Answer Key

Answer to Study Questions

1. Metamorphism is the solid-state transformation of pre-existing rock into texturally or mineralogically distinct new rock, as a result of high temperature, high pressure, or both.

2. Weathering is the alteration of rocks at the Earth's surface. Metamorphism is the alteration of rocks as a result of deep burial, tectonic forces, and high temperatures.

3. The banding often present in metamorphic rocks exhibits contortions and folds that indicate that the rocks must have been plastic, not liquid. Melting would have destroyed such banding.

4. The four most important factors in determining the characteristics of metamorphic rocks are
   - the composition of the parent rock before metamorphism,
   - the temperature and pressure during metamorphism,
   - the effects of tectonic forces, and
   - the effects of fluids, such as water.

5. A mineral is stable only within a given temperature range. At a certain temperature (which varies for each mineral and depends on the presence of other substances), the mineral will convert to a new mineral, or at high temperatures melting will occur. The temperature of metamorphism can be determined by observing which minerals are present in the metamorphic rock, and by knowing the temperature range for which these minerals are stable.

6. Chemical reactions proceed much faster at higher temperatures than at lower temperatures, so an increase in temperature will speed up chemical reactions.

7. Melting of a granite under high water pressure could occur at temperatures as low as 700° C. For a granite under high pressure, then, production of a metamorphic rock can only form at a temperature below 700° C.

8. Compare your diagrams to Figures 7.3 and 7.4 in the textbook. To indicate the confining pressure, use arrows of the same length pointing to each of the six sides of the box. For differential stress, the arrows pointing to two opposing sides of the box should be longer than the other arrows.

9. A new mineral formed under confining pressure would be denser than its low-pressure counterpart.

10. Directed comprehensive stress flattens an object perpendicular to the direction in which the stress is applied, whereas shearing tends to flatten objects parallel to the direction of the applied stress (see Figure 7.6 in the textbook).

11. Foliation is the parallel alignment of the textural and structural features of a rock.

12. Rocks that display slaty foliation split easily along nearly flat and parallel planes; those that display schistose foliation contain visible platy or needle-shaped minerals that are aligned parallel to one another; those showing gneissic foliation consist of new minerals separated into distinct light and dark lenses or layers.

13. Water acts to carry ions, thereby facilitating metamorphic reactions.

14. Meteorite impact can cause

    - the creation of rare minerals as the result of brief, very high pressures that occur on impact.
    - shock damage in minerals.
    - glass production through the melting and then hardening of some minerals.
    - production of a type of breccias.
    - the overturning, away from the crater, of beds near the rims of impact craters.

15. One theory of dinosaur extinction proposes that the impact of a large meteorite caused large quantities of dust to enter the Earth's atmosphere. This dust caused a world-wide cooling that created conditions in which dinosaurs could not survive.

16. Temperature is the dominant factor in contact metamorphism. The resulting metamorphic rocks are generally nonfoliated.

17. Metamorphic rocks and the dominant minerals produced by contact metamorphism of each:

Rock	Metamorphic Product	Dominant Mineral
a. shale	hornfels	mica
b. basalt	hornfels	amphibole
c. limestone	marble	calcite
d. sandstone	quartzite	quartz

18. The heat for contact metamorphism usually derives from magma intruding into country rock.

19. The high heat of regional metamorphism is generated either by the friction caused by movement of the Earth or from heat radiated by nearby magma bodies; the confining pressure comes from deep burial; the differential stress results from the constant movement and squeezing of the crust during mountain-building episodes.

20. Before we can see regional metamorphic rocks, they must be revealed through extensive erosion to expose the deeply buried cores of mountain ranges, where regional metamorphism takes place.

21. Six stages of regional metamorphism of shale:
    - shale: submicroscopic, platy, clay minerals
    - slate: realignment of submicroscopic, platy, clay minerals
    - phyllite: some clay minerals recrystallize to extremely fine-grained mica
    - schist: more intense recrystallization of shale mineral; megascopically visible, parallel oriented minerals.
    - gneiss: minerals separate into layers: light and dark coloured; crystallization of coarse feldspars, distinguished from granite by foliation
    - migmatite: partial melting of the rock and sweating out of magma into layers within the foliation of the solid rock

22. Compare your diagram to Figure 7.21 of the textbook.

23. No, the intensity of metamorphism at the base of the continental crust would not be expected to be uniform. It should increase from the edge of the crust towards the volcanic plutonic complex, and then decrease from there to the interior of the continent. Temperatures at

the base of the continental crust are highest below the volcanic plutonic complex.

24. Examine Figure 1 of Web Box 7.3 titled "Metamorphic Facies and the Relationship to Plate Tectonics" online. Go to http://www.mhhe.com/plummer14e, click on Student Edition (bottom left), click on Chapter 7, and click on Web Boxes (under More Resources).

    The metamorphic facies typical of the lowest pressures is zeolite, followed by prehnite-pumpellyite, blueschist, and eclogite, at progressively higher pressures.

25. Examine Figure 2 of Web Box 7.3 titled "Metamorphic Facies and the Relationship to Plate Tectonics" online. Go to http://www.mhhe.com/plummer14e, click on Student Edition (bottom left), click on Chapter 7, and click on Web Boxes (under More Resources).

    The metamorphic facies at shallowest depth is zeolite, followed by greenschist, amphibolites, and granulite, at progressively greater depths.

26. a. Where pressure is low but temperature is high, you would expect to find hornfels facies formed through contact metamorphism.

    b. Where pressure is high but temperature is relatively low, you would expect to find blueschist facies. In the plate tectonic model, you would expect to find this facies in the trench where the oceanic plate is being subducted.

27. A hydrothermal rock is a rock formed by precipitation from solution in hot water.

28. In metasomatism, ions are introduced from an external source, whereas in metamorphism, there is no introduction of external ions.

29. See Figure 7.15 in the textbook. During the formation of a contact metasomatic ore deposit, ions are introduced from the cooling magma and incorporated into the crystallizing ore minerals.

30. Quartz veins form when descending groundwater is heated by an igneous intrusion. The hot water dissolves silicate minerals. As the hot water moves upward through cooler rocks, it cools, and the water can no longer hold silica, so the silica precipitates as quartz in the fractures along which the water was moving.

31. Hydrothermal veins are the primary source of zinc, lead, silver, gold, and other metals.

32. Possible sources for the water involved in metamorphism:

- groundwater
- sea water trapped in sediment overlying the subducted oceanic crust
- water carried by basalt as it descends beneath the continental crust