1. The inner core of the Earth is composed of:
   a) solid silicate  b) liquid silicate magma  c) liquid metal  d) solid metal  e) olivine.

2. The upper mantle of the Earth is composed of:
   a) solid silicate  b) liquid silicate magma  c) liquid metal  d) solid metal  e) green cheese.

3. The water of the Earth’s oceans covers more than 70 percent of the surface but composes only what fraction of the mass?
   a) 50%  b) 10%  c) 1%  d) 0.5%  e) 0.025%

4. What is the most likely geologic setting in which to find basaltic volcanism?
   a) continent-continent convergent boundary (e.g. Himalayas)  b) ocean-continent convergent boundary (e.g. Andes Mountains)  c) ocean-ocean convergent boundary (e.g. Fiji-Tonga)  d) ocean-ocean divergent plate boundary (mid-ocean ridge), and oceanic islands  e) transform plate boundary (e.g. San Andreas Fault zone)

5. The earliest fossils of complex multi-celled organisms like trilobites are of about what age?
   a) 4.55 billion years (Hadean)  b) 3.8 billion years (Archean)  c) 1.8 billion years (Proterozoic)  d) 550 million years (Cambrian)  e) 66 million years (Tertiary or Cenozoic)

6. An external heat engine drives most of the surface processes on the Earth. The source of energy for this engine is:
   a) radioactive decay of U, Th, and K.  b) thermonuclear fusion in the sun.  c) burning of fossil fuels  d) gravitational collapse of the solar nebula  e) tides driven by lunar gravitation.

7. Plate motion is believed to be driven by solid state convection of the silicate mantle. This convection is driven by the Earth's internal heat engine, which is powered by:
   a) radioactive decay of uranium, thorium, and potassium  b) thermonuclear fusion in the sun  c) burning of fossil fuels  d) fission reactions in the Earth's core  e) radioactive decay of $^{14}$C.

8. The age of the Earth, as indicated by radiometric dating of meteorite, lunar, and terrestrial rocks, generally believed to be:
   a) 10 billion years  b) 4.5 billion years  c) 545 million years  d) 40 million years  e) 7000 years.

9. In the scientific method, an observation in the laboratory or field is considered fact if it is
   a) consistent with previous hypotheses  b) consistent with prevailing theory  c) repeatable  d) made by a reputable scientist  e) cited by a reputable scientist

10. The atomic number of an element is:
    a) the number of protons in the nucleus  b) the neutron in the nucleus  c) the number of electrons  d) protons plus neutrons in the nucleus  e) the average number of protons plus neutrons

11. Oxygen has 8 protons in the nucleus. $^{16}$O is:
    a) an oxygen atom with 8 protons and 8 neutrons  b) an oxygen ion with a charge of sixteen  c) a molecule composed of sixteen atoms of oxygen  d) an oxygen atom with sixteen neutrons  e) an atom of sixteenium.
12. MgSiO$_3$ is
a) a chemical formula with one atom of magnesium, one atom of silicon, and three atoms of oxygen
b) a polymer
c) a compound with 60 weight percent oxygen and 20 weight percent silicon, and 20 weight percent magnesium
d) a pyroxene
e) a feldspar

13. The most abundant element in the Earth's crust and mantle is:
a) aluminum  b) boron  c) silicon  d) magnesium  e) oxygen.

14. For a given element, the average mass number (number of protons plus neutrons in the nucleus) is known as the:
a) atomic number  b) atomic weight  c) mass number  d) ionic charge  e) ionic weight.

15. The number of electrons lost by an element in chemical reactions is its common ionic charge. This is also known as its:
a) atomic number  b) atomic weight  c) mass number  d) valence  e) ionic weight.

16. Those elements of the periodic table that form metallic bonds with iron and are enriched in the core of the Earth and in iron meteorites are termed:
a) atmophile  b) siderophile  c) chalcophile  d) lithophile  e) thermophile

17. A naturally occurring, homogeneous solid of definite chemical composition and ordered atomic arrangement that is usually formed by inorganic processes is known as a(n)
a) element  b) mineral  c) rock  d) crystal  e) planet.

18. Forsterite (Mg$_2$SiO$_4$) and fayalite (Fe$_2$SiO$_4$) are different chemical end-members of olivine and have the same crystal structure. They are known as
a) isomorphs  b) pseudomorphs  c) polymorphs  d) mightymorphs  e) tetrahedra.

19. The minerals, calcite and aragonite, both have the formula (CaCO$_3$), but have different crystal structures. These minerals are known as:
a) isomorphs  b) pseudomorphs  c) polymorphs  d) mightymorphs  e) tetrahedra.

20. Which of the following is a native-element mineral (a pure element that occurs naturally):
  a) quartz  b) beryl  c) calcite  d) graphite  e) pyrite

21. An example of a natural solid that is not a mineral is
  a) diamond  b) ice  c) obsidian  d) gold  e) graphite

22. In the crystal structures of the common silicate minerals, each silicon atom is surrounded by four oxygens in the form of a:
a) triangle  b) tetrahedron  c) hexahedron  d) octahedron  e) dodecahedron

23. Each of the oxygens in quartz is bonded to two silicon atoms, whereas in olivine each oxygen is bonded to only one Si atom. The degree to which the oxygens are shared between to Si atoms is the degree of:
a) allocation  b) bifurcation  c) polymerization  d) differentiation
e) elongation

24. The compositions of rocks composed almost entirely of quartz, alkali feldspar and mica are said to be:
a) felsic or silicic  b) intermediate  c) mafic  d) ultramafic  e) basaltic.
25. A small igneous body of rock that has intruded into sedimentary rocks and has an outcrop area of less than about 100 km² is known as a:
   a) aa  b) sill  c) stock  d) dike  e) pluton.

26. Which of the following is an ultramafic rock:
   a) granite  b) basalt  c) gabbro  d) diorite  e) peridotite

27. Ultramafic rocks are primarily found in the:
   a) oceanic crust  b) continental crust  c) mantle  d) core  e) ocean islands

28. Although silica (SiO₂) composes 40 to 70% by weight of most igneous rocks, the mineral quartz (SiO₂) is only abundant in the rock:
   a) lherzolite or peridotite (ultramafic)  b) gabbro  c) diorite  d) basalt  e) granite.

29. A rock formed by the processes of solid-state recrystallization of pre-existing rock is called:
   a) igneous  b) metamorphic  c) hydrothermal  d) sedimentary  e) limestone.

30. A rock formed by the processes of melting followed by cooling and crystallization is called:
   a) igneous  b) metamorphic  c) hydrothermal  d) sedimentary  e) limestone.

31. The most abundant mineral in ultramafic rocks is typically:
   a) quartz  b) feldspar  c) mica  d) olivine  e) epidote

32. A gabbro is the coarse-grained compositional equivalent of a:
   a) rhyolite  b) basalt  c) andesite  d) granite  e) peridotite.

33. A well-sorted, fine-grained quartz sandstone exhibiting large and extensive cross-bedding was probably deposited in a:
   a) alluvial fan  b) lagoon  c) abyssal plain  d) desert  e) shallow sea.

34. A sedimentary rock composed of rounded sand-, pebble-, and cobble-sized particles is a:
   a) sandstone  b) breccia  c) conglomerate  d) cobblestone  e) shale.

35. The most abundant mineral in most shale is:
   a) calcite  b) clay  c) quartz  d) gypsum  e) feldspar

36. Which of the following minerals would not occur in an evaporite?
   a) halite  b) gypsum  c) calcite  d) sylvite  e) quartz.

37. The polymerization of SiO₄ tetrahedra in a magma:
   a) increases with increasing silica content  b) causes a change of color
   c) causes an electrical discharge  d) is a major cause of earthquakes
   e) causes a rise in pressure.

38. Which of the following processes contributes to the formation of residual deposits?
   a) assimilation  b) igneous fractionation  c) subduction  d) xenolith formation
   e) explosive eruption

39. The polymerization of SiO₄ tetrahedra in a magma:
   a) increases with increasing silica content  b) causes a change of color
   c) causes an electrical discharge  d) is a major cause of earthquakes
   e) causes a rise in pressure.
Essays  (There will be one essay on the test. It will be something like one of the following:

1. How does the degree of polymerization of silicate tetrahedra at the atomic scale account for the different styles and processes of basaltic versus rhyolitic volcanism?

The silicon-oxygen tetrahedral bonds are among the strongest chemical bonds in rocks and minerals. The degree to which they form connected networks by sharing of oxygen atom between silica tetrahedra is the degree of polymerization. The degree of polymerization is high in quartz and alkali feldspar minerals and also in silicic (granitic) magmas and low in ferromagnesian minerals and in basaltic melts. Highly polymerized (silicic) melts are generally cooler and much more viscous so that volcanism is commonly explosive. Melts with a low degree of polymerization (basaltic) are more fluid, and volcanism is typically quiescent lava flows.

2. What is a mineral and how does it differ from a rock?

A mineral is a naturally occurring, homogeneous solid with a definite chemical composition and an ordered atomic arrangement that is formed by inorganic processes. It differs from a rock in that a rock is a physically coherent aggregate of different mineral grains which is not homogeneous, lacks a defined chemical composition and a defined crystal structure.

2. What are protons, neutrons, electrons, isotopes and elements and how are they formed?

A proton is a fundamental atomic particle with a rest mass of $1.67 \times 10^{-24}$ g and an electric charge of $+1$. A neutron is a fundamental atomic particle with a rest mass of $1.67 \times 10^{-24}$ g and an electric charge of 0. An electron is a fundamental atomic particle with a rest mass of $9.1 \times 10^{-28}$ g and an electric charge of -1. Protons, neutrons and electrons were formed in the Big Bang. Isotopes and elements are aggregates of these fundamental particles. Isotopes of a given element differ from each other in the number of neutrons. The two lightest elements, H and He, were formed in the Big Bang, whereas the heavier elements were formed by nuclear fusion reactions in stars.

3. What is igneous fractionation and how does it account for the differences between mantle, oceanic crust and continental crust?

Igneous fractionation is the process of deriving a magma of a different chemical composition from a rock of a definite composition, by partial melting and fractional crystallization. A typical mantle rock is a peridotite, whereas the magma extracted by 10% partial melt will be basaltic (mafic) in composition. Hence a 10% partial melt of the mantle gives basalts at the mid-ocean ridge. If this basalt is then remelted, a 10 to 20% partial melt will be andesitic in composition. If the andesite undergoes partial melting, a 10 percent partial melt can be granitic in composition. The first partial melt from the mantle gives basaltic ocean crust which is thin, dense, and young relative to the continents. Subsequent partial melting events can derive a thick, light, silica-rich residuum which accumulates as the continents.
4. What is the scientific method and how is it used to draw conclusions about the origin and age of the Earth?

The scientific method consists of four basic steps by which we can learn about our physical environment. The steps are: Observation, hypothesis, testing, and theory. First, a set of observations or measurements are made about a particular phenomenon, say the origin of the Earth. Second, one or more testable hypotheses are advanced to explain or link the observations. Third, the various hypotheses are tested against further observations. Finally the surviving hypothesis becomes the theory that explains the original and subsequent observations. In the case of the origin and age of the Earth, the observations are the many rocks of different radiometric ages and stratigraphic positions. The hypothesis is that it was formed 4.5 billion years ago and has evolved by processes observable today. Alternate hypotheses include formation at about 40 million years ago or as young as 7000 years ago by supernatural processes. The consistently very old ages of meteorites and lunar samples as well as most terrestrial igneous rocks are only consistent with the first hypothesis.

5. What are the two major energy sources that drive Earth processes and which processes does each primarily control?

The two major energy sources are the internal source that is powered by the decay of naturally radioactive elements, principally U, Th and K, and the external source that is powered by thermonuclear fusion in the Sun. The internal source powers mantle convection, plate tectonics, earthquakes, and volcanism, whereas the external source powers weather, climate, atmosphere and ocean circulation, weathering, erosion, and sediment transport and deposition.

6. What is igneous fractionation? How can it account for the difference between continents and oceans? (20pts)

Igneous fractionation is the process of deriving a magma of a different chemical composition from a rock of a definite composition, by partial melting and fractional crystallization.

10 points for knowing that a rock of one composition is derived from one of another composition by igneous fractionation consisting of partial melting and fractional crystallization.

A typical mantle rock is a peridotite, whereas the magma extracted by 10% partial melt will be basaltic (mafic) in composition. Hence a 10% partial melt of the mantle gives basalts at the mid-ocean ridge. If this basalt is then remelted, a 10 to 20% partial melt will be andesitic in composition. If the andesite undergoes partial melting, a 10 percent partial melt can be granitic in composition. The first partial melt from the mantle give basaltic ocean crust which is thin, dense, and young relative to the continents. Subsequent partial melting events can derive a thick, light, silica-rich residuum which accumulates as the continents.

5 pts for knowing that basalt that from the ocean crust is derived by partial melting of the mantle. 5 pts for knowing that continental rocks are derived from basaltic ocean crust by further partial melting ad refining.