Name: ______________________ Course/Section: ______________ Date: __________

A Analyze the metamorphic rocks in Fig. A7.1.1 and actual rock samples of them, if available. Beneath or beside each picture, describe the rock's **composition** (what it is made of) and **texture** (the size, shape, and arrangement of its parts) as well as you can, using your current knowledge and observational skills.

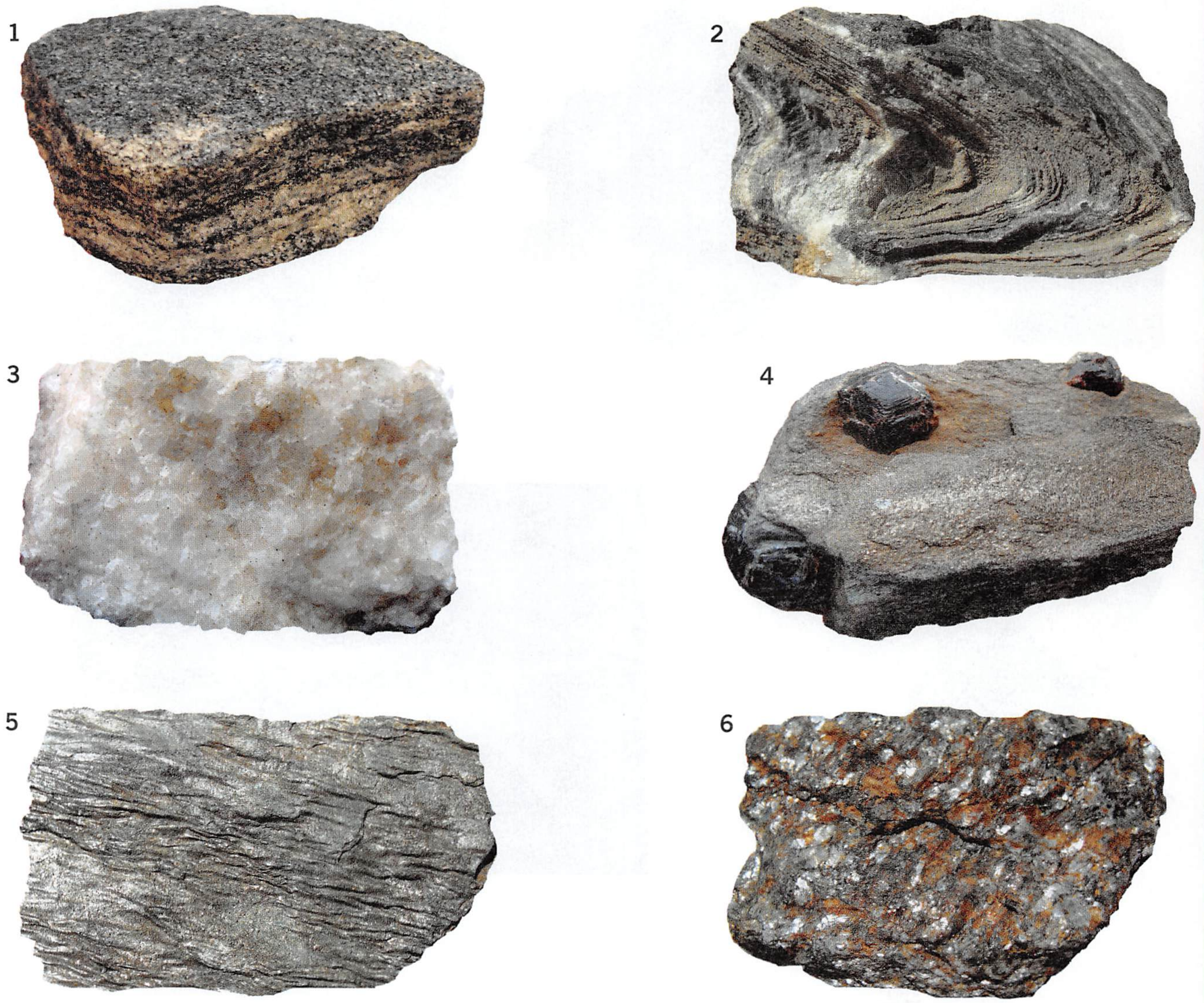


Figure A7.1.1

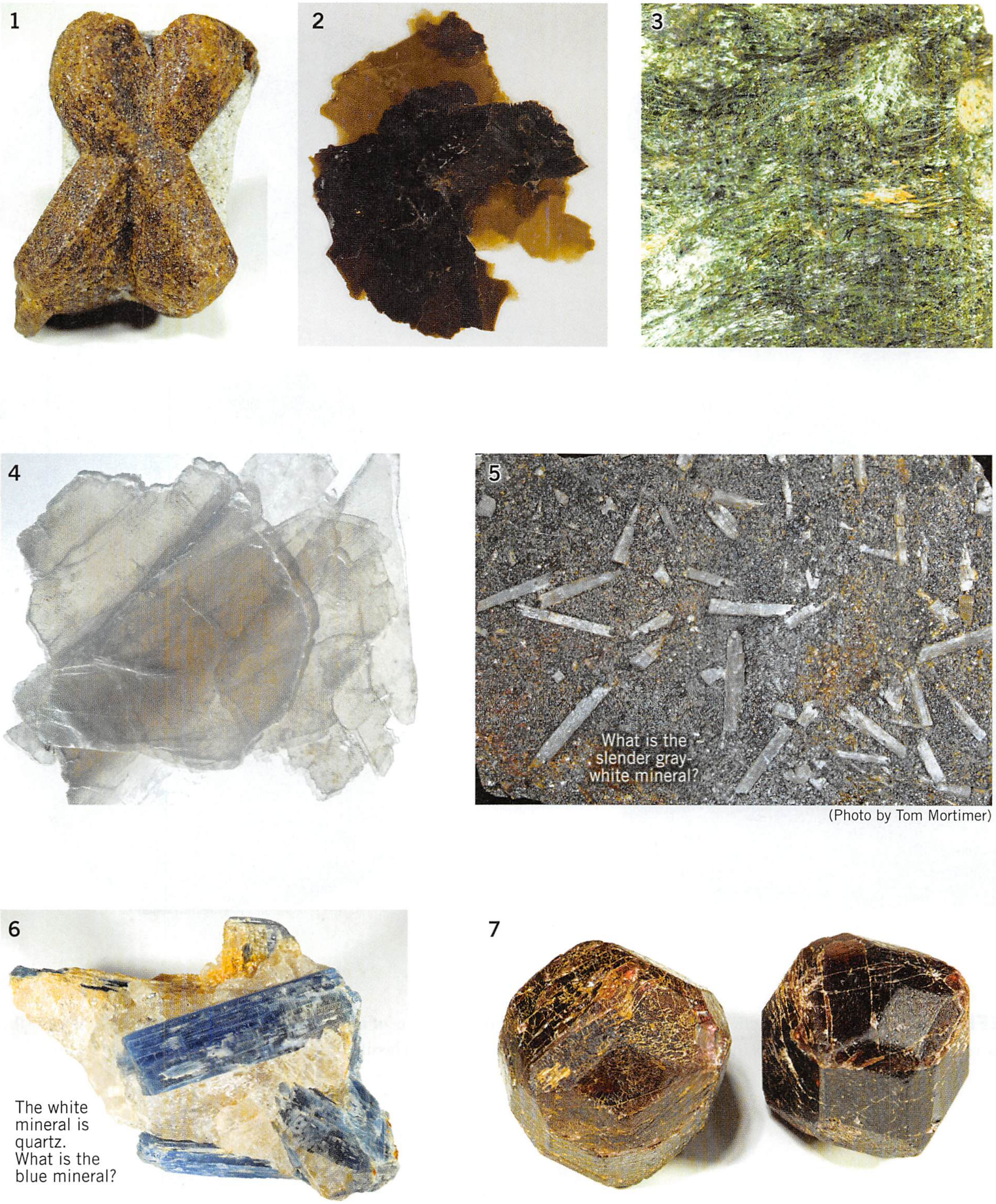
B **REFLECT & DISCUSS** Reflect on your observations and descriptions of metamorphic rocks in part **A**. Then describe how you would classify the rocks into groups. Be prepared to discuss your classification with your classmates or teacher.

Activity 7.2

Minerals in Metamorphic Rock

Name: ______________________ **Course/Section:** ______________ **Date:** __________

Review the descriptions of metamorphic minerals. Below each of the numbered photos in **Fig. A7.2.1**, identify the type of mineral shown. Be prepared to discuss your interpretations with your teacher or with others in your lab.



A7.2.1

Metamorphic Rock Analysis and Interpretation

Activity 7.3

Name: ______________________ **Course/Section:** ______________ **Date:** __________

A Analyze the samples of sedimentary limestone and metamorphic marble in Fig. A7.3.1.

1. These rocks are both composed of the same mineral. What is it? ____________

   What test could you perform on the rocks to be sure?

2. How is the texture of these two rocks different?

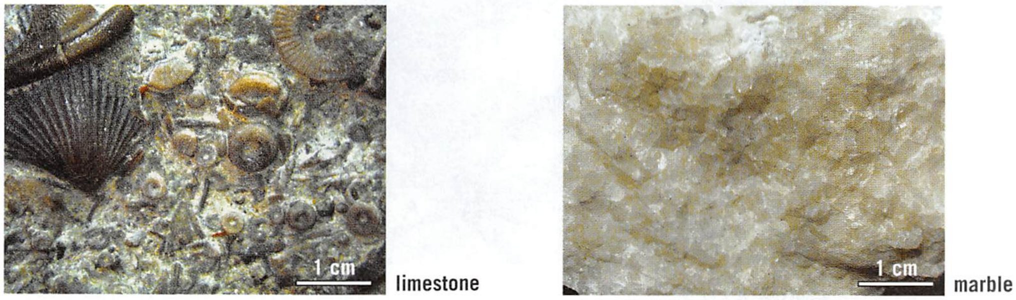


Figure A7.3.1

B Figure A7.3.2 shows three metamorphic rocks that had a mudstone or shale protolith and that display excellent foliation. The three specimens represent different metamorphic grades. Higher-grade types can also be formed from protoliths other than mudstone, but we are going to think about a progression from mudstone through successively more intense metamorphism.

1. Describe the change in grain size from slate to schist.
2. How does the texture of phyllite differ from that of schist?
3. Why do you think that the micas (flat minerals) in these rocks are all parallel, or nearly so, to one another?

A7.3.2

C Analyze the rock sample in Fig. 7.5A. The white layers in this metamorphic rock—a gneiss—were originally flat, parallel layers that were later folded during metamorphism. Describe a process that could account for how this strong, dense gneiss was folded without breaking during regional metamorphism. (*Hint*: How could you bend a brittle candlestick without breaking it?)

D Analyze the foliated metamorphic rock sample in Fig. A7.3.3.

1. What mineral defines the foliation in this rock?
2. Notice that the rock consists mostly of muscovite but also contains scattered garnet crystals. What is the name for this kind of texture?

3. What is the name of this metamorphic rock?

4. What type(s) of rock might have been the protolith for this rock?

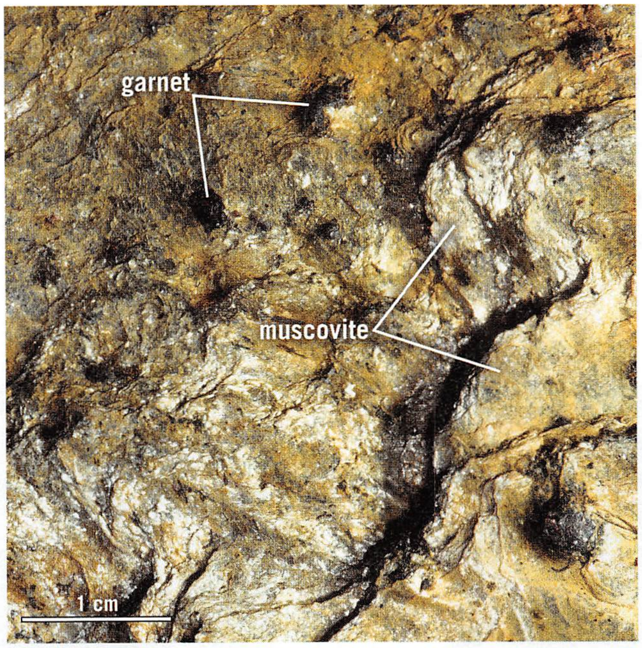


Figure A7.3.3

E Analyze the metamorphic rock sample in Fig. A7.3.4.

1. Is this rock foliated or nonfoliated (granofelsic)? What features in the photograph did you use to make your interpretation?

2. What is the name of this metamorphic rock?

3. What type(s) of rock might have been the protolith for this rock?

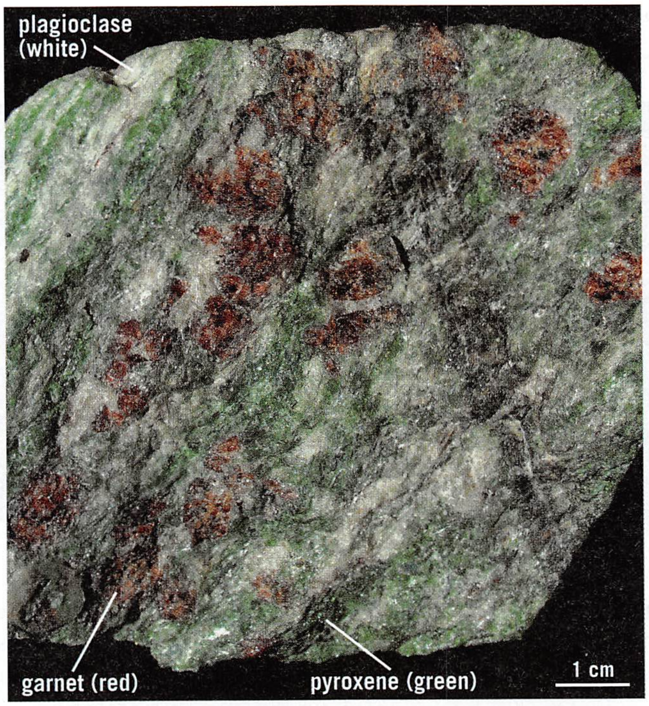


Figure A7.3.4

F **REFLECT & DISCUSS** Which one of the rocks in this activity do you think has the highest metamorphic grade? Explain your answer.

Hand Sample Analysis, Classification, and Origin

Activity 7.4

Name: ______________________ Course/Section: ______________ Date: __________

METAMORPHIC ROCKS WORKSHEET

Sample Letter or Number	Texture	Mineral Composition or Other Distinguishing Properties	Rock Name Interpretation	Possible Protolith(s)
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			

Figure A7.4.1

Name: ____________________ Course/Section: ____________________ Date: ____________

METAMORPHIC ROCKS WORKSHEET

Sample Letter or Number	Texture	Mineral Composition or Other Distinguishing Properties	Rock Name Interpretation	Possible Protolith(s)
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			

Figure A7.4.1 *(continued)*

Name: ______________________ Course/Section: ______________ Date: __________

METAMORPHIC ROCKS WORKSHEET

Sample Letter or Number	Texture	Mineral Composition or Other Distinguishing Properties	Rock Name Interpretation	Possible Protolith(s)
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			
	☐ foliated ☐ nonfoliated			

Figure A7.4.1 *(continued)*

Activity 7.5 Metamorphic Grades and Facies

Name: ______________________ **Course/Section:** ______________ **Date:** __________

A British geologist George Barrow mapped rocks in the Scottish Highlands that were metamorphosed by granitic igneous intrusions. He discovered that as he walked away from the granitic intrusive igneous rock, there was a sequence of mineral zones that generally reflected the intensity of metamorphism. He defined the following sequence of **index minerals**, which represent intensity of metamorphism along a gradient from low to high pressure-temperature (P-T) conditions:

Chlorite (lowest P-T), biotite, garnet, staurolite, kyanite, sillimanite (highest P-T)

1. Boundaries between Barrow's metamorphic zones are called **isograds**. On the geologic map (Fig. A7.5.1), color in the zone of *maximum* metamorphic intensity as indicated by Barrow's index minerals.

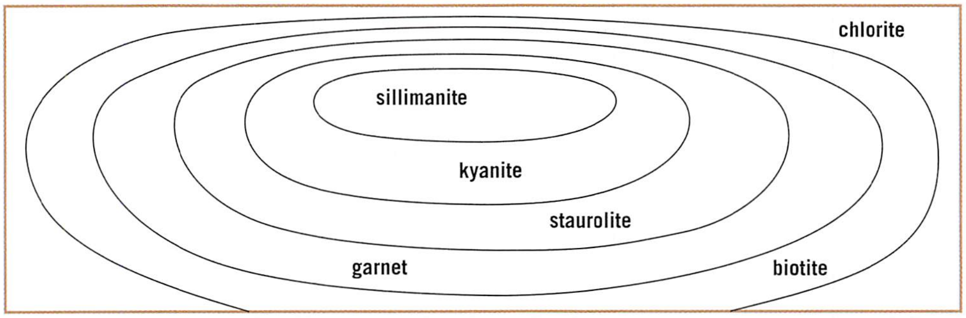


Figure A7.5.1

B Metamorphism is typically caused by increases of both pressure and temperature. Geologists represent these relationships on pressure-temperature (P-T) diagrams (or phase diagrams) showing the stability of different index minerals. The minerals andalusite, kyanite, and sillimanite shown on this phase diagram (Fig. A7.5.2) are *polymorphs*: minerals that have the same chemical composition but different crystalline structure and physical properties that can be used to distinguish them. Each polymorph is stable under pressure and temperature conditions that are different from the others. Note that any two of these minerals can occur together only under P-T conditions represented by the boundary lines in the diagram and that the three minerals can occur together only at the point where these three lines intersect: approximately 500°C and 4 kilobars, which normally occurs about 15 km below Earth's surface.

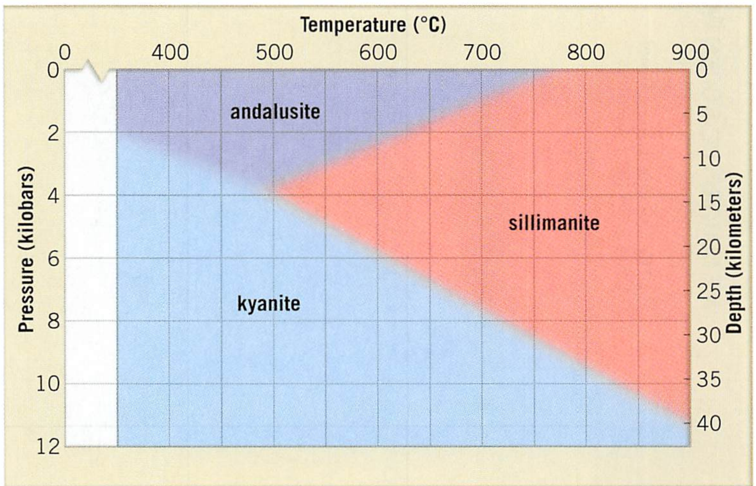


Figure A7.5.2

1. Study the mineral zones and isograds on the two maps in Fig. A7.5.3. Which region was metamorphosed at higher pressure? How can you tell?

2. What was the minimum temperature at which the rocks in Map **B** were metamorphosed? ______________

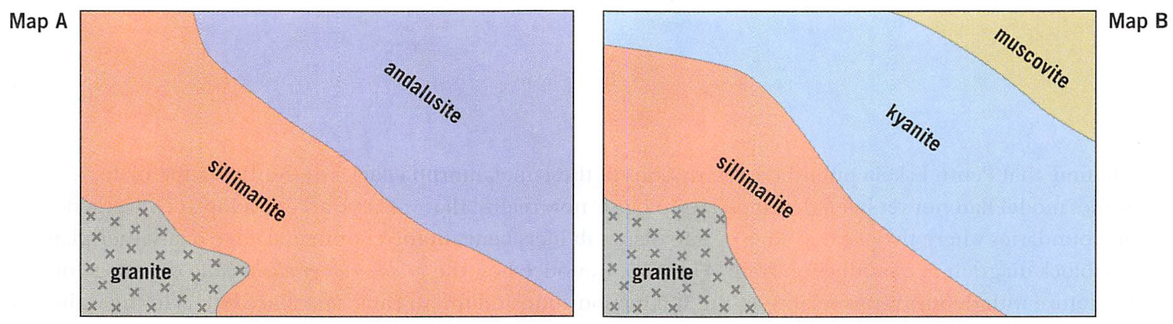


Figure A7.5.3

C Finnish geologist Pentti Eskola recognized that the volcanic rock *basalt* could be metamorphosed to different *metamorphic facies* (unique assemblages of several minerals) under changing conditions of pressure and temperature:

- Amphibolite facies (low pressure, high temperature): black hornblende amphibole, sillimanite.
- Greenschist facies (low pressure, low temperature): green actinolite amphibole and chlorite.
- Eclogite facies (high pressure, high temperature): red garnet, green pyroxene.
- Blueschist facies (high pressure, low temperature): blue amphibole (glaucophane, riebeckite) and lawsonite.

1. Write the names of these metamorphic facies in their proper places on the dotted lines marked A through D in the P-T diagram (**Fig. A7.5.4**). Notice that pressure and depth increase downward in this diagram, and temperature increases to the right.

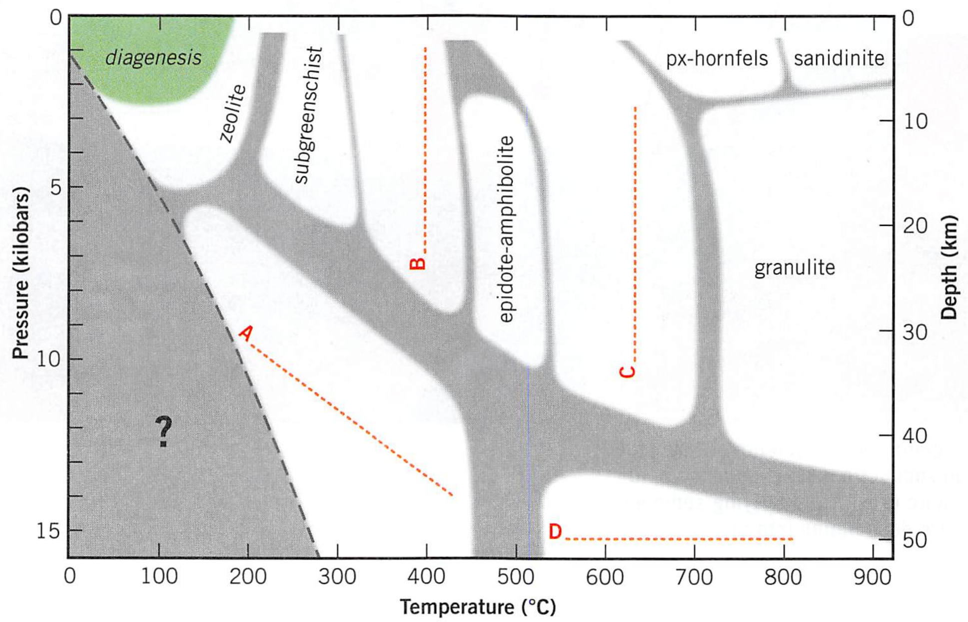


Figure A7.5.4

2. **REFLECT & DISCUSS** What is the significance of the gray area of the P-T diagram in **Fig. A7.5.4** that is marked by a large question mark? *Hint*: Where on or in Earth would you find the P-T conditions in that gray area?

3. At the time that Pentti Eskola published descriptions of these metamorphic facies in the 1920s, the plate tectonics model had not yet been developed. Geologists now realize that volcanic arcs develop at convergent plate boundaries where the oceanic edge of one plate subducts beneath the continental edge of another plate. In the block diagram of a subduction zone (**Fig. A7.5.5**), notice how the *geothermal gradient* (rate of change in temperature with depth) varies relative to the subduction zone and the volcanic arc. Place letters in the white circles that are linked to the starred locations on this illustration to show where Eskola's facies are most likely to occur: A = amphibolite, G = greenschist, E = eclogite, B = blueschist.

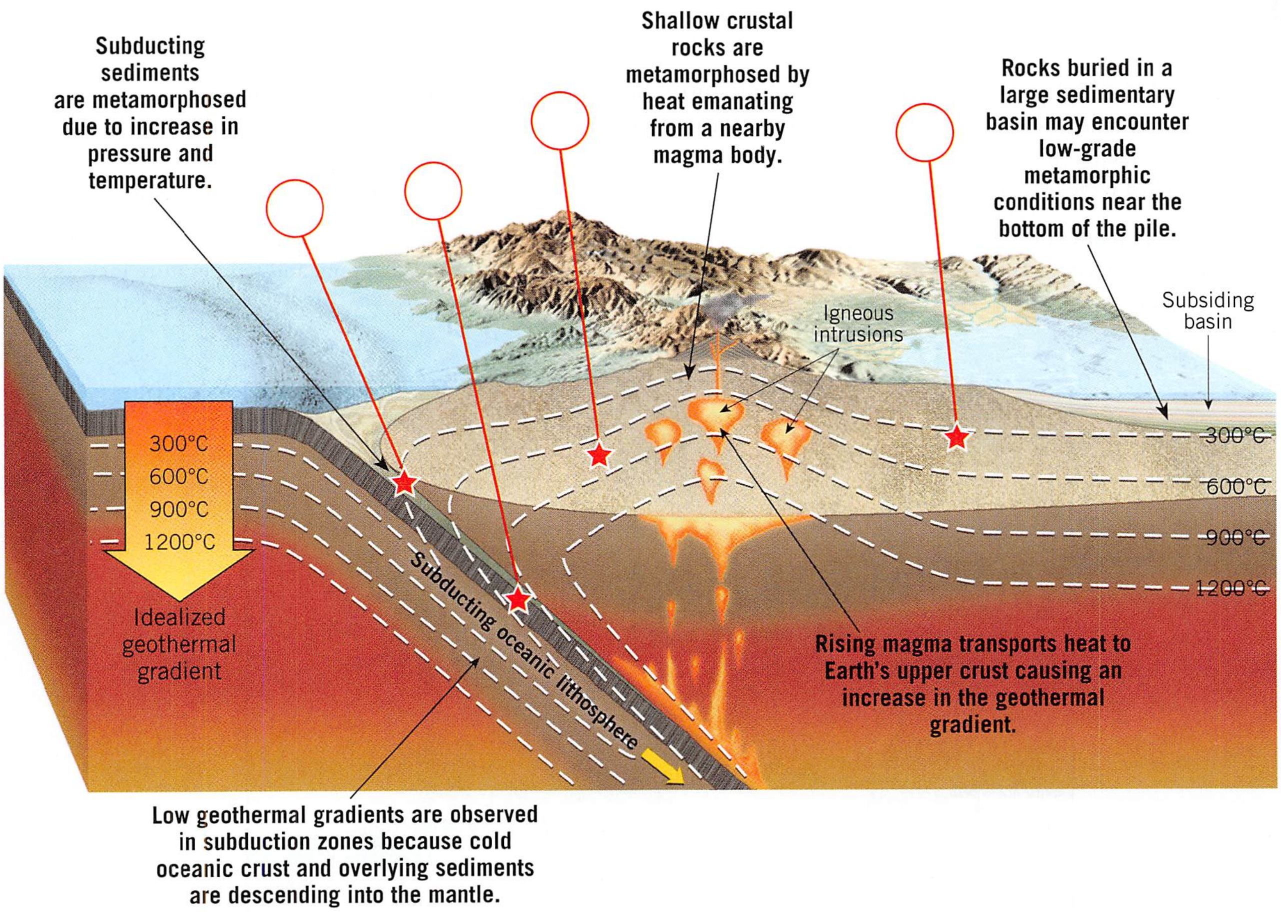


Figure A7.5.5

4. **REFLECT & DISCUSS** Based on what you learned in this activity, write a brief description of how pressure, temperature, depth, and intensity of metamorphism are related.