DEPARTMENT OF EARTH SCIENCES

PONDICHERRY UNIVERSITY

M.Sc. Geophysics

Course Structure

and

Syllabi

July 2022

Admission

Total number of seats for the new 2-year M.Sc. (Geophysics) program will be 10. The admission will be based on the merit in the nationwide test conducted by NTA. A student fulfilling the following criteria is eligible to apply.

Eligibility

Bachelor's degree with a minimum of 55% of marks and having studied Physics and Mathematics during the Bachelor program.

DEPARTMENT OF EARTH SCIENCES
PONDICHERRY UNIVERSITY, PONDICHERRY
Proposed Course structure of M.Sc. Geophysics

SEM	Hard-core Courses			Soft-core Courses		
	Course code	**Name of the Course**	**Credits**	**Course code**	**Name of the Course**	**Credits**
I	ESGP 4101	Solid Earth Geophysics	4	ESGP 4105	Geology I(General Geology, Mineralogy and Petrology)	4
	ESGP 4102	Mathematical Geophysics	3	ESGP 4106	Climatology	2
	ESGP 4103	Computer Programming in Geophysics	2			
	ESGP 4104	Geophysics Lab I (mathematical Geophysics 1, Computer programming-2)	3			
	Total credits (12+6) = 18					
II	ESGP 4201	Gravity and Magnetic Methods	3	ESGP 4206	Geology II (Structural Geology and Stratigraphy)	4
	ESGP 4202	Electrical Methods	3	ESGP 4207	Geothermics	2
	ESGP 4203	Seismic Methods	3			
	ESGP 4204	Field Training I	2			
	ESGP 4205	Geophysics Lab II	3			
	Total credits (14+ 6) = 20					
III	ESGP 5101	Electromagnetic Methods	3	ESGP 5107	Geology III (Economic Geology and Geohydrology)	3
	ESGP 5102	Seismology	2	ESGP 5108	Geodynamics	2
	ESGP 5103	Geophysical Well Logging	2	ESGP 5109	Basin Analysis	2
	ESGP 5104	Geophysical Signal Processing	3	ESGP 5110	Professional Training	2
	ESGP 5105	Field training II	2	ESGP 5111	Term paper	2
	ESGP 5106	Geophysics Lab III	4			
	Total credits 16+ 11 =27					
IV	ESGP 5201	Geophysical Inverse Theory	3	ESGP 5206	Physical Oceanography	3
	ESGP 5202	Remote Sensing and GIS	2	ESGP 5207	Hydrogeophysics	3
	ESGP 5203	Geophysics Lab IV	2	ESGP 5208	Offshore Exploration	2
	ESGP 5204	Project	6			
	ESGP 5205	Comprehensive Viva Voce	2			
	Total credits 15+8=23					
	Credit offered for Hard Core courses- 57 Credits offered for Softcore courses-31 Total credits offered-88 Minimum credits required -72 **Every student is required to complete all hardcore courses and minimum of 72 credits for award of degree.**					

DEPARTMENT OF EARTH SCIENCES
PONDICHERRY UNIVERSITY, PONDICHERRY
Proposed Syllabus of M.Sc. Geophysics

ESGP 4101 **SOLID EARTH GEOPHYSICS** HARD CORE

Credits :4

1. The Earth as a planet of the Solar System – evolution of the Earth, Description of Earth atmosphere, lithosphere, hydrosphere and earth‘s interior, Earth observation and measurement from space. Structure and composition of the earth, Physical Fields of the Earth. Introduction to Geophysical methods, applications.Theory and fundamental concepts of Plate Tectonics: continental drift, ocean floor spreading, plate tectonics,Rotation vectors, rotation poles, present day plate motions and triple junctions
2. Gravity: The nature and characteristics of the gravity field of the Earth, Figure and Shape of the Earth, Geoid, Spheroid, Global gravity anomalies, Satellite geodesy, temporal variations, tidal friction, Gravity field of the moon and other planetary bodies.Geomagnetism: Introduction to magnetic field of the Earth; Origin of magnetic field-internal and external origin,Components of the field, long and short period variations.. Rock Magnetism, Palaeomagnetism. Geomagnetic timescale; Geomagnetic polarity; seafloor spreading and plate tectonics
3. Seismology: Internal structure of the earth, Earthquakes. Earthquake characteristics and description of important earthquakes, Variation of physical properties and seismic wave velocities inside the earth. travel-time curves, Earthquake mechanism; plate boundaries
4. Earth’s Radioactivity, Thermal and Electrical properties: radiation, radioactivity, half-life, decay constant, Heat flow: Mechanisms of heat transport in the Earth, heat conduction equation, heat flow density, heat flow measurement, factors contributing to heat flow, oceanic and continental heat flow, global heat flow maps, volcanism, Hot spots and mantle plumes.
5. Electrical properties of rocks and minerals, influence of mineral composition, moisture, salinity and temperature. Natural potentials and currents; Archie's law. Earth resistivity: concept of apparent resistivity.

Text Books:

1. William Lowrie, Fundamentals of Geophysics, Cambridge Uni
2. Potential Theory in Gravity and Magnetic Applications, Richard J. Blakely, 1996, Cambridge.
3. Geodesy: Introduction to Geodetic Datum and Geodetic Systems, 2014, Springer.
4. Physics of the Earth, Frank D. Stacey, 2008, Cambridge.
5. Marine Geophysics, Jones E.J.W., 2016, Wiley.
6. D.L.Turcotte and G. Schubert, Geodynamics, Cambridge University Press, 2002
7. B.J. Skinner and S.C. Porter, The Blue Planet, Wiley, 1995
8. C.M.R.Fowler, Solid Earth: An introduction to Global Geophysics, Cambridge University Press, 1990
9. Kent C. Condie, Plate Tectonics and Crustal Evolution, Oxford, Pergamon Press, 1989

ESGP 4102 **MATHEMATICAL GEOPHYSICS** HARD CORE

Credits :3

1. Integral transforms: Fourier transform, Laplace transform, Hankel transform, and their applications in geophysics.
2. Orthogonal functions: Bessel's function, Hermite, Laguerre and Legendre polynomials, introduction and applications of orthogonal systems and Green's function, and their applications in solving geophysical problems. Solution of simultaneous linear equations; Non-linear system of equations and their application in solving geophysical problems.
3. Numerical Methods: Solution of algebraic and transcendental equations; Bisection and Newton-Raphson methods; Euler and Runga-Kutta methods. Interpolation Techniques: Newton and Lagrange formulae; Simpson rule method; Trapezoidal method; and Gaussian quadrature method. Least square curve fitting; and straight line and polynomial fits.
4. Numerical solution differential equations: Ordinary differential equation; Classification of linear partial differential equations, wave and diffusion equations; and applications in geophysics.
5. Finite difference methods: discretizations; numerical solution of linear and non-linear differential equations; Stability; Application of finite difference methods in geophysics. Finite element methods: Introduction to various element shapes; descritization of structures; numerical integration; applications of finite element method in geophysics.

Text Books:

1. Numerical analysis, Krishna Murthy.
2. Numerical analysis, S. S. Sastry.
3. Merriam D.F., (Ed.) 2000. Computer methods in the Geosciences, Elsevier.

ESGP 4103 **COMPUTER PROGRAMMING IN GEOPHYSICS** HARD CORE

Credits :2

1. **Introduction to Linux OS**, basic commands for files and directories- cd, ls, cp, md, mkdir, rm, pwd. file creations, reading and writing the files. File edittor commands vi and gedit. awk, grep, head and tail commands with combination of pipe, mathematical and logical commands.
2. **Shell Programming:** shell variables, reading writing commands, shell programming in bash, conditional and loop statements, creating shell programs for automate system tasks
3. **Python:** Intoduction to python, variables, data types, reading and printing of files, mathematical operators, conditional statements, loop statements- while and for loop; scripting for geophysical problems
4. **Matlab:** Introduction to Matlab; Arrays; vectors and matrices; Array indexing; linear and logical indexing; plotting commands for line, polar, rose, contour and others shapes, histograms and images; Matrix operations Example codes for geophysical problems.
5. Introduction to **Generic Mapping Tool, (GMT)** and basic commands in GMT; psbasemap, psxy, pstext, psimage, pscontour and other plotting commands.

Text books:

1. M.G. Venkateshmurthy: Introduction to UNIX and Shell programming
2. Van Loan, C.F. and Fan, K.Y.D. Insight Through Computing: A Matlab Introduction to Computational Science & Engineering.
3. Charles Severance: Python for Everybody: Exploring Data in Python 3
4. Merriam D.F., (Ed.) 2000. Computer methods in the Geosciences, Elsevier.
5. Stormy Attaway, (2018) MATLAB: A Practical Introduction to Programming and Problem Solving, ISBN-13: 978-0128154793.
6. Peter Issa Kattan, (2008) Matlab for Beginners: A Gentle Approach, ISBN: 1438203098

ESGP 4104 **GEOPHYSICS LAB I** HARD CORE

Credits: 3

1. Solving geophysical problems numerically using codes in MATLAB.

2. Writing/Practicing codes to solve different geophysical problems using shell, python and Matlab scripting.

3. Generic Mapping Tools (GMT): Creating different plots with combination of shell scripting.

ESGP 4105 **GEOLOGY I (**General Geology, Mineralogy and Petrology) SOFT CORE

Credits: 4

1. Introduction: Earth Sciences, its subdivisions and relation to other sciences. Importance of geology to mankind. Historical Geology: Materials and methods of historical geology, Geologic time scale, Age of the earth.
2. Fundamental principles of geology. Geomorphological Processes: Exogenic and endogenetic processes., cycle of erosion, work of river, wind, glacier, waves and tides.
3. Mineralogy: Mineral- its definition and mode of occurrence. Physical properties of minerals like form, colour, lustre, streak, cleavage, fracture, hardness and specific gravity. Chemical composition of the following rock forming minerals: Quartz, Orthoclase, Microcline, Plagioclase, Nepheline, Muscovite, Biotite, Augite, Hornblende, Olivine, Garnet, Epidote, Calcite, Beryl, graphite, tourmaline, talc, Kaolinite, Kyanite and Corundum.
4. Petrology: Definition and distinguishing characteristics of Igneous, Sedimentary and Metamorphic rocks. Elementary ideas regarding formation, texture and classification of Igneous, Metamorphic and Sedimentary rocks. Rocks in hand specimen.
5. Brief petrographic description and occurrences of the following rocks: Granite, Syenite, Gabbro, Rhyolite, Dolerite, Basalt, Conglomerate, Breccia, Sandstone, Limestone, Shale, Gneiss, Schist, Quartzite and Marble. Formation of rocks in plate tectonic settings.

Textbooks :

1. Berry & Mason: Mineralogy
2. Mukherjee: A Text Book of Geology
3. Read & Rutley's: Elements of Mineralogy
4. Smith: Minerals and Microscope
5. Tyrrell: Principles of Petrology

ESGP 4106 **CLIMATOLOGY** SOFT CORE

Credits :2

1. Atmosphere- Composition, Vertical structure, Air pressure, air density, Temperature and Heat transfer, Atmospheric greenhouse effect. Greenhouse gases and global warming. Atmospheric pollution, ozone depletion, Earth's changing Climate.
2. Earth's radiation balance; latitudinal and seasonal variation of insolation, temperature, pressure, wind belts, humidity, cloud formation, Cloud Classification
3. Atmospheric stability, Cloud development, condensation nuclei, growth of cloud drops and ice-crystals, precipitation mechanisms: Bergeron, collision- coalescence process – Type of Precipitation, artificial precipitation, hail suppression, fog and cloud-dissipation, radar observation of clouds and precipitation.
4. Atmospheric circulation- Single cell and three cell model, El Nino Southern Oscillation (ENSO). Air masses- Classification; Fronts- Stationary, cold, Warm and occluded fronts. Koppen's classification of climate.
5. General weather systems of India, - Monsoon system, cyclone and jet stream, Western disturbances and severe local convective systems, distribution of precipitation over India.

Text books:

1. Edward Agnado, James E. Burt ; Understanding Weather and Climate; Pearson Prentice Hall, 2007.
2. D.S.Lal; Climatology, Sharda Pustak Bhavan, 2003.
3. John E. Oliver, John H.Hidore; Climatology: An Atmospheric Science; Prentice Hall, 2002.
   Donald Ahrens; Essentials of Meteorology: An Introduction to Atmosphere; Cengage Learning, 2008

ESGP 4201 **GRAVITY AND MAGNETIC METHODS** HARD CORE

Credits :3

1. Potential field and its classification. Newtonian potential and its properties. Laplace and Poisson's equation, Gauss' Law, Green's theorem, Spatial and temporal variation of gravity and magnetic fields and anomalous field. Density and Susceptibility of rocks and minerals, Measurement of density and susceptibility, in-situ measurements, Concept of anomaly. Magnetic elements, magnetism on atomic scale, Dia- para-ferromagnetic materials. Susceptibilities and densities of various rocks and minerals,
2. Instrumentation: Static and Astatic gravimeters, Astatic Zero length spring, Worden and Lacoste Romberg gravimeters. Magnetometers: Total field measurement: Proton Precession Magnetometers, optically pumped magnetometers, SQUID, fluxgate. Gradiometers. Ship-borne and air-borne gravity and magnetic instrumentations.
3. Data acquisition and processing : concept of base station, recording station, Planning of surveys, traverse and profile, station spacing, diurnal and drift variations. Surveying in a grid. Airborne and ship-borne surveys. Reduction of gravity data. Reduction of magnetic data. Anomaly and its visualization. Regional-Residual Separation, Analytic continuation, vertical derivatives. Reduction to pole. Ambiguity in interpretation.
4. Modelin**g:** Forward response of bodies: Gravity anomaly of point and line masses, sheets circular discs, vertical cylinders, rectangular slabs, dykes, faults and irregular geometries. Magnetic anomaly of monopole, dipole, sphere, cylinder, sheet, dyke, fault and irregular geometries. Preparation of pseudo- gravity map from magnetic data. Modeling of sedimentary basins.
5. Applications: Applications in petroleum exploration, Application in mineral exploration, Application in crustal studies, groundwater and other natural resources

Text books:

1. Dobrin, M. B. and Savit, C., Introduction to Geophysical Prospecting, 1988.
2. Nettleton, L. L., Gravity and Magnetics in Oil Prospecting, 1976.
3. Rao, B. S. R. and Murthy, I.V.R., Gravity and Magnetic Methods of Prospecting, 1978.
4. Telford, W. M., Geldart, L. P., Sheriff, R. E., and Keys, D. A., 1988, Applied
5. Geophysics, 1990.
6. Parasnis, D.S “Principles of applied geophysics”, Chapman & Hall, London, 1997.
7. The Earth and its gravity field, Heiskanen. A.A. and Veningmeinesz F., 1958, Mc Graw-Hill.
8. Gravity and magnetics in oil prospecting, Nettleton. L.L., 1976, Mc Graw-Hill.
9. Gravity and magnetic methods of prospecting, Rao. B.S.R. and I.V.R. Murthy, 1978, Arnold-Heinemann.
10. Gravity, Tsuboi C., 1983, harpercollins.
11. Interpretation of gravity and magnetic anomalies in space and frequency domains, murthy I.V.R., 1989, Association of Exploration Geophysics.

ESGP 4202 **ELECTRICAL METHODS** HARD CORE

Credits :3

1. Electrical Properties of rocks. Potentials in homogenous media. Equipotential surface generated by single and two electrodes. Effects of inhomogenous ground. Analogy between optical and electrical images.
2. Fundamental relation between potential, apparent resistivity, resistivity transform and layer distribution of a stratified earth (multiplayer). Electrode Configuration, Geometrical constant, definition of apparent resistivity.
3. Application of linear filter theory analogy. Frequency characteristics of Schlumberger filter. Sampling interval, Shanon's Sampling theorem. Nyquist Rule. Determination of Sampling Interval. Determination of Schlumberger filters coefficients. Sinc response of the Schlumberger filter. Filter coefficients, length of filter. Recurrence relation, Flathe and Pekris Recurrence relations. Determination of resistivity transform by using Pekris Recurrence Relation.
4. Potential due to a point source in an anisotropic medium. Triangle of anisotropy, Paradox of Anisotropy, Principle of equivalence and suppression. Electrical resistivity tomography: Principle and Acquisition, Frechet Derivative for homogenous half-space, 1-D view of the sensitivity function- depth of investigation, 2-D view of the sensitivity function lateral and vertical resolution of the different arrays.
5. Self-Potential Method: Causes of Self-Potential, Interpretation of SP Data. Introduction, Sources of IP, Membrane polarization, Electrode polarization, Time and Frequency Domain measurements. Chargeability, Frequency effect and metal factor. Apparent Chargeability over layered earth, Application in Hydrocarbon Exploration. Mise-a-la-masse Method.

Text Books:

1. Bhattacharya, B. B., and Shalivahan, 2016, Geoeletcric Methods: Theory and Applications: McGraw Hill Education (india) Private Limited.
2. Telford, W. M., Geldart, L. P., Sheriff, R. E., and Keys, D. A., 1988, Applied Geophysics.
3. Parasnis, D. S., 1997, Principles of Applied Geophysics (Fifth Edition), Chapman and Hall.
   Bhattacharya, B. K., and Patra, H. P., 1968, Direct Current Electric Sounding (Methods in Geochemistry and Geophysics) Elsevier Publishing Co.

ESGP 4203 **SEISMIC METHODS** HARD CORE

Credits :3

1. Introduction to seismic method and its importance in geophysical exploration, seismic waves, seismic velocity of rocks, snells' law, ray theory, seismic source energy-explosive and non-explosive, detectors, refraction, reflection and diffraction, seismic wave attenuation, reflection and refraction transmission coefficients, Zoeppritz equation, seismic noise and their causes.
2. Refraction surveys: Types of seismic waves, travel times equations for two layered Earth case, dipping layer case, and n number of layered Earth, interpretation of travel time curves
3. Data Acquisition: Selection of field surveys parameters,different kinds of spread geometries, end on spread, broad size configuration, 2D and 3D configurations, common depth point, Weathering and Dynamic Corrections In Refraction and Reflection Data, Random and Non Random Noise, Grouping of Geophones, Data Acquisition for Vertical Seismic Profiling, Deep Seismic Sounding, Diffraction Method of Data Interpretation.
4. Introduction to Seismic data processing: data processing sequence- preparation of processing geometry, quality checks, true amplitude recovery, deconvolution, filtering, velocity analysis, noise elimination. Stacking section- common depth stacking, migration and depth section preparation.
5. Interpretation: Study of seismic sections- pattern recognition, mapping geological structures (faults, folds, anticlines), hydrocarbon bearing and water bearing structures, gas hydrates, thin bed modeling, seismic lithology modeling, geological interpretation, wave equation migration, and gas detection using AVO analysis

Text books:

1. Dobrin & Savit: Introduction to geophysical Prospecting
2. Telford et.al.: Applied Geophysical
3. Keary & Brooks: Introduction to Geophysical Exploration
4. Waters: Reflection Seismology
5. Robinson: Basic Exploration Geophysics
6. Scheriff: Seismic Stratigraphy
7. Lavergne: Seismic Methods.

ESGP 4204 **FIELD TRAINING I** HARD CORE

Credits: 2

Introduction to Topographic maps, identifying various topographic features like peaks, hills, valleys etc., and relating them to topographic maps / aerial photographs /satellite imageries. Basics of Global Positioning System (GPS).

Identification of various igneous, metamorphic and sedimentary rocks in the field and Identification of minerals and characterizing the rocks on the basis of mineralogy and texture

Location of contacts between different rock units, lithological mapping on topographic maps / aerial photographs /satellite imageries.

Identifying planar and linear structures in field: - folds, faults, joints, unconformity, lineations and foliations. Use of clinometer compass to measure various structural elements: Measurement of attitude of planar and linear structure: dip, strike, pitch, plunge and trend. Collection and plotting of structural elements. Field training on reconstruction of surface and subsurface geological units from available exposures. Total duration of the training will be about three weeks in the field.

ESGP 4204 **GEOPHYSICS LAB II** HARD CORE

Credits: 3

1. Gravity and magnetic measurements; Computing Bouger anomaly and magnetic anomalies; Regional residual separation techniques.

2. Resistivity measurements; Calculation of apparent resistivity; Curve matching techniques.

3. Travel time curves, determination of Seismic wave velocities and geometry of Earth's sub-surface layer, travel time curves interpretation

ESGP 4206 **GEOLOGY II (Structural Geology and Stratigraphy)** SOFT CORE

Credits: 4

1. Overview and classification of rock structures, Rock fabrics, Description and measurement of attitude of fabric elements. Concept of stress and strain, Stress-strain relationship and rock deformation behaviour
2. Definition, structural elements, classification of Joint and Fault. Mechanism of faulting. Recognition criteria for different types of faults.
3. Definition, structural elements, classification of fold. Mechanism of folding and fold superposition. Overview of shear zone and shear zone rocks.
4. Principles of stratigraphy. Fundamentals of litho-, bio- and chrono-stratigraphy. Stratigraphic classification and correlation. Concept of facies, unconformity and paleogeography. Physiographic and tectonic subdivisions of India. Precambrian geology of Indian shield- Archean cratons and Proterozoic basins.
5. Phanerozoic Stratigraphy of India. Geology of important Paleozoic, Mesozoic and Cenozoic successions of Peninsular India and Himalaya. Volcanic provinces of India. Important stratigraphic boundaries in India.

Text Books:

6. Ghosh, S.K. 1993. Structural Geology: Fundamentals and modern developments.
7. Davis, G.H., Reynolds, S.J., 1996. Structural geology of rocks and regions, 2nd Edition, John Wiley & sons.
8. Park, R. G., 1983. Foundations of Structural Geology, Blackie Academic and Professional
9. Billings, M. P. Structural Geology, Prentice Hall
10. Lemon,R.R .1990. Principles of stratigraphy.. Merrill Publ. New York
11. Krishnan, M.S. 1982 Geology of India and Burma, CBS Publ. & Distr., New Delhi
12. Ravindra Kumar 1985 Fundamentals of Historical Geology and Stratigraphy of India, Wiley Eastern.
13. Pollard, D.D. & Fletcher, R.C. 2005. Fundamentals of Structural Geology, Cambridge University Press
14. Ramsay, J.G. & Huber, M.I. 1987. The Techniques of Modern Structural Geology, Vol 2: Folds and Fractures, Academic Press.
15. Moores, E.M., Twiss, R.J. 1995. Tectonics, W.H. Freeman
16. Hamblin, W.K., Christiansen, E.H. 2003. Earth's Dynamic Systems, 10th Edition, Prentice Hall
17. Turcotte, D.L., & Schubert, G., 2001. Geodynamics 2nd Edition, Cambridge University Press

ESGP 4207 **GEOTHERMICS** SOFT CORE

Credits :2

1. Basics of geothermal history- Evolution of the earth as a member of the solar system.
2. Patterns of distribution of major chemical elements in the inner and outer planets of the solar system, major sources of heat inside the Earth since its accretion, role of radioactive heating, distribution of long-lived radioactive elements in crustal rocks.
3. Thermal history of the Earth, its solidification from molten magma, sinking of iron and formation of proto-core; geothermal gradient, adiabatic self-compression.
4. Terrestrial heat flow studies: Terrestrial heat flow as a controlling factor of the geologic processes, Various processes of heat flow inside the earth, Bathymetry, measurement of continental and sub oceanic heat flow, temperature gradient probe, thermal conductivity of rocks, pattern of continental heat flow, heat flow values for continental shields and orogenic areas, Stacey's model, Introduction to mantle dynamics.
5. Geothermal provinces in India: An overview of heat flow studies for different geological provinces in India, Geothermal provinces in India and their characteristics. Heat flow zones in India and their characteristics.

Text Books:

1. C.M.R. Fowler, 2004. The Solid Earth: An introduction to Global Geophysics, Cambridge University Press.
2. D. Turcotte, G. Schubert, Geodynamics, 2014. Cambridge University Press.
3. Bott, M. H. P., The Interior of the earth, Hodder & Stoughton Educational.
4. J. P. Muffler. Wiley, Chichester, 1981. Geothermal Systems: Principles and Case Histories.
5. GSI, Geothermal Atlas of India.
6. Xavier Le Pichon Jean Francheteau Jean Bonnin, 1973. Plate Tectonics, Elsevier.
7. O. Kappelmeyer; Ralph Haenel, 1974. Geothermics with Special Reference to Applications,
8. Geoexploration Monographs, Number 4.

ESGP 5101 **ELECTROMAGNETIC METHODS** HARD CORE

Credits: 3

1. Introduction: Principle of electromagnetic induction, Magnetic field due to a current carrying loop, Elliptical polarization, plane of polarization, dip and tilt angles. Maxwell's equations, propagation of electrical and magnetic field as a dissipative wave, diffusion equation, propagation constant, Hertz vector, Lorentz condition, boundary conditions.
2. Response of a single closed conducting circuit by using a fixed horizontal transmitter-receiver system. Analysis of response functions with frequency and different ranges of conductivities, amplitude and phase relations, vector diagrams and their significance. Interpretation: Nomograms for quantitative determination of parameters by dip angle method, VLF and AFMAG methods, TURAM method. Response of a thin conducting sheet in half-space, phasor diagrams, effect of a conducting host medium to the response of a thin conducting vein embedded in a conducting host, concept of current channelling.
3. Transient electromagnetic Method: Basic principles, Transient emf and magnetic field behavior due to various, behavior of current density in half space by rectangular loop with time, conductors concept of smoke ring, Concepts of toroidal and poloidal induction in a conductive zone. Brief account of various time domain systems frequency sounding and geometric sounding, merits of time domain methods over frequency domain methods.
4. Principles and practices of Ground Penetrating Radar.
5. Magnetotelluric (MT) method: Origin and characteristic of MT fields, MT instrumentation, field practices, MT effect over a conducting half space and two layer model. MT Data processing and analysis, MT data interpretation. Audiomagnetotelluric methods. Case Studies.

Text Book:

1. Telford, W. M., Geldart, L. P., Sheriff, R. E., and Keys, D. A., 1988, Applied Geophysics.
2. Nabighian, M. N., 1988, Electromagnetic Methods in Geophysics, Volume 1, SEG Publication.
3. Nabighian, M. N., 1991, Electromagnetic Methods in Geophysics, Volume 2, Parts A and B, SEG, Publication.
4. Mining Geophysics, 1967, Volume II, SEG Publication.
5. Grant, F. S., and West, G. F., 1965, Interpretation Theory in Applied Geophysics.
6. Gupta Sarma, D., and Maru, V. M., 1981, A study of some effects of a conducting host rock with a new modelling approaches: Geophysics, 36, 166-183.
7. Fiona Simpson and Karsten Bahr, Practical Magnetotellurics, 2005. Cambridge University Press.
8. Alan D. Chave and Alan G. Jones, The Magnetotelluric Method, 2012. Cambridge University Press.
9. Vozoff K. , The Magnetotelluric Method, 1996; in Nabighian, M. N., Ed., Electromagnetic Method in Applied Geophysics: 2, Soc. Of Explor. Geophysics., 641-711.

ESGP 5102 **SEISMOLOGY** HARD CORE

Credits: 2

1. Introduction to seismology, Elasticity, Stress-strain relationships, Equations of motion, seismic wave equations.
2. Body waves and ray theory, Partitioning of energy, Attenuation, anisotropy and anelasticity, Travel times in layered media, Surface waves dispersion and free oscillations,
3. Seismometry and Principles of Digital seismographs, Seismic observatory practices, Seismogram interpretation – Nomenclature of seismic phases, Body wave travel times in earth, Internal structure and composition of the earth,
4. Earthquakes – Seismic sources, Directivity, Scaling laws, Magnitude scales, Location, Focal mechanisms, Moment tensors, Stress drop, Earthquake characteristics, effects and distribution, Seismotectonics, Earthquake prediction, Seismic hazard and risk, Waveform modeling and Inverse problems.
5. Seismicity of India, Himalayas and global seismicity, induced seismicity seismic zonation, seismic zoning of India, seismic hazards and hazard analysis, seismic micro-zonation.

Text Books:

1. T. Lay and T.C. Wallace, Modern Global Seismology, Academic Press, 1995
2. P.M.Shearer, Introduction to Seismology, Cambridge University Press, 1999
3. S. Stein and M. Wysession, An introduction to seismology, earthquakes and earth structure, Blackwell Publishing, 2003
4. K. Aki and P.G. Richards, Quantitative Seismology, University Science Books, 2002
5. L. Reiter, Earthquake hazard analysis: issues and insights, Columbia University Press, New York. 1990

ESGP 5103 **GEOPHYSICAL WELL LOGGING** HARD CORE

Credits: 2

1. Introduction to well logging, formation evaluation,objectives of well logging, reservoir rock types, properties of reservoir rocks- Porosity, Permeability, fluid saturarion, invasion process and various profiles, classification of well logging methods, objective of well logging methods, logging operational field system and its procedure.
2. Resistivity-Logging: Spontaneous Potential (SP) logging: Spontaneous potentials in boreholes and its sources, SSP and its measurements, SP curves and its interpretation factors affecting the shape and amplitude of SP curve, Non-focussed, focused and induction logging, principles and sondes, Interpretation of resistivity Log Data: Determination of resistivity water, porosity andter water saturation of clean and shaly sandstone, determination of resistivity of clean sandstone from SP curve, estimation of of permeability.
3. Radiation Well Logging: Gamma ray logging, details of the radiation logging, density or gamma-gamma logging, principle of the neutron-gamma logging, neutron-epithermal-neutron logging, neutron-thermal-neutron logging, interpretation and applications of radiation logging for evaluation of reservoir characteristics. Other Miscellaneous Logging Techniques: Acoustic velocity (Sonic) logging, Cement Bond Log (CBL), Litho-density Tool (LDT), Thermal log, caliper or section gauge log, Casing Collar Locator's (CCL), dip and direction logging, Formation micro Image logging, nuclear magnetic resonance logging.
4. Advanced Logging Tools: Introduction of induced gamma-ray spectrometry, chlorine logging, introduction to natural Gamma-ray Spectrometry (NGS), Cased Hole Neutron Tool (Thermal Decay Time or TDT) measurements, Introduction to wire line formation testing; Repeat formation testing (RFT) and drill stem testing (DST).
5. Cross Plots: Resistivity-porosity cross plots, Porosity Cross plots: neutron-density, sonic density and sonic neutron density cross plots. Application of well logging to ground water mineral and petroleum resources.

Text books:

1. Lynch: Formation Evaluation
2. Serra: Fundamentals of Well - Log Interpretation
3. Wyllie: Fundamentals of Well Log Interpretation
4. Vaish : Geophysical Well Logging : Principles and Practices
5. Pirson: Hand book of Well log Analysis for Oil and Gas Formation Evaluation
6. Schlumberger: Schlumberger Log Interpretation Principles/ Applications
7. Schlumberger: Schlumberger Log Interpretation Charts
8. Deveton: Log analysis of subsurface Geology: Concepts and Computer Methods

ESGP 5104 **GEOPHYSICAL SIGNAL PROCESSING** HARD CORE

Credits :3

1. Introduction, Definition of signal and noise and their classifications, various signal classes such as continuous, piece wise continuous, absolute integrable, singularity, unit impulse, unit step etc. Fourier series and Fourier Transforms: Time and frequency domain, convolution, relations between various operations in both domains, Fourier Transform and its properties, Fourier Transforms of some important functions: Rectangular, exponential functions, singularity functions and periodic functions, Hilbert, Hartely, Henkel, Walsh and Laplace transforms.

2. Time-series analysis: Discrete time signals, Correlation and convolution functions, impulse response and Transfer function spectrum of observational data: Discrete Fourier Transform (DFT), FFT, Z-Transforms, Wavelets and delay properties.

3. Band limited signals: Properties, Sampling Theorem, Nyquist frequency, Aliasing, Sampling of band and time limited signals; Effect of sampling on spectrum and vice-versa; reproduction of continuous function from sampled data.

4. Importance and effects of Windowing, Gibbs phenomenon, spectral leakage, various types of windows; power spectrum; Estimation of power spectrum, Wiener Khinchin theorem, use of various windows in power spectrum computation, spectrum computation via Auto and crosscorrelation and Periodogram.

5. Digital filtering: Design of digital filters, amplitude and phase response of various filters; one-sided and two sided filters, low-pass, high pass and band-pass, optimum filters, Butterworth filter, Recursive and non-recursive filters, optimal and Weiner filters, Deconvolution and predictive deconvolution, Analytic signal.

Text Books :

1. Modern Spectral analysis with Geophysical applications, Markus Bath, Society of Exploration Geophysicists, 2005
2. Theory and application of digital signal processing, Rabiner,L.R and Gold, B., Prentice Hall, 1975.
3. Digital signal processing and time series analysis, Enders A. Robinson and Manuel T Silvia, Holden Day, 1978.
4. Analysis of Geophysical Potential Fields, P.S.Naidu & M.P.Mathew, Elsevier Science, 1998. 5) Time sequence analysis in Geophysics, E.R.Kanasewich
5. Signal Analysis, B.P.Lathy

ESGP 5105 **FIELD TRAINING II** HARD CORE

Credits :2

Geological field training in lithological and structural mapping in sedimentary, igneous and metamorphic terrains. Study of igneous, metamorphic and sedimentary rocks and fossil occurrences in the field. Total duration of the training will be about three weeks in the field.

ESGP 5106 **GEOPHYSICS LAB III** HARD CORE

Credits 4

1. Conductivity measurements and interpretation using various electromagnetic methods.
2. Practical training in seismological data acquisition, processing and interpretation, Seismogram analysis and interpretation, Identification of seismic phases, Determination of earthquake parameters – location, magnitude, stress drop, focal mechanism, Seismological data analysis using standard seismological softwares.
3. Measurements of properties of reservoir rocks, borehole log interpretations
4. Application of signal processing in Geophysics

ESGP 5107 **GEOLOGY III** (Economic Geology and Geohydrology**)** SOFT CORE

Credits :3

1. Economic minerals: ore minerals and industrial minerals. Physical properties, chemical composition and mode of occurrence of important ore minerals, industrial minerals, fossil fuels and building stones.

2. Mineral deposits – types, morphology and forms of ore bodies. Genetic classification of mineral deposits. Ore forming processes: magmatic (early magmatic, late magmatic, volcanic), sedimentary (syn-sedimentary, diagenetic), metamorphic, hydrothermal, and supergene processes. Geological characteristics and distribution of important mineral deposits in India.

3. Coal and petroleum deposits – types, mode of occurrence and process of formation. deposits, Coal and lignite deposits in India. On-shore and off-shore petroliferous basins of India.

4. Concepts of hydrogeology-Water cycle and hydrological processes; hydrological properties of water bearing materials, Darcy's law, flow nets, recharge estimation techniques, groundwater exploration, methods and techniques.

5. Water quality and Management- Aqueous geochemistry, water quality, saline water intrusion, pumping tests, drilling and well types, flow and transport modeling, water harvesting techniques, Remote Sensing and GIS for water resources, water policy, law, climate change impact on water resources.

Text books:

1. A.M.Evans. 1993. Ore geology and industrial minerals - an introduction. Blackwell Science.
2. S.C.Sarkar and A.Gupta. 2012. Crustal Evolution and Metallogeny in India. Cambridge University Press.
3. D.Chandra, R.M.Singh and M.P.Singh. 2000. Text book of coal (Indian context). Tara Book Agency, Varanasi.
4. D.Chandra and R.M.Singh. 2003. Petroleum (Indian context). Tara Book Agency, Varanasi.
5. Raghunath H.M., 2006. Hydrology: Principles, Analysis and Design, New Age International (P) Ltd., Publishers.
6. Fetter, C.W., 1984. Applied Hydrogeology, McGraw-Hill Book Co., New York.
7. Todd, D.K., 2004. Ground Water Hydrology, John Wiley & Sons, New York.
8. Karanth K .R., 1987. Groundwater: Assessment, Development and Management, Tata McGraw-Hill Pub. Co. Ltd.

ESGP 5108 **GEODYNAMICS** SOFT CORE

Credits:2

1. Internal constitution of the earth, characteristics of lithosphere and asthenosphere, causes of geodynamical process, continental drift, Ocean floor spreading, Plate tectonics and its geological implications, oceanic ridges, trenches and island arcs, triple junction, hot spot.
2. Crustal structure studies, Composition and structure of upper and lower continental crust, layering in oceanic crust, geophysical evidence for their evolution, isostasy, schemes of isostasy,reduction procedures, isostatic anomalies, study of isostatic compensation, crustal structure studies for mountains, plateau, basins in India,
3. Origin of the geomagnetic field, secular variations and westward drift, geomagnetic storms, geomagnetic time scale, Earth's current, sun spot, solar flares, lunar and solar variations, Palaeomagnetic studies of rock samples and their applications in geophysics, polar wandering, Marine magnetic anomalies and reversals of geomagnetic field.
4. Seismological evidences for lithospheric deformation, plate margins and processes at plate margins, DSS studies
5. Tectonic activity within the Indian Plate. Characteristic movement of Indian plate and formation of the Himalayas,Andaman subduction zone.

Text Books

1. Bott, M. H. P., The Interior of the earth
2. LePicheon and Franchateau, Plate Tectonics
3. Robertson, The Nature of the Solid earth
4. Kearey, P. and Vine, F.J. (1996) Global Tectonics. Blackwell Science.
5. Windley, B.F. (1995) The evolving continents. John Wiley & Sons, 526 pp.
6. Rogers, J.J.W. A history of the Earth. Cambridge University Press.
7. Fowler, C.M.R. (1990) The solid Earth: an introduction to Global Geophysics. Cambridge University Press.
8. Brown, G., Hawkesworth, C. and Wilson, C. (1992) Understanding the earth. Cambridge Univesity Press.
9. Condie, K.C. (1976) Plate Tectonics and Continental Evolution. Pergamom Press Inc.

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ESGP 5109 **BASIN ANALYSIS** SOFT CORE

Credits: 2

1. Basin Analysis: Introduction to basin analysis. Classification of sedimentary basins ,oncept of tectonics and sedimentation; Mechanisms involved in formation of basins, subsidence, and filling of sedimentary basins. Concept of sedimentary environments; Environmental parameters and their control; The three-dimensional facies architecture of terrigenous clastic sediments; Facies model and environmental reconstruction
2. Carbonate sedimentation model, platform geometry,Shallow and deep water sandstone reservoir geometry,Basin modeling and its uses, Basin modeling techniques.
3. Sequence stratigraphic concepts: sea level/base level changes, Systems Tracts: Lowstand, Transgressive, Highstand, Falling stage; Hierarchy of sequences and bounding surfaces. Application of sequence stratigraphy on outcrop data and seismic data; well log analysis, Seismic data interpretation
4. Basin mapping methods- structure and isopach contouring, lithofacies and biofacies maps, preparation of stratigraphic cross- sections and palaeogeographic synthesis;
5. Heat flow analysis for understanding maturity of the basin, Resource potential of sedimentary basins, use of modelling in hydrocarbon generation and exploration.

Text Books :

1. Allen, P.A. and Allen, J.R., Basin Analysis: Principles and applications Blackwell publishing, 2005.
2. Miall, A.D. Principles of Sedimentary Basin Analysis, 3rd Edition, Springer-Verlag, Berlin, 2000.
3. Busby, C.J. and Ingersoll, R.V. Tectonics of Sedimentary Basins, Blackwell Science, Oxford, 1995.
4. Reading, H. Sedimentary Environments: Processes, Facies and Stratigraphy, Blackwell Science, Oxford, 1996.

ESGP 5110 **PROFESSIONAL TRAINING** SOFT CORE

Credits 2

Intensive industry/laboratory/field or hands-on training on any applied aspect of geophysics. Training will be conducted through professional organisations engaged in above activities. Total duration of the training will be about three weeks.

EAGP 5111 **TERM PAPER** SOFT CORE

Credits :2

Individual literature survey and preparation of a term paper on a specialized topic in geophysics, under the supervision of a faculty member of the Department, followed by a seminar presentation.

ESGP 5201 **GEOPHYSICAL INVERSE THEORY** HARD CORE

Credits: 3

Unit 1: Fundamental concepts of modelling and inverse theory, Probability, Inverses with discrete and continuous models, generalized matrix inverses and maximum likelihood methods, non-uniqueness, applications of vector spaces, resolving kernels, use of prior information.

Unit 2: Non-linear inverse problems, continuous inverse theory and tomography, Backus-Gilbert inverse problem, Global Optimization Algorithms.

Unit 3: Gauss Seidel iteration, Gauss Jordan elimination, singular value decomposition (SVD), Gaussian elimination, Cholesky decomposition, successive relaxation.

Unit 4: Principle of minimization, weighted residual method. Formulation of 2D and 3D problems using finite difference, finite element and integral equation methods, Automatic mesh generation boundary conditions, maximum likelihood, Formulation of joint inversion problems using various geophysical data sets.

Unit 5: Applications for Geological and geophysical phenomena: Computer models, anomalies of 2D, 2.5D and 3D source geometries, Principles of inversion, Inversion of gravity and magnetic anomalies of 2D polygonal bodies, dykes and magnetic/density interfaces, thermal modeling of lithospheric plates, Viscous flow in geological systems

Textbook:

1. Geophysical data analysis: Discrete inverse theory, by W. Menke, Academic Press, International Geophysical series, Vol. 45, 1989.

2. Introductory Geophysical Inverse Theory by , J. A. Scales, M. L. Smith and S. Trietel , Samizdat Press, Golden Colarado, USA, 2001

3. Inverse Problem Theory by A. Tarantola, Elsevier Publishers, New York, 1987.

4. Parameter estimation and Inverse Problems, Richard C. Aster, Brian Borchers and Clifford H. Thurber, Elsevier Academic Press, 2005, ISBN: 0-12-065604-3

ESGP 5202 **REMOTE SENSING AND GIS** HARD CORE

Credits: 2

1. Basic concepts of remote sensing. - Introduction to Electromagnetic Radiation (EMR) and its relationship to remote sensing in the ultraviolet, visible, infrared, and microwave region; Interaction of EMR with objects and Atmosphere; Spectral signature of common earth objects – water, vegetation, soil etc; Platforms and sensors - Ballons, Aircraft, Satellites- sun synchrounous/ geosynchrounous; Sensors – Active/passive; Imaging/Non imaging; push broom/ wishk broom.
2. Developments in aerial photography; Geometry and types of aerial photographs – vertical/oblique; Scale of photographs; Types of aerial cameras, films, and filters - Panchromatic, colour and infra-red films; Multiband photography; Tilt and height displacement; Vertical exaggeration; parallax; stereoscopy; Photo Mosaic; Flight planning.
3. Acquisition and processing of multispectral remote sensing data from satellites; Panchromatic, Multispectral and Hyperspectral remote sensing; Digital representation of satellite Image; concept of grey colour, RGB, natural color and FCC.
4. Interpretation of aerial photo/satellite images using photo interpretation elements - tone, texture, pattern, size, shadow, and association. Geological applications of remote sensed data.
5. Fundamentals of Geographical Information System (GIS). Data models – spatial and non spatial data; vector and raster formats; spatial data input and editing, visualization and query of spatial data, overlay analysis; geological application of GIS.

Text books

1. Lillesand, T.M. and Kiefer, R.W. (1987) Remote sensing and Image Interpretation, John Wiley.
2. Avery, T.E. and Berlin, G.L. 1992 Fundamentals of remote sensing and Airphoto intepretation. McMillion Publishing Co., New York.
3. Miller, V.C. & Miller, C.F. (1961). Photogeology. McGraw Hill, New York.
4. Ray, R.G. (1969) Aerial photographs in geologic interpretation. USGS Professional Paper 373.
5. Pandey, S.N. (1987). Principles and applications of photogeology. Wiley Eastern, New Delhi.
6. Gupta, R.P. (1991) Remote Sensing Geology. Springer-Verlag
7. Drury, S.A. 1987. Image interpretation in Geology. Chapman and Hall.

ESGP 5203 **GEOPHYSICAL LAB IV** HARD CORE

Credits : 2

Solving inverse problems using computer language like MATLAB.

Image processing and GIS softwares.

ESGP 5204 **PROJECT** HARD CORE

Credits :6

Individual project work on applied aspects of current interest in geophysics. One faculty member of the Department will be assigned as the Supervisor. In case of inter-disciplinary project, one more faculty member from related discipline can be co-opted as the second Supervisor.

ESGP 5205 **COMPREHENSIVE VIVA VOCE** HARD CORE

Credits: 2

Student will be assessed for his comprehensive knowledge of geophysics.

ESGP 5206 **PHYSICAL OCEANOGRAPHY** SOFT CORE

Credits: 3

1. Ocean basins- Distribution of land and water, Hypsography of the continents and ocean floor –continental shelf, slope, rise and abyssal plains, Physiography of the Ocean floor.
2. Physical and chemical properties of sea water and their spatial variations- Chlorinity, salinity, thermal properties, density, pressure, optical properties, transmission of sound. Residence times of elements in sea water.
3. Ocean currents, causes of ocean currents and important current systems. surface circulation, thermohaline circulation, Ekman theory, Water masses- their formation and characteristics; T-S diagram, Upwelling and sinking of ocean waters
4. Formation of subtropical gyres; western boundary currents; equatorial current systems; El Nino; monsoonal winds and currents over the North Indian Ocean; Somali current; Upwelling process in the Arabian Sea.
5. Waves and Tides-Wave celerity, group velocity, theory of surface gravity waves, short and long waves, transformation of waves in shallow water; effects of stratification; effect of bottom friction, breakers and surf; littoral currents; Tide generating forces, principal harmonic components, theories of tides, description and types of tides, prediction of tides, tidal gauges, seiches; tsunami, Sea level changes.

Text books:

1. George L. Pickard, William J. Emery; Descriptive Physical Oceanography: An Introduction, Elsvier, 1990.
2. M. Grant Gross – Oceanography: A view of the earth, 1987.
3. M. Grant Gross-Prnciples of Oceanography,1995.
4. John A. Knauss, Introduction to Physical Oceanography, Waveland Press,2005.
5. Tom Garrison; Oceanography: An invitation to Marine Science, Cengage Learning,2008
6. M.P.M Reddy; Descriptive physical Oceanography, Taylor and Francis, 2001.
7. J.P.Kennet; Marine geology. Printice Hall Inc., New Jersy, 1982.

ESGP 5207 **HYDROGEOPHYSICS** SOFT CORE

Credits: 3

1. Background and Hydrogeology: Introduction to Hydrogeophysics; Hydrogeological Methods for Estimation of Spatial Variations in Hydraulic Conductivity; Geostatistics.
2. Fundamentals of Environmental Geophysics:Relationships between the Electrical and Hydrogeological Properties of Rocks and Soils.
3. Different Geophysical methods:Geophysical methods, DC Resistivity, SP Method and Induced Polarization Methods; Near-Surface Controlled-Source Electromagnetic Induction: Background and Recent Advances; GPR Methods for Hydrogeological Studies; Shallow Seismic Methods; Relationships between Seismic and Hydrological Properties; Geophysical Well Logging: Borehole Geophysics for Hydrogeological Studies: Principles and Applications; Airborne Hydrogeophysics.
4. Hydrogeophysical Case Studies:Hydrogeophysical Case Studies at the Regional Scale; Hydrogeophysical Case Studies at the Local Scale: the Saturated Zone; Hydrogeophysical Case Studies in the Vadose Zone; Hydrogeophysical Methods at the Laboratory Scale.
5. Hydrogeophysical Frontiers:Emerging Technologies in Hydrogeophysics; Stochastic Forward and Inverse Modeling: the 'Hydrogeophysical Challenge'

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Text Books:

1. Yoram Rubin and Susan S. Hubbard, Hydrogeophysics, 2005. Springer.
2. Poeter, EP, S.A. McKenna, and W.L. Wingle, Improving groundwater project analysis with geophysical data, The Leading Edge, 1675–1681, November 1997.
3. Purvance, D.T., and R. Andricevic, Geoelectric characterization of the hydraulic conductivity field and its spatial structure at variable scales, Water Resour. Res., 36(10), 2915–1924, 2000.
4. Berthold S., Bentley L, and Hayashi M (2004) Integrated hydrogeological and geophysical study of depression-focused groundwater recharge in the Canadian prairies. Water Resources Research 40, W06505.
5. Binley A. and Kemna A. (2005) DC resistivity and induced polarization methods. In: Y. Rubin and S. Hubbard, eds. Hydrogeophysics. Chapter 5, pp 129–156. The Netherlands, Springer.

ESGP 5208 OFFSHORE EXPLORATION SOFT CORE

Credits: 2

1. Hypsography of the continents and ocean floor –continental shelf, slope, rise and abyssal plains. turbidity currents, submarine sedimentation and stratigraphy, occurrence of mineral deposits and hydrocarbon in offshore

2. Gravity Surveys: Gravity measurements in underwater, types of gravity meters- ship borne gravimeters, vibrating string accelerometer, Lacoste Romberg gravimeter limitations with shipborne gravity measurements, data reduction and interpretation.

3. Magnetic Survey: Types of magnetometer used in a survey ship, towing cable and fish, data collection their reduction and interpretation.

4. Seismic Surveys : Marine energy sources, Finger, Boomer, Sparker, explodor, airgun, vapour cook etc. hydrophones active section and streamer towing gear, shooting methods near offshore and offshore exploration techniques, recording of signals by digital system, analysis of seismic data their processing and interpretations, refraction survey with Sonobuoy's and interpretation.

5. Radio Positioning System: Short range and long range Doppler Sonar, satellite navigation, Global Position System

Text books:

1. Dobrin & Savit: Introduction to Geophysical prospecting
2. Telford et.al.: Applied Geophysics
3. Defant: Physical Oceanography, Vols. I and II
4. Sverdrup, Johnson & Fleming: The Oceans
5. Duxbury: The Earth and its Oceans
6. WMO No.364: Marine Meteorology