Chapter 2

1. Earth is a member of the solar system. Cosmic theories on the evolution of solar system suggest that it evolved from a low-temperature dust cloud at about 50^o K (K=Kelvin thermometric scale; 0^o K is absolute zero or -273.13^o C). The cosmic dust cloud condensed by the gravitational energy, evolving members of the solar system. The gravitational energy converted to heat.

2. Theories on the evolution of stars suggest that the sun's luminosity has increased by a factor of 1.6 since the origin of the earth. This would lead to a rise in the earth's temperature, such that the mean surface temperature of the earth would have been below 0^o C before 3×10^9 years.

3. Geologic evidence also suggests a lowered temperature thermal regime for the earth through early geologic times. With one or two exceptions, the sedimentary rocks are not known to be older than this reference time. The 'cold' origin of the earth also finds support from the near absence of terrestrial vegetation in early geologic periods. Vigorous metabolism requires a mean annual temperature of 0 to 50^o C.

4. Continents and ocean basins are two primary divisions of the earth. They fundamentally differ in age, composition and thickness of the lithospheric crust, and hypsometric aspects. The continents lie at the mean elevation of 875 m above the msl and ocean basins at the mean depth of 3800 km from the sea-surface level. The continents are 35 and oceans 65 per cent of the earth's area. The continents are built of silica-aluminium rich rocks that are 2 to 3 billion years old and the oceanic crust comprises of silica-manganese rich rocks that are 100 to 200 million years old. The oldest known continental crust or the earth's primordial crust is 4.28 billion years old along the Hudson Bay in northern Quebec, Canada.

5. Initially the proto-earth was all mantle, abundantly rich in homogeneously distributed silicates of iron and nickel. Presently, the upper mantle consists essentially of low-density magnesium iron silicate minerals, suggesting it to be the silicate residue of the original mantle that has its iron and nickel content separated from the lighter silicates by gravitational fractionation. The gravitational separation, which caused the heavy metals to sink and lighter silicates to move up, resulted from internal heating of the earth from the heat-producing decay of radioactive elements.

6. Gravitational fractionation has evolved the layered internal structure of the earth, giving the core, the mantle and the crust as three distinct divisions. The core, which consists of an iron-nickel alloy, is the central part of the earth at a depth of about 2900 km from the earth's surface. The outer core is liquid and inner core of about 1300 km radius is solid in nature. The behaviour of core as a liquid and solid

substance depends on the relationship between temperature and pressure conditions obtaining there. The mantle extends to some 2900 km depth from the surface of the earth. It comprises of ferromagnesian silicates, metallic oxides and metals as copper, gold, iron, platinum, silver, and others. The upper mantle of some 100 km depth, called asthenosphere, is a zone of discontinuous melting and plastic deformation. This zone is probably periodite or magnesium iron silicate mineral of olivine and pyroxene. The boundary between the mantle and the crust, called the Moho discontinuity, is about 35 km beneath the continents and some 10 km below the oceans. The lithospheric crust is continental and oceanic in nature. The continental crust is silica-aluminium rich and plutonic in nature. It has evolved in series of cascading events through geologic time. The oceanic crust is basaltic in nature. It is thicker in shallower seas than in areas of open sea. The oceanic crust of shallower seas has undergone rapid up and-down motions. Areas of such crustal deformation are called quasi-cratonic belts or depressions. Data on the interior of the earth comes from seismology, a geophysical science concerned with the study of earthquakes and measurement of the elastic properties of the earth.

7. The earth loses its internal heat at the average rate of 2.4×10^{20} cal / yr from both the continents and ocean basins. The heat loss, however, is uneven from major geologic features of the earth. It varies inversely with the age of the lithospheric crust. The uneven distribution of geothermal heat is due primarily to the decay of radioactive elements in the lithopsheric crust. The geothermal heat is the cause of plate tectonics.

8. The theory of plate tectonics explains the internal geologic processes and the general pattern of tectogenic features of the earth. The theory suggests that the earth's lithosphere is divided into major and minor plates. The plates move over the asthenosphere at different rates and in sense of direction. They diverge, converge or slide past each other.

9. The creation of oceanic crust at mid-oceanic ridges and destruction of the oceanic crust in subduction zones of the earth is central to the sea-floor spreading hypothesis.

10. The plate tectonics envisages that a super-continent called Pangea split at the beginning of the Cretaceous period, creating tear zones through to the depth of the asthenosphere. The rifting lowered the melting temperature of magma. The magma possibly originates at the mantle-core boundary, converges at narrow rift zones and escapes laterally and sideways, forming the mid-oceanic ridge system.

11. The palaeomagnetic record in the oceanic crust suggests that the ocean basins are no more than 200 million years old. The dated remains of protozoa in sediments overlying the oceanic crust suggest that North Atlantic is spreading at the rate of 2 cm / yr and the Pacific Ocean at the rate of 10 cm / yr. Seamounts and guyots that have moved away from the mid-oceanic ridge system similarly attest to the seafloor spreading.

12. Rapidly sliding and steeply inclined zones of plate subduction are called the Benioff zone.

13. The relative movement of lithospheric plates causes volcanic and seismic activity of the earth.

14. The sliding of plates disturbs the mantle equilibrium, producing earthquakes.

15. The earth is probably aseismic at depths greater than 720 km.

16. The subducting plates evolve orogenic belts. The colliding plates result in an enormous compressive stress in the subcrust. The gravitational collapse of the Tibetan Plateau 14 million years ago is attributed to the compressive stress of collision between the Indian and Eurasian plates. Several tectogenic features of compressive and tensile stress release in Asia are the product of continent-continent collision.

17. Sliding of lithospheric plates relative to each other evolves transform fault boundary at the surface. The San Andreas Fault is one such example.

18. Rock-forming minerals are recycled into new products in subduction and collision zones of plate interaction.

19. Rocks are igneous, sedimentary and metamorphic in type. Igneous rocks evolve from the solidification of magma and lava either at or within the earth's crust, evolving extrusive and intrusive varieties as the two principal types. The extrusive variety of quieter magma release, called lava, evolves plateaus of regional dimension. The extrusive variety comprising of volcanic fragments and ash, called pyroclasts, form shield volcanoes from the fluid type flow and conical volcanoes from the viscous flow of lava and volcanic ash. The cooling of igneous rocks and crystallisation of lava within the earth's crust form intrusive volcanic rocks.

20. Extrusive and intrusive varieties of igneous rocks evolve distinct landforms and landscape characteristics, and minor geologic structures.

21. The extrusive lava flows can obliterate drainage systems and even cause inversion of relief.

22. Sedimentary rocks evolve from lithification or compaction and cementation of sediments that had settled in sedimentary basins. They are clastic or detrital and chemical sedimentary in type. The

clastic sedimentary rocks are classified by grain-size composition into three principal varieties. The sedimentary basins are also distinct in the geologic environment, giving chemical and biochemical varieties of sedimentary rocks. Limestone is a chemical sedimentary rock. Chalk, which is released in the tests of sea-dwelling organisms, is biochemical in origin. The chemical environment of sedimentary basins strictly governs the precipitation of siliceous, ferruginous, carbonaceous and phosphatic sediments.

23. Metamorphic rocks evolve by regional and local processes of metamorphism. Regional metamorphism is associated with the dragging of igneous and sedimentary rocks in subduction zones and of pre-existing rocks in continent-continent collision zones of plate interaction. Given these conditions, the rocks are subject to increased temperature and pressure environment by which their mineral suits become unstable, breakdown or re-crystallise into new mineral varieties. Contact metamorphism and dislocation metamorphism are two localised processes of metamorphic rocks. Contact metamorphic rocks represent changes in the mineral suites around a narrow zone of igneous intrusion, called aureole, where pre-exiting minerals alter or are completely replaced by the fluid transport of some chemical components. Dislocation metamorphism is associated with the frictional heat and elevated pressure conditions obtaining in certain situations. The rocks of regional metamorphism are classified by their pressure and temperature regime into low, medium and high-grade metamorphics, in which each group is distinct in petrographic and minerologic attributes.

24. Metamorphic rocks, in general, comprise of minerals that are hard and resistant to weathering. Quarts, thus, survives pulverisation in terrestrial environments. However, metamorphic rocks of a large mineral assemblage are relatively more susceptible to weathering than rocks of lesser mineral diversity. Schist, which comprises of a variety of mineral assemblages, decomposes in the hot-humid tropical environment to clay minerals and mica. Marble dissolves by the solvent action along joints and cleavage separation at the boundary of the mineral calcite.

25. Metamorphic rocks, in general, represent high relief of geomorphic landscapes.

26. Rocks and sediments are characteristic of certain inherent strength. The rock strength varies with its mineral constituents, fissure frequency, and placement relative to the earth’s surface and climatic environment. The strength of a sediment aggregate depends on interrelated solid, air and water phases in the system.

27. The earth materials are subject to internal and external stress forces. They deform at a stress magnitude exceeding the strength of materials. Measured as force per unit area, the stress creates strain or deformation in solids at a threshold exceeding the elasticity of the body. A material is said to be elastic if it returns to its original shape or size upon the removal of deforming force. A plastic deformation produces permanent change in the shape or size of solid bodies.

28. In rocks and sediment aggregates, the stress is due to the weight of masses and the applied force. The force due to the weight of individual bodies is called the normal stress and that due to the applied force is known as the shear stress. The normal force acts vertically through the centre of gravity of the mass. The applied force can act in any possible direction.

29. Compressive stress squeezes, tensile stress stretches and shear stress produces planar (or shear) deformation in rocks. The tensile stress is defined as the ratio of force of tension to the cross-sectional area. The resulting tensile strain is the ratio of change in length to the original length. Tensile and compressive stresses are known as the longitudinal stress.

30. Rock strength is difficult to measure. It is experimentally determined as compressive, tensile and shear at which a stressed rock sample breaks.

31. Compression is rare at the earth's surface but it is common in the subcrust where rocks are confined on all sides except to the sky.

31. Rocks at the earth's surface deform by tensile and shear forces.

32. Rocks are brittle at the earth's surface and ductile within the subcrust. This difference in the deformation behaviour of rocks results from thermal and geodynamic stress conditions within deeper parts of the crust.

33. The stress is relieved by a corresponding strain or change in the shape of rock bodies.

34. If applied forces are within the elastic limit, the stress is proportional to the resulting strain. This is the Hooke's Law.

35. The ratio between stress and strain is called Young's modulus of elasticity.

36. The ratio between volume stress and volume strain is the bulk modulus.

37. The reciprocal of bulk modulus is the modulus of compressibility.

38. The stress normal to cube-shaped rock is the principal stress. It develops two shear forces at right angle to the normal and to each other.

39. Rocks deform when the magnitude of shear stress exceeds that due to the normal stress.

40. The magnitude of normal and shear stress varies with the angle of inclination of the plane on which it acts.

41. The deformation behaviour of rocks varies with their geologic attributes, conditions of confining pressure and temperature, and duration of stress application.

42. Anisotropic than isotropic rocks withstand a greater magnitude of stress before rupture. Pore water reduces the brittle character and enhances the ductile properties of rocks. Ductile materials undergo plastic deformation under stress.

43. Subcrustal stress increases rigidity, elasticity and strength of rocks.

44. Rocks are brittle at low and ductile at higher temperatures.

45. Rocks in natural setting are presumed Newtonian materials. In Newtonian solids, the relation of shear stress to strain rate is linear.

46. Sediment aggregates, loosely called soils, are a system of solids, water and air phases. The solid phase represents the particulate matter, and intergranular voids in the aggregate provide for water and air phases of the system.

47. The deformation behaviour of sediments varies with the physical and chemical properties of the particulate matter, the pore water content and the duration of applied load.

48. The solid phase is clay through to boulder in size class and massive and clay minerals by the mineral composition. These properties variously affect the shear strength and susceptibility of sediments to failure under stress.

49. The deformation behaviour of fine-grained soils varies with the moisture content.

50. Atterberg Limits quantify the plastic limit, liquid limit and shrinkage limit of cohesive sediments. At the plastic limit, the sediments change from a friable to plastic consistency. The upper plastic limit signifies a moisture content at which the water film is thick enough to decrease cohesion among grains. The soil mass, therefore, flows under the force of applied load.

51. The effective normal stress governs the behaviour of compression and strength of saturated cohesive sediments.

52. The shear resistance of fine-grained soils varies with the void ratio and pore pressure in the system.

53. The pore pressure shares a part of the applied load. This is the concept of effective normal stress.

54. Dry soil grains deform by interparticle sliding at their contact points.

55. The interparticle sliding describes a plane inclined at an angle to the horizontal. This angle is called the angle of internal friction.

56. The angle of internal friction describes the maximum shear stress in dry soils.

57. Dry soils are cohesionless. They deform at all levels of stress.

58. Dry soils deform at primary, secondary and tertiary rates of creep.

59. The strain behaviour of loaded saturated soils varies with the effective stress.