GG Geology and Geophysics

Part A: Common Section

This section includes various introductory topics related to geology and geophysics.

Introduction to Earth and planetary systems: Terrestrial planets and moons of the solar system; Concept of isostasy, Internal structure of Earth – elasticity, body and surface waves, propagation of body waves in the Earth's interior; Heat flow within the Earth; Gravitational field of the Earth; Continental and oceanic crust – composition, structure and thickness.

Plate Tectonics: Type of plate boundaries; Plate motions and driving mechanisms; Processes at plate boundaries - volcanism, seismicity, orogenesis, sea-floor spreading and magnetic anomalies and paleomagnetism, formation of back-arc basins; Continental rifting, mantle plumes, hotspots; Numerical problems related to plate motions.

Earth surface processes: Landforms created by hillslopes, rivers, wind, glaciers, oceans, and volcanoes.

Basic structural geology: Mohr's circle, stress, strain, and material response; Brittle and ductile deformation; Nomenclature and classification of folds and faults.

Mineralogy: Silicate crystal structure, physical and chemical properties of common rock-forming minerals.

Common Igneous: Sedimentary, and metamorphic-rocks: composition, structure, and formation processes.

Stratigraphy and Geological time scale: Relative and absolute time, Half-life, decay constant, radioactive equilibrium, stratigraphic principles, and major stratigraphic divisions of India; Major metallic ores, coal and petroleum resources of India.

Introduction to remote sensing: Energy sources and radiation principles, atmospheric absorption, interaction of energy with Earth's surface; Engineering properties of rocks and soils; Natural hazards (landslide, volcanic, seismogenic, coastal) and mitigation; Principles of climate change;

Elements of hydrogeology: Principles and applications of gravity, magnetic, electrical, electromagnetic, seismic, and radiometric methods of prospecting for oil, mineral, and groundwater.

Part B1: Advanced topics in Geology

Geomorphology: Basic geomorphic concepts, Geomorphic processes, and agents; Development and evolution of landforms in continental and oceanic settings; Landscape evolution in response to tectonics, climate, and base-level change. Quaternary geomorphology.

Structural Geology: Stress and strain analysis, deformation mechanisms, primary and secondary structures; Geometry and genesis of planar and linear structures (bedding, cleavage, schistosity, lineation); Folds, faults, joints, and unconformities; Shear zones, thrusts, and superposed folding; Geological maps-interpretation, measurements, and numerical analysis; Stereographic projection.

Crystallography and Mineralogy: Elements of crystal symmetry, form, and twinning; Crystallographic projections; Classification of minerals, physical and optical properties of rock-forming minerals; Mineral nucleation; Mineral chemistry (major, trace, and rare earth elements), cation re-calculations.

Geochemistry: Nucleosynthesis and cosmic abundance of elements; Classification and components of meteorites; Geochemical affinities and distribution of major, minor and trace elements in crust, mantle, and core; Planetary differentiation and geochemical evolution of the earth; Radiogenic (long-lived) isotopic evolution (Rb-Sr, Sm-Nd, U-Th-Pb) of the crust and the mantle, mantle reservoirs; Stable isotope geochemistry (H, O, C), isotope fractionation; geochemical cycles; Elements of high-temperature and low-temperature geochemical thermodynamics; Geochemical and isotopic (C-O, Sr isotopes) composition of river water, groundwater and

seawater, residence time, and water-rock interaction; Principles of environmental geochemistry (pH, Salinity, TDS, BOD, COD).

Igneous Petrology: Classification and textures of common igneous rocks; Mantle melting; Magmatic differentiation; Role of major, trace, and rare earth elements in igneous petrogenesis; Magma evolution, modeling crystallization and melting processes, plate margin volcanism; Intra-plate volcanism and large igneous provinces.

Thermodynamics: Equilibrium, Gibbs free energy; enthalpy, entropy, energy, Clapeyron Equation, Mineral stability and Phase equilibria, Schreinmakers rules; Phase rule; Phase diagrams, Activity-composition; Mineral solid solutions; Enthalpy and entropy of magma crystallization, Binary and ternary phase diagrams in igneous systems; Chemical speciation and equilibrium in natural waters, solubility and precipitation of minerals - saturation index calculations, Eh-pH diagrams and redox equilibria.

Sedimentology: Texture, structure, sedimentary processes, physical principles related to fluid flow; Statistical analysis in sedimentology; Petrology of common sedimentary rocks; Sedimentary facies and environments, cyclicities in sedimentary succession; Provenance and basin analysis.

Metamorphic Petrology: Structures and textures of metamorphic rocks; Extreme metamorphism; Metamorphic facies and grades; Paired metamorphic belts; Mineral reactions and chemographic projections; Metamorphism of pelitic, mafic and impure carbonate rocks; role of bulk compositions and fluids in metamorphism; Thermobarometry; Timing of metamorphism.

Paleontology: Diversity of life through time, mass extinctions- causes and effects; Taphonomy - processes of fossilization. functional morphology of invertebrates (bivalves, brachiopods, gastropods, echinoids, ammonites) and microfossils - (foraminifera, Ostracoda, conodonts, bryozoa); Statistical analysis of morphology; Vertebrate paleontology. Basic concepts of paleoecology; Fossils and paleoenvironments.

Stratigraphy: Principles of stratigraphy, concepts of correlation and their applications in Indian stratigraphy; Quantitative Lithostratigraphy, biostratigraphy, and chronostratigraphy - statistical and probabilistic approaches; Isotope stratigraphy; Principles of sequence stratigraphy and applications; Boundary problems in Indian stratigraphy.

Resource Geology: Ore-mineralogy; Ore forming processes - magmatic, hydrothermal, sedimentary, supergene, and metamorphogenic ores; Fluid inclusions in ore genesis; Coal and petroleum geology; Marine mineral resources; Prospecting and exploration of economic mineral deposits - sampling, ore reserve estimation, geostatistics, and mining methods; Distribution of strategic, essential, and critical minerals and fossil fuel deposits in India.

Engineering Geology: Physico-mechanical properties of rocks and soils; rock index tests; Rock failure criteria (Mohr-Coulomb, Griffith, and Hoek-Brown criteria); Shear strength of rock discontinuities; Rock mass classifications (RMR and Q Systems); in-situ stresses; Geological factors in the construction of engineering structures including dams, tunnels, and excavation sites; Analysis of slope stability.

Hydrogeology: Porosity and permeability; Groundwater storage and aquifer properties; Darcy's law; Hydraulic conductivity and groundwater flow dynamics; Groundwater exploration, well hydraulics.

Remote Sensing: EM spectrum, multispectral remote sensing in visible, infrared, thermal IR and microwave regions including hyperspectral; Digital processing of satellite images. GIS – basic concepts, raster and vector mode operations; Applications of remote sensing tools and techniques in geology.

Part B2: Advanced topics in Geophysics

Heat flow: Elements of conduction and convection within the mantle and the core, Half-space cooling, calculation of simple geotherms, geothermal gradient, equilibrium geotherms, thermal models in plate tectonics, adiabat, and melting in the mantle.

Geodesy: Gravitational Field of the Earth; Clairaut's theorem, size and shape of Earth; Geoid; Ellipsoid; Geodetic Reference Systems; Datum; GPS.

Seismology and Interior of the Earth: Variation of density, velocity, pressure, temperature, electrical and magnetic properties of the Earth; Conservation laws, Newton's law of viscosity, elements of laminar and turbulent flow; Elements of elasticity theory- stress and strain tensors, Generalized Hooke's Law; Body and Surface Waves; Rotational, dilatational, irrotational, and equivoluminal waves; Reflection and refraction of elastic waves; Inhomogeneous and evanescent waves and bounded waves; Eikonal Equation and Ray theory; Wave propagation in elastic media, Seismic Tomography.

Earthquake Seismology: Earthquakes-causes and measurements, magnitude and intensity, focal mechanisms; Earthquake quantification, source characteristics, seismotectonics and seismic hazards; Digital seismographs, Earthquake statistics, quantifying earthquake source from seismological data; Uniqueness Theorem, Representation Theorems of correlation and convolution type, Reciprocity.

Potential and Time Varying Fields: Scalar and vector potential fields; Laplace, Maxwell and Helmholtz equations for solution of different types of boundary value problems in Cartesian, cylindrical, and spherical polar coordinates; Green's theorem; Image theory; integral equations in potential and time-varying field theory.

Gravity: The earth as a planet; Absolute and relative gravity measurements; The various corrections for gravity data reduction – free air, Bouguer and isostatic anomalies; density estimates of rocks; Regional and residual gravity separation; Principle of equivalent stratum; Upward and downward continuation; Wavelength filtering; Gravity anomalies and their interpretation – anomalies due to geometrical and irregular shaped bodies, depth rules, calculation of mass.

Magnetic Methods: Geomagnetic field, paleomagnetism; Inclination, declination; Magnetic induction equation – convection, diffusion, Ohm's law for a moving conductor, frozen flux theorem, magnetic fields of planets in the Solar System, Geodynamo and origin of Earth's Magnetic field, magnetic susceptibility of rocks and measurements; Various corrections applied to magnetic data, IGRF, Poisson's relation of gravity and magnetic potential field, upward and downward continuation, magnetic anomalies due to geometrical and irregular shaped bodies; Interpretation of processed magnetic anomaly data; Derivative, analytic signal and Euler Depth Solutions.

Electrical Methods: Conduction of electricity through rocks, electrical conductivities of metals, non-metals, rock-forming minerals and different rocks, concepts of D.C. resistivity measurement and depth of investigation; Apparent Resistivity and Apparent Chargeability, Theory of Reciprocity, Sounding and Profiling, Various electrode arrangements, application of linear filter theory, Sounding curves over multi-layered earth, interpretation of resistivity field data, Principles of equivalence and suppression.

Electromagnetic Methods: Geo-electromagnetic spectrum; Biot Savart's Law; Maxwell's Equation, Helmholtz Equation, Basic concept of EM induction in the earth, Skin-depth, elliptic polarization, in-phase and quadrature components, phasor diagrams; Response function and response parameters; Measurements in different source receiver configurations; Earth's natural electromagnetic methods- tellurics, geomagnetic depth sounding and magnetotellurics; Electromagnetic profiling and Sounding, Time domain EM method; EM scale modelling, processing of EM data and interpretation; Ground Penetrating Radar (GPR) Methods; Effect of conducting overburden.

Seismic Methods: Elastic properties of earth materials; Reflection, refraction, generation, and propagation of elastic waves, velocity – depth models, seismic noise and noise profile analysis, processing, and interpretation; CDP stacking charts, binning, filtering, static and dynamic corrections, Digital seismic data processing, seismic deconvolution and migration methods, attribute analysis, bright and dim spots, seismic stratigraphy, high-resolution seismics, VSP, AVO, multi-component seismics, and seismic interferometry; Kirchhoff migration, Time Reversal, Time-Reversal imaging, Reverse-Time Migration; Representation theorem of cross-correlation

and convolution type.

Reservoir Geophysics: Rock Physics and Petrophysics, Failure Criteria, stress concentration, Linear elasticity fracture mechanics, Elastic-Plastic Fracture mechanics; Griffith's criterion, dynamic fracture mechanics; Lithology and Porosity Estimation; Saturation and Permeability Estimation; application of borehole geophysics in groundwater, mineral, and oil exploration.

Geophysical Signal Processing: Sampling theorem, Nyquist frequency, aliasing, Fourier series, periodic waveform, Fourier and Hilbert transform, Z-transform and wavelet transform; power spectrum, delta function, auto-correlation, cross-correlation, convolution, deconvolution, principles of digital filters, windows, poles, and zeros, Basics of Time-frequency analysis.

Geophysical Well Logging: Principles and techniques of geophysical well-logging, SP, resistivity, induction, gamma ray, neutron, density, sonic, temperature, dip meter, caliper, nuclear magnetic resonance- longitudinal and transverse relaxation, CPMG sequence, porosity characterization, cement bond logging, micro-logs, Quantitative evaluation of formations from well logs.

Geophysical Inversion: Basic concepts of forward and inverse problems, Ill-posedness of inverse problems, condition number, non-uniqueness and stability of solutions; L1, L2, and Lp norms, overdetermined, underdetermined and mixed determined inverse problems, quasi-linear and non-linear methods including Tikhonov's regularization method, Singular Value Decomposition, Backus-Gilbert method, simulated annealing, genetic algorithms, swarm intelligence, Statistics of misfit and likelihood, Random Variables and Processes, Probability distribution functions - Gaussian, Poissonian, log-normal; Spatial analysis, Hypothesis testing; Bayesian construction of posterior probabilities, sparsity promoting L1 optimization; Ambiguity and uncertainty in geophysical interpretation; PDE constrained optimization, Adjoint-state method.