED ROCKS

- Generally, these are rocks that have been heated and recrystallized with no obvious banding, so there have been very few pressure effects. Sometimes the original sedimentary bedding may be visible.

Marble

- Marble is a medium to coarse grained rock that forms from the recrystallization of **limestone**.
- It may be plain white or variable colours. Marble is often used by sculptors as it is not too hard to work with and takes a high polish.

Quartzite

- Quartzite is usually a very pale coloured rock that results from the recrystallization of **sandstone**.
- Under a magnifying glass, the separately fused sand grains are frequently visible, as well as the bedding planes of the original sandstone.

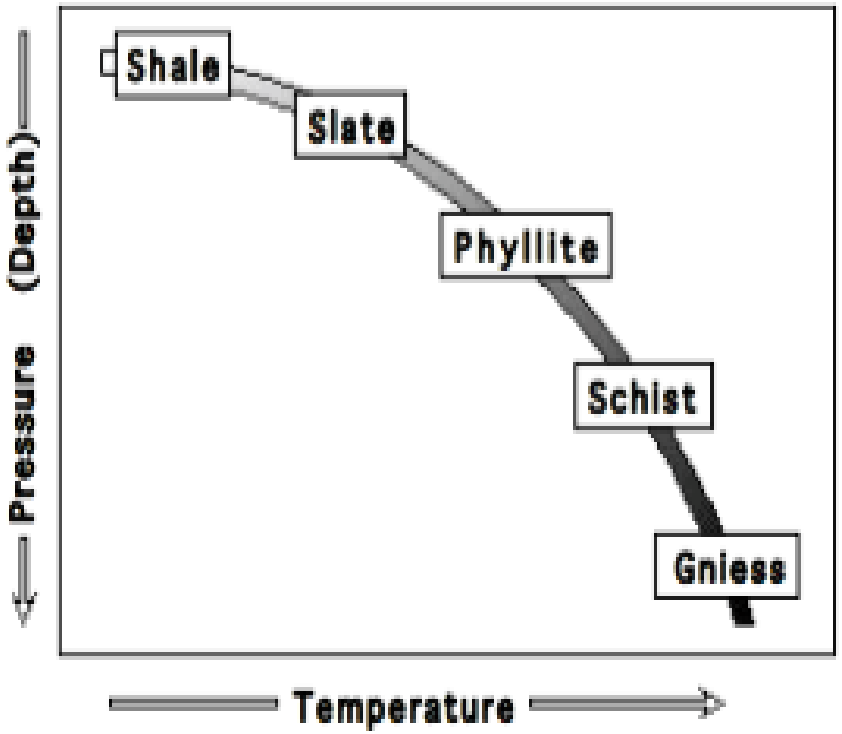

7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

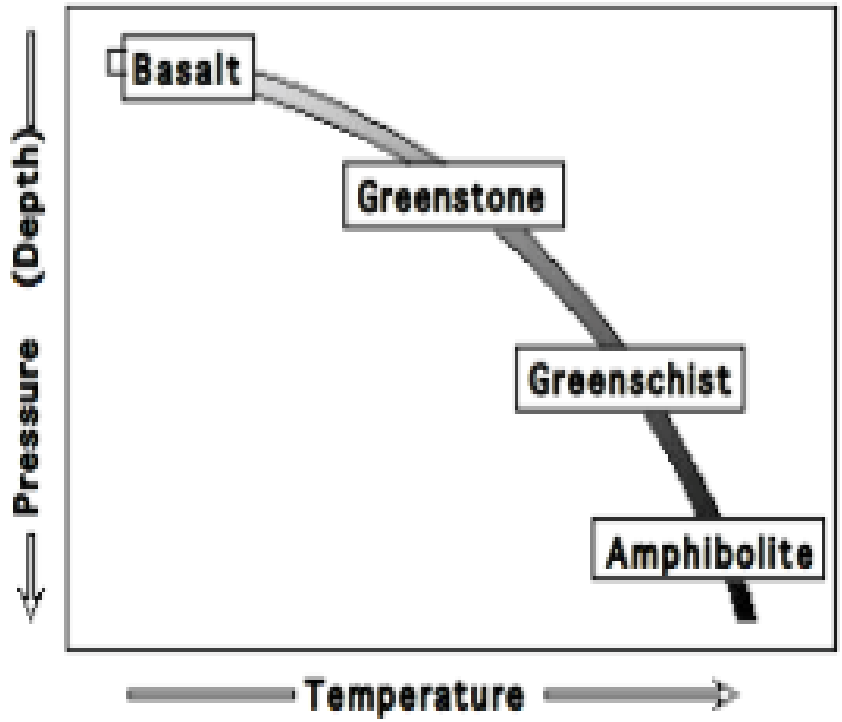
Parent Rock and Metamorphic Grade

- It is **often difficult** to tell what the parent rock was without very complex analysis, both chemical and geological.
- If the parent rock is chemically simple, however, then the changes tend to reflect changes in texture only

- Limestone ($CaCO_3$) transforms into Marble ($CaCO_3$)
-
- Sandstone (SiO_2) transforms into Quartzite (SiO_2)

- Generally, clay based sediments and felsic igneous rocks progress form shale to gneiss.
- Mafic igneous rocks progress to amphibolite. This is not always the case, as a chemically complex parent rock has more reactions that can occur.


Shale
Slate
Phyllite
Schist
Gniess
Pressure (Depth)
Temperature


Basalt
Greenstone
Greenschist
Amphibolite
Pressure (Depth)
Temperature

Barrovian Sequence

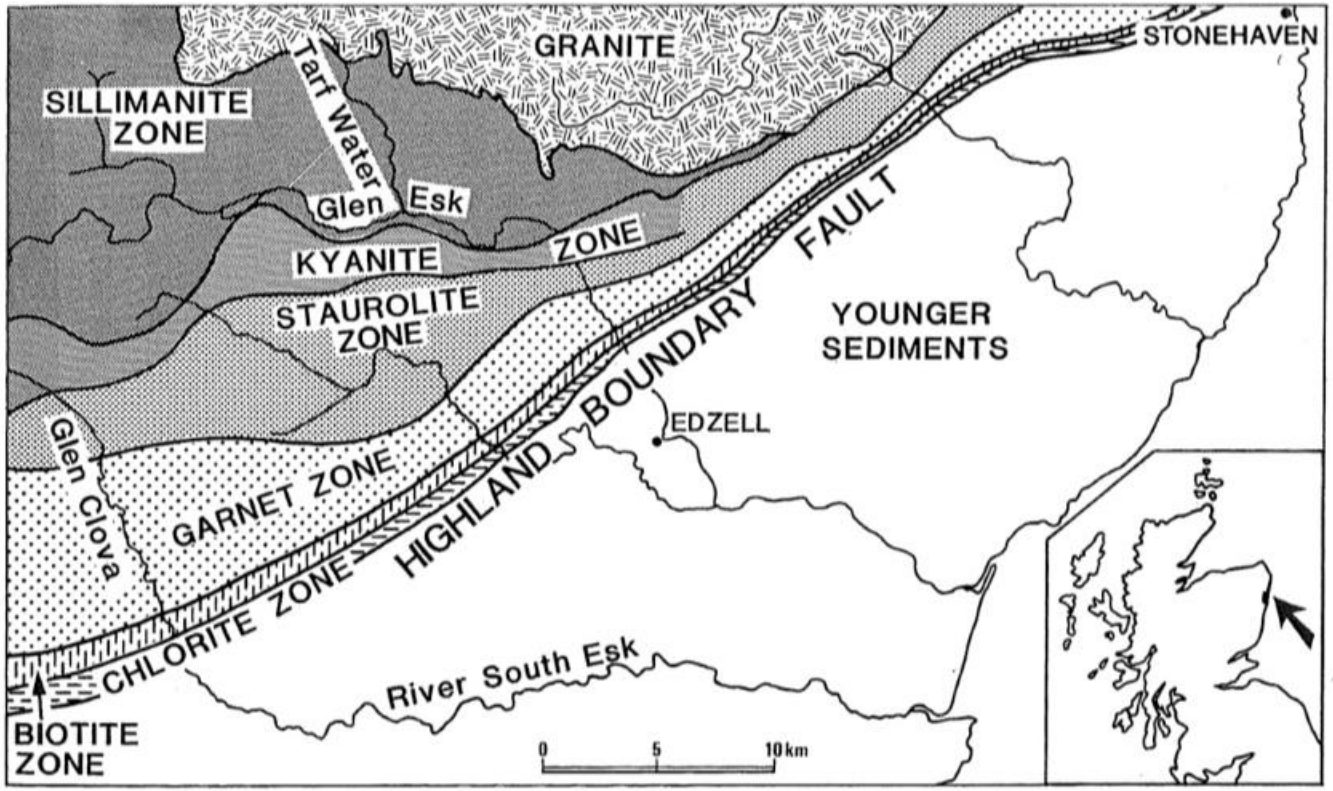


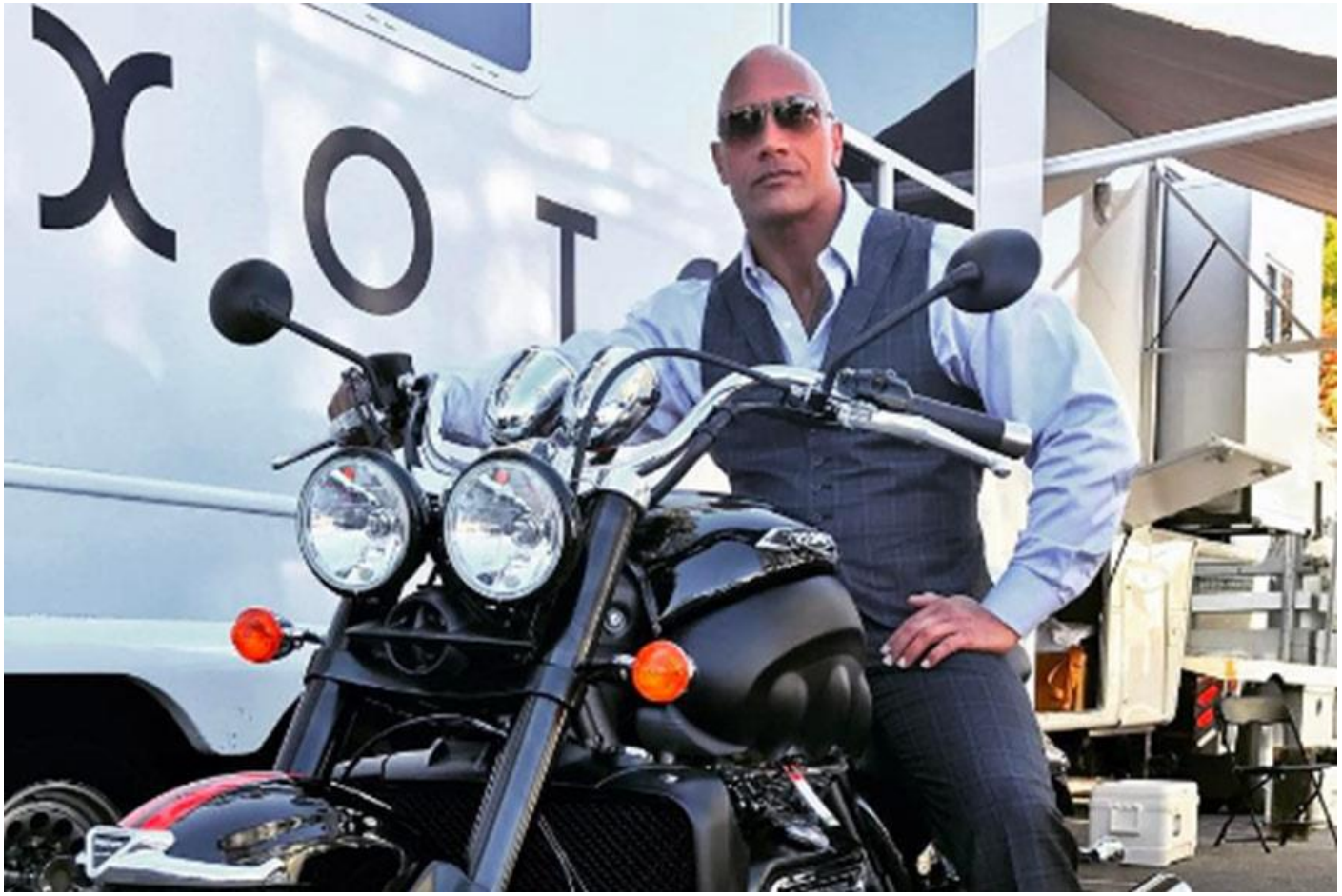
Fig. 1.2 Metamorphic zones defined by the mineralogy of pelitic schists in the eastern Highlands of Scotland. Based on Tilley (1925).

Barrovian Sequence Zone

Zone	Typical Mineral Assemblage
Chlorite	chlorite-K-feldspar-muscovite-quartz
Biotite	biotite-chlorite-muscovite-quartz
Garnet	garnet-biotite-chlorite-muscovite-quartz
Staurolite	staurolite-garnet-biotite-muscovite-quartz
Kyanite	kyanite-garnet-biotite-muscovite-quartz
Sillimanite	sillimanite-garnet-biotite-muscovite-quartz

The Rock Cycle

The Rock Cycle



The Rock Cycle

- The 3 classes of rocks (igneous, sedimentary and metamorphic) are categorized based on how they form. The rock cycle shows how rocks are continually changing through time. The time scale is usually very long. We would not be able to see changes overnight or rarely even in our lifetime.