IISER
BERHAMPUR

BS-MS SYLLABUS

Earth & Environmental Sciences

I Semester

Cours eNo.	Course Name	LecHr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 101	Introduction to Biological Sciences	3	0	1	6	3
BIO 103	General Biology Laboratory I	0	3	0	0	1
CHM 101	General Chemistry	3	0	1	6	3
CHM 103	General Chemistry Laboratory	0	3	0	0	1
CDS 101	Introduction to Computers	2	1	0	6	3
HSS 103	Basics of Communication Skills	1	0	0	2	1
MTH 101	Introduction to Mathematics	3	0	1	6	3
PHY 101	Mechanics	3	0	1	6	3
PHY 103	Mathematical Methods	1	0	1	0	1
EES 101	Introduction to Earth System Sciences	3	0	1	6	3
Total		19	07	06	38	22

II Semester

Course No.	Course Name	LecHr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 102	Biochemical and Cellular basis of life	3	0	1	6	3
BIO 104	General Biology Laboratory II	0	3	0	0	1
CHM 102	Basic Inorganic Chemistry	3	0	1	6	3
CHM 104	Inorganic Chemistry Laboratory I	0	3	0	0	1
HSS 104	Oral and Written Communication	1	0	0	2	1
EES 102	Introduction to Environmental Sciences	3	0	1	6	3
MTH 102	Calculus of One Variable	3	0	1	6	3
PHY 102	Electromagnetism	3	0	1	6	3
PHY 104	General Physics Laboratory I	0	3	0	0	1
Total		16	09	05	32	19

III Semester

Course No.	Course Name	LecHr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 201	Introduction to Genetics and Evolution	3	0	1	6	3
BIO 203	General Biology Laboratory III	0	3	0	0	1
CHM 211	Basic Organic Chemistry	3	0	1	6	3
CHM 213	Organic Chemistry Laboratory I	0	3	0	0	1
EES 201	Foundation of Earth Sciences: Part 1 (Introduction to Mineralogy, Petrology)	3	0	1	6	3
HSS 209	Technical Writing	2	0	0	4	2
MTH 201	Linear Algebra	3	0	1	6	3
PHY 201	Waves and Introductory Optics	3	0	1	6	3
PHY 203	General Physics Laboratory II	0	3	0	0	1
Total		17	09	05	34	20

IV Semester

Course No.	Course Name	LecHr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 202	Molecular Biology and Developmental Biology	3	0	1	6	3
BIO 204	General Biology Laboratory IV	0	3	0	0	1
CHM 222	Classical Thermodynamics	3	0	1	6	3
CHM 224	Physical Chemistry Laboratory I	0	3	0	0	1
EES 202	Foundation of Earth Sciences: Part 2 (Introduction to Rock Deformation and Plate Tectonics)	3	0	1	6	3
HSS 207	Macroeconomics	1	0	0	2	1
MTH 202	Multivariable Calculus	3	0	1	6	3
PHY 202	Quantum Physics	3	0	1	6	3
PHY 204	General PHY Lab III	0	3	0	0	1
CDS 202	Information for Science and Technology	2	0	0	4	2
Total		18	09	05	36	21

V Semester

Course No.	Course Name	Class Hr	Lab Hr	Tut Hr	Field Work	Total Credit
EES 301	Mineralogy	3	0	0		3
EES 303	Igneous Petrology	3	0	0		3
EES 305	Environmental Chemistry	3	0	0		3
EES 307	Sedimentology	3	0	0		3
EES 309	Science of Sustainability	3	0	1		4
EES 311	Mineralogy Laboratory	0	3	0		1
EES 313	Igneous Petrology Laboratory	0	3	0		1
EES 315	Environmental Chemistry Laboratory	0	3	0		1
EES 317	Sedimentology Laboratory	0	3	0		1
EES 319	Introductory Fieldwork of Environmental Sciences & Geology	0	0	0	6-7 days	3
Total		**15**	**12**	**1**	**6**	**23**

VI Semester

Course No.	Course Name	Class Hr	Lab Hr	Tut Hr	Field Work	Total Credit
EES 302	Metamorphic Petrology	3	0	0		3
EES 304	Structural Geology & Geodynamics	3	0	0		3
EES 306	Chemical Petrology (Geochemistry)	3	0	0		3
EES 308	Science of Sustainability: Methods and Processes	3	0	1		4
EES 310	Oceanography	4	0	0		4
EES 312	Metamorphic Petrology Laboratory	0	3	0		1
EES 314	Structural Geology Lab	0	3	0		1
EES 316	Chemical Petrology & Geochemistry(Lab)	0	3	0		1
EES 320	Introduction to Geophysics	4	0	0		4
Total		**20**	**9**	**1**		**24**

VII Semester

Course No.	Course Name	Class Hr	Lab Hr	Tut Hr	Field Work	Total Credit
EES 401	Paleontology	3	0	0		3
EES 403	Economic Geology	3	0	0		3
EES 405	Evolution of the Indian Plate	3	0	1		4
EES 407	Remote Sensing and GIS	3	0	1		4
EES 411	Paleontology-(Lab)	0	3	0		1
EES 413	Economic Geology-(Lab)	0	3	0		1
EES 415	RS-GIS &Geoinformatics Lab	0	3	1		4
EES 417	Geological Fieldwork	0	0	0	6-7 Days	4
Total		**12**	**9**	**3**	**0**	**24**

VIII Semester

Course No.	Course Name	Class Hr	Lab Hr	Tut Hr	Field Work	Total Credit
EES 402	Global Climate Change	2	0	1		2
EES 404	Basin Analysis & Geology of Fuels	3	0	0		3
EES 406	Geohydrology	3	3	0		4
EES 408	Sustainability Informatics	3	0	1		4
EES 412	Practices in Sustainability Informatics	0	2	2		2
Total		**11**	**5**	**3**	**0**	**15**

Open Electives (ANY ONE)

Course No.	Course Name	Class Hr	Lab Hr	Tut Hr	Field Work	Total Credit
EES 414	Atmospheric Science	3	0	0		3
EES 416	Aerosol Science	3	0	0		3
EES 418	Indian Monsoon and Variability	3	0	0		3
EES 420	Mineral Exploration	3	0	0		3
EES 422	Statistics & Analytics for Earth, Environment &	3	0	0		3
	Sustainable Development Sciences					
EES 424	Isotope Geochemistry	3	0	0		3
EES 426	Marine Biogeochemical Cycle	3	0	0		3
EES 427	Conservation of Nature & Natural Resources	3	0	0		3
EES 428	EIA and Environmental Planning	3	0	0		3
EES 429	Earth Surface Processes	3	0	0		3

BS-MS SYLLABUS, EARTH AND ENVIRONMENTAL SCIENCE

EES 101: Introduction to Earth System Sciences (3)

***Learning Objectives*:**

To introduce students to the emerging discipline of Earth Sciences.

***Course Contents*:**

Unit-1: Introduction to ESS: scope, sub-disciplines and relationship with other branches of sciences..

Unit-2: Origin of the Universe and stars, Solar System- Introduction to various planets and Meteorites, Earth in the solar system, origin, differentiation.

Unit-3: Mechanical layering of the Earth: lithosphere, asthenosphere, mantle and core.Origin of atmosphere and evolution of atmosphere. Earth's magnetic field, Geothermalgradient and internal heat of the Earth.

Unit-4: Earth's Surface Processes: Weathering and Erosion. Landforms in deserts, glaciated regions and river valleys.

Unit-5: Age of the Earth; radioactivity and its application in determining the age of the Earth. Geological Time Scale, Life through ages and Mass Extinction.

Unit-6: Global warming, Ice ages and snowball Earth.

***Suggested Readings* :**

1. John Grotzinger, Thomas H. Jordan: Understanding the Earth
2. Stephen Marshak: Essentials of Geology
3. Arthur Holmes: Holmes Principles of Physical Geology
4. Mukerjee P. K: Textbook of Geology

EES 102: Introduction to Environmental Sciences (3)

***Learning Objectives*:**

Introduce students to the emerging discipline of environmental science. Create awareness amongst students for being environmental sensitive and install a sense of urgency towardsenvironmental protection.

***Course Contents*:**

Unit-1: Introduction, Definition, scope and importance, multi-disciplinary nature of environmental sciences.

Unit-2: Natural resources, renewable and non-renewable (forest, water, mineral, food, energy and land/soil).

Unit-3: Ecosystems: definition, concept, structure & function (producers, consumers, decomposers), energy flow, ecological succession, food chain, food web, ecological pyramids, specialised ecosystems (forest, grassland, aquatic, desert, etc.).

Unit-4: Biodiversity: introduction, definition, biogeographical classification of India, value of biodiversity, global to local biodiversity, India, a mega-biodiverse country, biodiversity hotspots, threats to biodiversity, concept of conservation (in-situ, ex-situ).

Unite-5: Environmental pollution: Definition, causes, effects and control of air, water, soil, marine, noise & thermal pollution, solid waste management, disaster management, prevention of pollution.

Unit-6: Social issues & the environment: unsustainable use of resources, urban issues, water (conservation, harvesting, watershed management), environmental ethics, waste-land restoration.

Unit-7: Environmental laws & legislations in India: environmental protection act, air act, water act, forest act, wildlife protection act, biological diversity act, implementation of laws & regulations.

Unit-8: Human population & environment: population explosion, food security, health, equitable sharing & justice.

Suggested Readings **:**

1. ErachBharucha (2021). Text book for Environmental studies (3rd edition), UniversityGrants Commission.
2. Khoiyangbam and Gupta (2012). Introduction to Environmental Sciences. TERI, NewDelhi.

EES 201: Foundation of Earth Sciences: Part 1 (Introduction to Mineralogy, Petrology) (3)

***Learning Objectives*:**

To introduce students to the elementary idea of mineralogy, petrology and rock deformation.

***Course Contents*:**

Unit-1: Introduction to Mineralogy
Definition of mineral and crystal. Classification of Minerals. A brief introduction to rock-forming minerals (silicate structure and classification).

Unit-2: Mineral Chemistry
Introduction to crystal chemistry - ionic radii and coordination number; Chemical affinity andgeochemical classification of elements; Mineralogy of the Solar System; Chemical bonding,coordination polyhedra, radius ratio, and Pauling's rules.

Unit3: Introduction to Petrology
Igneous, Metamorphic and Sedimentary rocks. Concept of Magma and magmatic crystallization, Bowen's Reaction series. Classification of igneous rocks, igneous textures and forms of igneous rocks. Metamorphism and agents of metamorphism, types of metamorphism, metamorphic texture, classification of metamorphic rocks Sedimentary rocks: classification, texture. Grain-size scale, preliminary idea on primary sedimentary structure, preliminary idea on siliciclastic and carbonate rocks.

Suggested Readings **:**

1. Deer, W. A., Howei, R. A., and Zussman, J., 2013 An Introduction to Rock FormingMinerals (3rd Edition), Mineralogical Society of Great Britain and Ireland.
2. Klein, C., and Butrow, B., 2008, The 23rd edition of the Manual of Mineral Science(4th Edition), John Wiley and Sons.
3. Nesse, W. D., 2011, Introduction to Mineralogy (2nd Edition), Oxford University Press.
4. Winter, J. D., 2010, An Introduction to Igneous and Metamorphic Petrology (2nd Edition), Prentice Hall.

5. Philpotts, A. and Auge, J., 2009, Principles of Igneous and Metamorphic Petrology(2nd Edition), Cambridge.

EES 202 : Foundation of Earth Sciences: Part 2 (Introduction to Rock Deformation and Plate Tectonics) (3)

***Learning Objectives*:**

To introduce students to the elementary idea of rock deformation and plate tectonics.

***Course Contents*:**

<u>Unit-1:</u> Basic Structural Elements
Diastrophic and non-diastrophic Structures, Structural elements: planar and linear structures, concept of strike and dip, trend and plunge, rake/pitch, Concept of scale of observation of structures. Topographic maps. Outcrop patterns of different structures.

<u>Unit-2:</u> Folds, Faults and Foliation:
Fold morphology; Geometric classification of folds; Fault zone terminology, Geometric classification of faults, Morphological features of foliations and lineations.

<u>Unit-3:</u> Plate Tectonics & Fundamental Earth process:
Continental Drift and plate tectonics. Plates and plate boundaries. Supercontinent Cycles. Earthquake and earthquake belts, Volcanoes, Concept of isostasy.

<u>Unit-4:</u> Internal Structure of the Earth (Mineralogical phase changes), earthquakes and Volcanoes.

<u>Unit-7:</u> Brief outline of major geological subdivisions of India.

***Suggested Readings* :**

1. Twiss, R. J., and Moores, E. M., 2007, Structural Geology (2nd Edition), W. H.Freeman and Company.
2. Ghosh, S. K., 1993, Structural Geology Fundamentals and Modern Developments(1st Edition), Pergamon Press.
3. Davis, H., Reynolds, S. J., and Kluth, F. C., 2012, Structural Geology of Rocks and Regions (3rd Edition), Wiley.
4. Jain, A. K., 2014, An Introduction to Structural Geology (1st Edition), Geological Society of India.
5. Kearey, P., Klepeis, K.A., and Vine F. J., 2009, Global Tectonics (3rd Edition), John Wiley and Sons.
6. Donald, L. G., and Turcotte, S., 2000, Geodynamics (3rd Edition), CambridgeUniversity Press.
7. Fowler, C. M. R., 2005, The Solid Earth: An Introduction to Global Geophysics (2ndEdition), Cambridge University Press

EES 202B : Foundation of Earth Sciences (Introduction to Mineralogy, Petrology and Rock Deformation) (3)

***Learning Objectives*:**

To introduce students to the elementary idea of mineralogy, petrology and rock deformation..

***Course Contents*:**

Unit-1 Introduction to Mineralogy
Definition of mineral and crystal. Classification of Minerals. Brief introduction to rock-forming minerals (silicate structure and classification).

Unit-2 Mineral Chemistry
Introduction to crystal chemistry - ionic radii and coordination number; Chemical affinity and geochemical classification of elements; Chemical bonding, coordination polyhedra, radius ratio, and Pauling's rules.

Unit-3 Introduction to Petrology:
Igneous, Metamorphic and Sedimentary rocks Concept of Magma and magmatic crystallization, Bowen's Reaction series. Classification of igneous rocks, igneous textures and forms of igneous rocks. Metamorphism and agents of metamorphism, types of metamorphism, metamorphic texture, classification of metamorphic rocks. Sedimentary rocks: classification, texture. Grain-size scale, preliminary idea on primary sedimentary structure.

Unit-4: Basic Structural Elements
Diastrophic and non-diastrophic Structures, Structural elements: planar and linear structures,the concept of strike and dip, trend and plunge, rake/pitch, Concept of scale of observation of structures. Topographic maps. Outcrop patterns of different structures.

Unit-5: Folds, Faults and Foliation
Fold morphology; Geometric classification of folds; Fault zone terminology, Geometric classification of faults, Morphological features of foliations and lineations.

Unit-6: Plate Tectonics & Fundamental Earth process Continental Drift and plate tectonics. Plates and plate boundaries. Supercontinent Cycles. Earthquake and earthquake belts, Volcanoes, Concept of isostasy.

Unit-7: Brief outline of major geological subdivisions of India.

***Suggested Readings* :**

1. Deer, W. A., Howei, R. A., and Zussman, J., 2013 An Introduction to Rock FormingMinerals (3rd Edition), Mineralogical Society of Great Britain and Ireland.
2. Klein, C., and Butrow, B., 2008, The 23rd edition of the Manual of Mineral Science(4th Edition), John Wiley and Sons.
3. Nesse, W. D., 2011, Introduction to Mineralogy (2nd Edition), Oxford University Press.
4. Winter, J. D., 2010, An Introduction to Igneous and Metamorphic Petrology (2ndEdition), Prentice Hall.
5. Philpotts, A. and Auge, J., 2009, Principles of Igneous and Metamorphic Petrology(2nd Edition), Cambridge.
6. Twiss, R. J., and Moores, E. M., 2007, Structural Geology (2nd Edition), W. H. Freeman and Company.
7. Ghosh, S. K., 1993, Structural Geology Fundamentals and Modern Developments(1st Edition),Pergamon Press.
8. Kearey, P., Klepeis, K.A., and Vine F. J., 2009, Global Tectonics (3rd Edition), JohnWiley and Sons.

EES 301 : Mineralogy (3)

Prerequisites:: All CHM 100 level courses and EES 100 and 200 level courses

Learning Objectives:

As minerals are the basic building blocks of Earth materials, this course is designed to give afundamental understanding of their classification, structure, and properties. The student will learn the basic principles of crystal chemistry and how this is related to the external form, chemical composition, and physical properties of minerals. Identification, classification and interpretation of the occurrence of rock-forming minerals will be addressed.

Course Contents:

Unit-1: Introduction
Structure of the course, introduction to the subject and history of mineralogy.

Unit-2: Crystallography
Definition of mineral and crystal; Fundamental laws of crystallography; Introduction to crystallography and the seven crystal systems; Hermann Mauguin Notations; Miller's Indices; X-ray crystallography.

Unit-3: Mineral Chemistry
Introduction to crystal chemistry - ionic radii and coordination number; Chemical affinity and geochemical classification of elements; Mineralogy of the Solar System; Chemical bonding, coordination polyhedra, radius ratio, and Pauling's rules; Major and minor trace elements in minerals; Isomorphism, polymorphism, twinning, phase transformations and crystalline defects; Mineralogical Phase Rule, phase diagrams (binary eutectic, peritectic, solid solutions, exolution), phase equilibria and introduction to the stable mineral assemblages of rocks.

Unit-4: Physical Properties of Minerals in Hand Specimen
Color, luster, form, streak, hardness, fracture, cleavage, habit, specific gravity, crystal system, magnetic properties, optical properties, other special properties and occurrences.

Unit-5 Optical Mineralogy
Introduction to optical mineralogy; Petrological microscope, isotropic and anisotropic minerals; Uniaxial and biaxial indicatrices; Optical properties in relation to indicatrices absorption and pleochroism, extinction, birefringence; Interference figures.

Unit-6: Descriptive Mineralogy
General structure, composition and salient properties of Common Rock Forming Minerals: Olivine, Pyroxene group and Amphibole group, Mica group, Feldspars, Quartz

Suggested Readings :

1. Putnis, A., 1992, An Introduction to Mineral Science, Cambridge University Press.
2. Deer, W. A., Howei, R. A., and Zussman, J., 2013 An Introduction to Rock FormingMinerals (3 rd Edition), Mineralogical Society of Great Britain and Ireland.
3. Klein, C., and Butrow, B., 2008, The 23 rd edition of the Manual of Mineral Science (4 th Edition), John Wiley and Sons.
4. Wenk, H.-R. and Bulakh, A., 2016, Minerals – Their Constitution and Origin (2 ndEdition), Cambridge University Press.
5. Nesse, W. D., 2011, Introduction to Mineralogy (2 nd Edition), Oxford University Press.

EES 302 : Metamorphic Petrology (3)

Prerequisites:**:** EES 301

Learning Objectives**:** The study of metamorphic rocks encompasses the chemical and physical transformations that take place in response to changing pressure, temperature, and chemical environments in the Earth's interior. In this course, different petrogenetic processes involving mineral reactions will be explored using equilibrium thermodynamics. The thermodynamic principles related to metamorphic petrology will then be applied to a number of orogenic events in time and space to derive the different pressure- temperature conditions during orogenesis. Finally, the quantitative estimation of P-T conditions through forward and backward modeling of reaction textures will be explored.

Course Contents**:**

<u>Unit-1:</u> An Introduction to Metamorphism
Definitions, factors and conditions of metamorphism; Variation in pressure (P) and temperature (T) in the Earth, lithostatic pressure, stress anisotropy and overpressure, temperature–geotherm, heat flow, pressure and temperature limits of metamorphism; Types of metamorphism - orogenic metamorphism, ocean-floor metamorphism, regional metamorphism, contact metamorphism, cataclastic metamorphism, hydrothermal metamorphism, other types of small-scale metamorphism.

<u>Unit-2:</u> Types of Metamorphic Rocks and Concept of Metamorphic Facies
Classification and nomenclature of metamorphic rocks; Relationship between rock composition and mineral assemblages, index minerals and mineral zones, metamorphic facies; Concept and origin of isograds.

<u>Unit-3:</u> Metamorphic Textures
Classification and types of textures; Interpretation of porphyroblast–inclusion relations.

<u>Unit-4:</u> Metamorphic Reactions, Chemographic Projections and Gibbs Phase Rule
Pressure and temperature changes in crust and mantle, heat flow and geotherms, different types of metamorphic reactions, reactions among solid-phase components, reactions involving volatiles as reacting species, controls of pressure, temperature and chemical compositions on the metamorphic reactions, time scale of metamorphism, phase diagrams, the Gibbs phase rule and its application in simple and complex systems, Schreinemakers analysis in simple and complex systems.

<u>Unit-5:</u> Introduction to Elementary Thermodynamics Related to Mineral Science
Introduction, energy in the form of heat and work, first law of thermodynamics, standard heat of formation, second law of thermodynamics- definition of entropy, third law of thermodynamics - measurement of entropy, thermodynamic equations, thermodynamic potentials, free energy of formation of minerals at any temperature and pressure, free energy surface in G–T–P-X space, conservative and non-conservative components of a solution, free energy of ideal and non-ideal solutions, the regular solution model, mechanism of unmixing of non-ideal solutions, equilibrium constant of a reaction and its relation with Gibbs free energy.

<u>Unit-6:</u> Quantitative Estimation of P-T Conditions
Forward and backward modeling of mineral reactions; Geothermobarometry - Concepts and general principles, assumptions and precautions, exchange reactions, solvus thermometry, uncertainties in thermobarometry, P-T pseudosection analysis.

<u>Unit-7:</u> Metamorphism of Ultra-Mafic Rocks, Quartzofeldspathic Rocks, and Pelitic Rocks
Characteristics minerals and rock compositions - Chemographic projections, characteristic mineral assemblages under different chemical systems and P-T conditions.

Suggested Readings **:**

1. Winter, J. D., 2010, An Introduction to Igneous and Metamorphic Petrology (2 ndEdition), Prentice Hall.
2. Philpotts, A. and Auge, J., 2009, Principles of Igneous and Metamorphic Petrology (2nd Edition), Cambridge.
3. Bucher, K., and Grapes, R., 2011, Petrogenesis of Metamorphic Rocks (8 thEdition), Springer.

EES 303 : Igneous Petrology (3)

***Prerequisites:*:** credited or registered in EES 301

***Learning Objectives*:**

This is an introductory course to provide a basic understanding of the different groups of igneous rocks and the processes involved in their formation. This course starts with the chemistry and physics of melts and their behavior under varying temperature and pressure conditions, and goes on to discuss the different kinds of igneous rocks and rock suites that form under different tectonic conditions. The generation of primary basalts at mid-ocean ridges and hotspots, and the generation of all other igneous rocks (ranging from acidic to ultrabasic) from primary basalts is discussed. Upon completion of this course the student will have a comprehensive understanding of the mechanisms which control the diversity of igneous rocks and their relationships with tectonic regimes.

***Course Contents*:**

Unit-1: Some Fundamental Concepts
Introduction; The Earth's interior; Origin of the Solar System and differentiation of Earth;Meteorites; P-T variations with depth; Review of mineralogy.

Unit-2: Classification of Igneous Rocks
Compositional terms; IUGS classification; Aphanitic and pyroclastic rocks; Primary textures and crystal melt interactions; Secondary textures and post-magmatic changes; Igneous textural terms; Extrusive processes, products and landforms; Intrusive processes and bodies; Hydrothermal Systems.

Unit-3: Phase Rule and Various Igneous Systems
Revision of thermodynamics; Melting behavior of magmas; Phase equilibrium and phase rule; Application of the phase rule to the H2O system; One component systems; Binary systems; Ternary systems; Systems with more than three components; Reaction series; Effect of pressure on melting behavior; Effect of fluids on melting behavior. Unit-4: Generation of Basaltic Magmas and their Diversification Petrology of the mantle; Mantle melting; Generation of basalts from a chemically uniform mantle; Primary magmas; A chemically heterogeneous mantle model; Partial melting; Magma differentiation; Magma mixing; Assimilation; Boundary layers, in-situ crystallization, and compositional convection; Tectonic-igneous association.

Unit-5: Layered Mafic Intrusions
Igneous layering; Examples of layered mafic intrusions; processes of crystallization, differentiation and layering in these complexes.

Unit-6: Mid-Ocean Ridge Volcanism
Volcanism at constructive plate boundaries; Mid-ocean Ridge Basalts (MORB); Structure of the oceanic crust and upper mantle; MORB chemistry; Petrogenesis of MORB.

Unit-7: Continental Flood Basalts (CFB) and Oceanic Island Basalts (OIB)
Tectonic setting for CFBs; Classical examples of CFBs, chemistry and petrogenesis of CFBs; Oceanic intraplate volcanic activities; Types of OIB magmas; Chemistry and petrogenesis of OIBs.

Unit-8: Subduction-Related Igneous Activity
Island arc volcanism, rocks suites, and magma series; Chemistry of island arcs; Spatial andtemporal variations in island arcs; Petrography and petrogenesis of island arc magmas; Continental arcs; Classical examples of continental arcs; Chemistry and petrogenesis of

continental arc magmas.

Unit-9: Continental Alkaline Magmatism
Continental rift-associated alkaline magmatism; Carbonatites; Highly potassic rocks; Mantle metasomatism and mantle xenoliths.

Unit-10: Granitoids and Anorthosites
Petrography, chemistry and petrogenesis of granitoids; Granitoid classification; Chemical discrimination of tectonic granitoids; Origin of the continental crust; Archaean anorthosites; Proterozoic anorthosites; Lunar anorthosites.

Suggested Readings **:**

1. Winter, J. D., 2009, An introduction to Igneous and Metamorphic Petrology (2 nd Edition), Prentice Hall.
2. Philpotts, A., and Auge, J., 2009, Principles of Igneous and Metamorphic Petrology(2 nd Edition) Cambridge University Press.
3. Carmichael, I., Turner, F., and Verhoogen, F., 1974, Igneous Petrology, McGraw Hill Publications.

EES 304 : Structural Geology & Geodynamics (3)

***Prerequisites:*:**credited or registered in All EES 300 level courses

***Learning Objectives*:**

This course is designed to understand the natural processes by which geological structures were developed in the lithosphere. Study of geologic structures provides the information necessary to understand the deformational history of rocks and regions from the micro-scale to the scale of tectonic plates. After completion of the course, students will develop the skills necessary to recognize complex geological structures and will gain an appreciation of analyzing the various deformational patterns of the lithosphere.

***Course Contents*:**

Structural Geology

Unit-1: Introduction
Structure of the course; Introduction to structural geology and tectonics; Interior of the Earth and other planetary bodies; Earth's crust and plate tectonics; Structure of the continental crust.

Unit-2: Stress and Strain
Stress - definitions, different types of stress tensors, two and three-dimensional stress, Mohr's diagram for graphical analysis of stress; Strain - definitions, measurement of strain, Mohr's diagram for strain calculation, rheology of rocks and minerals; Concept of brittle andductile deformation.

Unit-3: Rock Failure
Fracturing, Mohr-Coulomb criteria for rock failure, classification for fractures, geometry of fracture systems in three dimensions, microscopic features of fractured surfaces, effect of confining pressure on fracturing and frictional sliding, Griffith theory of fracture, deduction of fluid pressure from dykes and quartz veins.

Unit-4: Faults
Different types of faults, recognition of faults, measurement of fault displacements, fault geometry, orientation of stress fields and fault kinematics, paleo-stress from the fault slip data, fault bend folds, and fault propagation folds.

Unit-5: Folding
Geometric descriptions and classification of folds, fold scale and attitude, the element of fold styles, order of folding, common styles and structures associated with folding.

Unit-6: Kinematics of Folding
Folding mechanisms, buckling and shear folding of single layers, multilayer folding, formation of kink and Chevron fold.

Unit-7: Foliation and Lineation in Deformed Rocks
Different types of foliations - compositional, disjunctive, crenulation and continuous; Lineation - structural and mineral, association of lineation and other structures.

Unit-8: Microscopic Aspects of Ductile Deformation
Mechanisms of low temperature deformation, twin gliding, diffusion and solution creep, linear crystal defects; Microscopic criteria for identification of dislocation and diffusion creep.

Unit-9: Shear Zone and Progressive Deformation
The nature of shear zone, mechanism of formation of shear zone, strain in shear zone, determining the sense of shear in shear zone, active tectonics.

Geodynamics

Unit-10: The Dynamic Earth
Continental drift, seafloor spreading, continental reconstructions, geologic evidence for continental drift, paleoclimatology, paleontologic evidence for continental drift, paleomagnetism, sea floor spreading and transform faults, mantle plumes and igneous activities.

Unit-11: The Framework of Plate Tectonics
Plates and plate margins, distribution of earthquakes, relative plate motions, absolute plate motions, hotspots, direct measurement of relative plate motions, finite plate motions, stability of triple junctions, present-day triple junctions.

Unit-12: The Mechanism of Plate Tectonics
Contracting Earth hypothesis, expanding Earth hypothesis, driving mechanisms of plate tectonics, mantle drag mechanism, edge-force mechanism, evidence for convection in the mantle, the mechanism of the supercontinent cycle.

Suggested Readings **:**

1. Twiss, R. J., and Moores, E. M., 2007, Structural Geology (2 nd Edition), W. H. Freeman and Company.
2. Ghosh, S. K., 1993, Structural Geology Fundamentals and Modern Developments (1st Edition), Pergamon Press.
3. Davis, H., Reynolds, S. J., and Kluth, F. C., 2012, Structural Geology of Rocks andRegions (3 rd Edition), Wiley.
4. Jain, A. K., 2014, An Introduction to Structural Geology (1 st Edition), Geological Society of India.
5. Kearey, P., Klepeis, K.A., and Vine F. J., 2009, Global Tectonics (3 rd Edition), John Wiley and Sons.
6. Donald, L. G., and Turcotte, S., 2000, Geodynamics (3 rd Edition), Cambridge University Press.
7. Fowler, C. M. R., 2005, The Solid Earth: An Introduction to Global Geophysics (2 ndEdition), Cambridge University Press

EES 305 : Environmental Chemistry (3)

***Prerequisites:*:**CHM and EES 100 and 200 level courses

***Learning Objectives*:**

To understand the chemistry that governs natural and polluted environments by utilizing and building on the tools acquired in general chemistry, chemical kinetics, and thermodynamics. The chemistry of species in the atmosphere, hydrosphere, lithosphere, and their interactions will be examined. Additionally, concepts of ecotoxicology will be introduced.

***Course Contents*:**

Unit-1: Introduction to Environmental Chemistry
Natural processes in the biosphere and processes associated with pollution; Review of chemical equilibria, acid-base reactions, redox parameters, chemical kinetics including photochemistry and radiochemistry.

Unit-2: Atmosphere
Composition of tropospheric air, sources, transport, and sinks of important trace gases (O_3, CO, OH, SOx, NOx, and VOCs); Tropospheric aerosol, sources, composition, chemistry, transport, residence times, and sinks; Urban pollution episodes and smog formation; Overview of stratospheric chemistry, Chapman mechanism for O_3 formation/destruction, NOx cycle, and halogen cycles; Ozone hole; Stratospheric aerosols.

Unit-3: Hydrosphere
Natural waters and their composition, aquatic chemistry – Henry's law, dissolved O_2, CO_2, physico- chemical processes – acid base reactions, redox reactions, complexation in natural and polluted waters, photochemical reactions.

Unit-4: Lithosphere
Weathering – physical and chemical, dissolution and precipitation of solids, dissolution of natural oxides, stable and metastable processes, biological weathering; Soil composition and characteristics; Acid-base and ion-exchange reactions; Micronutrients and macronutrients.

Unit-5: Global Biogeochemical Cycles
Carbon cycle — short and long term carbon cycles, atmospheric and marine Carbon; Carboncycle in the terrestrial biosphere, human influences on the cycle; Nitrogen - forms of nitrogen, Nitrogen biochemistry, microbial processes, other natural Nitrogen processes, fertilization, human influences on nitrogen cycling; Sulfur - forms, natural processes, Sulfur reservoirs, natural Sulfur cycles, cloud and gas phase processing in the atmosphere.

Unit-6: Ecotoxicology
Toxic chemicals in the environment, carcinogens, and biochemical effects of some species, including As, Cd, Pb, Hg, SO_x, NO_x, O_3, and pesticides.

***Suggested Readings* :**

1. Manahan, S. E., 2009, Environmental Chemistry, CRC Press.
2. Andrews, J. E., Brimblecombe, P., Jickells, T. D., Liss, P. S., and Reid. B. J., 2004,Introduction to Environmental Chemistry, Blackwell Publications.
3. Schlesinger, W. H., 1997, Biogeochemistry: An Analysis of Global Change, Academic Press.
4. Jacobson, M. C., Charlson, R. J., Rodhe, H., and Orians, G. H., 2000, Earth SystemScience: From Biogeochemical Cycles to Global Change, Elsevier.
5. Sawyer, C. N., McCarty, P. L., and Parkin, G. F., 2003, Chemistry for Environmental Engineering, McGraw-Hill Inc.

EES 306 : Chemical Petrology (Geochemistry) (3)

Prerequisites::All 100 and 200 level CHM, EES and PHY courses, credited or registered in EES 303, EES 307

***Learning Objectives*:**

This course first lays out the basic principles and techniques of modern geochemistry, beginning with a review of thermodynamics and kinetics as they apply to the Earth and its environment. These basic concepts are then applied to understanding processes in aqueoussystems and the behavior of trace elements in magmatic systems. This course also introduces radiogenic and stable isotope geochemistry and illustrates their application to such diverse topics as determining geologic time, ancient climates, and the diets of prehistoric peoples. The focus then broadens to the formation of the solar system, the Earth, and the elements themselves. Then the composition of the Earth itself becomes the topic, examining the composition of the core, the mantle, and the crust and exploring how this structure originated. This course also covers organic chemistry, including the origin of fossil fuels and the carbon cycle’s role in controlling Earth’s climate, both in the geologic past and the rapidly changing present.

***Course Contents*:**

Unit-1: Introduction
History of geochemistry; The philosophy of science; Standard units of measurements; Geochemical systems and variables; Elements, atoms, and the structure of matter; Elementsand the periodic table; Elemental associations and bonding; Goldschmidt's rules of substitution.

Unit-2: Aqueous Solutions and their Chemistry
Water as a solvent; Activity-concentration relationships; Acid–base reactions; Solubility of salts; The Carbonic Acid System; Complexation; Dissolution and precipitation reactions and the calcium carbonate system; pH control of dissociation equilibria; Solubility of amorphous Silica; Clays and their properties; Mineral surfaces and their interaction with solutions; Reaction path calculations.

Unit-3: Oxidation-Reduction Reactions
Balancing redox equations; The Nernst equation; Oxidation potential; Eh-pH diagrams; Stability limits of water in terms of Eh and pH; Stability of Iron compounds; Role of microorganisms in redox reactions; Oxidation of sulphide minerals; Oxygen Fugacity.

Unit-4: Radiogenic Isotope Geochemistry
Physics of the nucleus and the structure of nuclei; Basics of radiogenic isotopegeochemistry; Decay systems and their applications; Principles of radiometric geochronology; Cosmogenic and fossil isotopes.

Unit-5: Stable Isotope Geochemistry
Theoretical considerations; Isotope geothermometry; Isotopic fractionation in the hydrologic system; Isotopic fractionation in biological systems; Evaporation and condensation processes; Estimation of water-rock ratios.

Unit-6: Mixing and Dilution
Binary mixtures; Dilution; Evaporative concentration; Ternary mixtures; Isotopic mixtures of one element; Isotopic mixtures of two elements.

Unit-7: Chemical Petrology
Major and minor elements in the crust; Analytical methods and results; Normative minerals; Variation diagrams using major and minor elements; Using variation diagram to model magmatic evolution; Trace element distribution; Batch melting and Rayleigh fractionation; Rare Earth Elements; Spider diagrams; Applications of trace elements to igneous systems; Geochemical criterion for distinguishing between tectonic environments; Isotopes and their applications to igneous processes.

Unit-8: The Core-Mantle-Crust System

Cosmic perspective; Big Bang and nucleosynthesis; Origin of the solar system; Origin of the Earth-like planets; Satellites of the outer planets; Evolution of the Earth; Chemical differentiation of the Earth; The Earth's mantle; Estimating mantle and bulk Earth composition; The Earth's core and its composition; Mantle geochemical reservoirs; The crust; Generation and crystallization of magmas; Geochemical discrimination of paleo-tectonic settings.

***Suggested Readings* :**

1. White, M., 2013, Geochemistry, Wiley Publication.
2. Walther, J., 2009, Essentials of Geochemistry (2 nd Edition), Jones and Bartlett Learning.
3. McSween, H. Y., Richardson, S. M., and Uhle, M., 2003, Geochemistry Pathwaysand Processes (2 nd Edition), Columbia University Press.
4. Faure, G., 2012, Inorganic Geochemistry - Principles and Applications (3 rd Edition), Wiley Publications.
5. Misra, K. C., 2012, Introduction to Geochemistry - Principles and Applications, Wiley-Blackwell Publications.

EES 307 : Sedimentology (3)

Prerequisites:**:**All 100 and 200 level CHM, EES and PHY courses, credited or registered in EES 303, EES 307

Learning Objectives**:**

Sedimentology is the study of sediments, particularly focusing on how it is produced, transported, and deposited. Stratigraphy, which is a synthesis of the stratal record, emphasizes the analysis of layered sequences, principally sedimentary, that cover about 3/4th of the Earth's surface. Sedimentary rocks illuminate many of the details of the Earth's history - effects of sea level change, global climate, tectonic processes, and geochemical cycles. This course will cover basics of fluid flow and sediment transport, sedimentary textures and structures, and provide an overview of facies analyses, modern and ancient depositional sedimentary environments, and the relationship of tectonics and sedimentation.

Course Contents**:**

Unit-1: Development of Concepts in Sedimentology
The context of sedimentology, Origin and classification of sedimentary rocks.

Unit-2: Textural Properties of Sediments and Sedimentary Rocks
Grain Size and scale, grain size distributions; Grain orientation and fabric.

Unit-3: Sediment Transport
Fluid gravity flows & Sediment Gravity Flows, Hjulstrom's diagram, Bedforms and structures under unidirectional flow – Flow regime concept, bedform stability diagrams.

Unit-4: Primary Sedimentary Structures
Primary structures and their directional significance, bedding, cross-bedding – planar, trough, HCS, Herringbone, normal and inverse graded beds; Bedding plane markings, biogenic sedimentary structures - Stromatolites and Ichnofossils; Penecontemporaneous Deformation Structures (PCD).

Unit-5: Depositional Sedimentary Environments: Facies Models
Walther's Law of correlation of sedimentary facies, migration of facies tracts; Facies models and interpretation of depositional environments – Examples from continental, transitional and marine depositional environments.

Unit-6: Sedimentary rocks
Components, classification and diagenesis of sandstones and carbonate rocks and BIFs.

Unit-7: Tectonics of Sedimentary Basins: Basin classification –Divergent and convergent – margin basins, collision and post-collision basins, strike-slip basins.

Unit-8: Principles of Stratigraphy
Lithostratigraphy, Biostratigraphy and Chronostratigraphy: Stratigraphic units, stratigraphic correlation, Principles of geochronology and radiometric dating methods, magnetostratigraphy.

Suggested Readings **:**

1. Prothero, D. R., and Schwab, F., 2013, Sedimentary Geology (3 rd Edition), Freeman Publishers.
2. Nichols, G., 2009, Sedimentology and Stratigraphy (2 nd Edition), Wiley-Blackwell Publication.
3. Boggs, S., 2011, Principles of Sedimentology and Stratigraphy (5 th Edition), Prentice Hall.
4. Miall, A. D., 2000, Principles of Sedimentary Basin Analysis (3 rd Edition), Springer.
5. Leeder, M. R., 2011, Sedimentology and Sedimentary Basins – From Turbulence toTectonics, Wiley-Blackwell.

EES 308 : Science of Sustainability: Methods and Processes (4)

***Learning Objectives*:**

This course is an expansion of EES 309. In this session, special emphasis will be placed onassessing the connections between economic activities, the natural environment, and our society. On completion of this course, the student will be able to understand and appreciate

the complexity of the interaction between the industrial processes and earth resources, the concept of “systems” and industrial symbiosis. Additionally, the students will be able to formulate and apply equations to solve numerical problems to evaluate products, processes, and systems in their entire life-cycle, including materials flow analysis, design for environment, input-output analysis, and life-cycle assessment (LCA).

***Course Contents*:**

Unit-1: Materials and the Environment: Adopting a systems perspective, defining system boundaries, life cycle of materials, definitions and terminology, assessing material and energy flows, eco-efficiency, pollution prevention principles, cradle to grave approach - waste and recycling, resource dissipation, and cradle to cradle approach; Case studies.

Unit-2: Life-Cycle Analysis (LCA): Introduction – History and definition of LCA, LCA stages –Definition of goal and scope, level of detail for boundaries, natural ecosystem boundaries, LCA inventories,input/output assessment, LCA impact and interpretation, identifying issues in the results, drawing conclusions and recommendations, prioritizing recommendations, comparative LCA modeling; Limitations of LCA; Case studies.

Unit-3: Industrial Ecosystems: Environmental impact assessment, policy implications, eco-industrial parks, development of industrial symbiosis, socio-economic dimensions of industrial symbiosis.

***Suggested Readings* :**

1. Dahlem Workshop Reports, 2004, Earth System Analysis for Sustainability.
2. Graedel, T. E., and Allenby, B. R., 2003, Industrial Ecology, Pearson Education.
3. Ashby, M. F., 2009, Materials and the Environment: Eco-informed Material Choice, Elsevier.

OR

EES 318 : Natural Hazards and their Mitigation-2 (4)

***Learning Objectives*:**

This course is an expansion of EES 321

***Course Contents*:**

Unit-1: Landslides and other Downslope Movements: Terminology and classification; rock falls; debris flows; shallow landslides; Stress conditions of unstable slopes; Slow rock slope creep, rapid rock slope failure; Causes of landslides, landslide monitoring using satellite remote sensing techniques, susceptibility and hazard mapping, risk assessment; Impact of climate change; Avalanche control measures; Localized hazard mitigation; Case studies.

Unit-2: Rivers and Flooding: Types of floods; Geography of floods in India; Flood control — levee systems and embankments; Flood risk assessment, warning, preparedness, and mitigation; Water logging; Annual floods in India; Case studies (Kedarnath 2013, Kosi 2008, Indus 2010).

Unit-3: Droughts: Causes of droughts; Agricultural droughts; Hydrological droughts; Case Studies.

Unit-4: Tropical Cyclones and Severe Weather: Global overview of extreme weather events;Tropical cyclones and their life cycle; Surface and upper air structure; Pressure, temperature, wind, humidity, and cloud fields; Energy aspects, formation of tropical storms, theories of formation, frequency, intensification and movement of tropical storms; Tropical atmosphere as a hurricane incubator; Thunderstorms; Forecasting tropical cyclones; Early warning and preparedness of Cyclones; Cloudbursts and extreme rainfall events; Case studies (Phailin, Hudhud, Ladakh).

Unit-5: Disaster Management - Policy and Economics Issues: Legislative framework in India; Assessment of economic repercussions, risk assessment, and insurance.

Suggested Readings **:**

1. Hyndman, D., and Hyndman, D., 2014, Natural Hazards and Disasters (4th Edition),Cengage Learning.
2. Keller, E. A., and DeVecchio, D. E., 2012, Natural Hazards; Earth's Processes as Hazards, Disasters, and Catastrophes (3rd Edition), Pearson Prentice Hall.
3. Kapur, A., 2010, Vulnerable India – A Geographical Study of Disasters, SAGEPublications

EES 309: Introductions to the Science of Sustainability (4)

Learning Objectives**:**

This course will introduce ideas of sustainability at the global scale across earth systems andthe drivers of sustainability. The course will introduce methods necessary for designing and implementing changes in various manufacturing processes to increase sustainability.

Course Contents**:**

Unit-1: Background, status and trends of Human populations, economic growth, environment, water and food security, mineral and material resources, energy; Climate - status, trends, and the climate of the near future, proxy and climate data evidence; Consumption patterns; Ecological footprints.

Unit-2: Definitions and drivers for sustainability; Sustainability indicators - Social and demographic equity; Economics – Genuine Progress Indicator (GPI); Ecological/Environmental – Ecological footprint; Tragedy of the commons, Neo-malthusians,J-curves, S-curves and the IPAT equation; Major transitions and role of disturbances in the evolution of life and of Earth systems; Sustainability grand challenges.

Unit-3: Natural Ecosystems and Industrial Systems: Introduction to the concept of industrial ecology, historical development of industrial ecology, linking industrial activity with Earth resources; Biological and industrial organism/systems, similarities and differences, concept of metabolism - biological and industrial organisms, industry-Earth interactions, utility of the ecological approach, and discussion of practical symbiotic cases from a sustainability perspective.

Suggested Readings **:**

1. Dahlem Workshop Reports, 2004, Earth System Analysis for Sustainability.
2. Graedel, T. E., and Allenby, B. R., 2003, Industrial Ecology, Pearson Education.
3. Ashby, M. F., 2009, Materials and the Environment: Eco-informed Material Choice, Elsevier.

OR

EES 321: Natural Hazards and their Mitigation-1 (4)

***Prerequisites*:**All EES 300 level courses

***Learning Objectives*:**

As a result of lithospheric plate interactions, the energy is released in the form of earthquakes of different magnitudes and volcanism which constitute significant natural hazards. Further there are other natural hazards which result from disturbances in the climate system such as tropical cyclones and tsunamis. Students will be provided an opportunity to gain insights into the natural mechanisms causing these hazards besides, being exposed to other aspects such as droughts, flooding and landslides in the Himalaya and peninsular India.

***Course Contents*:**

Unit-1: Introduction: Understanding hazards, disaster, risk, vulnerability; Overlap of human population and natural hazards; Mitigation and management; Institutional frameworks for disaster mitigation in India.

Unit-2: Earthquakes: Causes of earthquakes; Geodesy; Seismotectonics and Stable Continental Region (SCR) seismicity; Quantification of earthquakes; Seismometer design; Early warning systems; Earthquake preparedness; Strong motion seismometers and building codes; Centralized hazard mitigation; Case studies (Gurkha, Bhuj, Latur, Jabalpur).

Unit-3: Volcanoes: Tectonic environments and types of eruptions; Products of volcanic eruptions; Volcano monitoring (seismicity, gases, and crustal deformation); How do contrasting eruptive styles effect societies differently; Monitoring the spread of volcanic ash; Mitigating volcanic hazards; Case studies (Iceland, Barren Island).

Unit-4: Tsunamis: Physical characteristics of tsunamis and tsunami-related terminology; Historic - oral and written records of tsunamis and earthquakes; Causes and prediction; Tsunami warning system (INCOIS) — Ocean bottom sensors; Tsunami modeling; Paleotsunamis; Case studies.

EES 310: Oceanography (4)

***Prerequisites*:**All 100 and 200 level CHM, EES, MTH and PHY courses

***Learning Objectives*:**

Exploration of modern oceans is done from a wide range of perspectives, economic to social, encompassing fisheries, transport, mapping/extraction of mineral/petroleum resources, CO2 sinks,sea level rise, Tsunami prediction, ocean acidification, and human impacts on the health of coastal ecosystems. The importance of orbital, climate, and environmental conditions on various Earth surface processes can be learnt from marine fossil, geochemical, and isotope records.

***Course Contents*:**

<u>Unit-1:</u> Geological Oceanography
Dimensions and morphological features of modern oceanic basins, and their time evolution in response of plate tectonics, continental ice cover and erosion; Dynamics of coastal environment and role of past sea level changes on its morphology; Marine sediments, their formation/degradation, types, spatial distribution and classification Roles of lysocline/CCD, productivity, monsoon, ocean circulation, and orbital controls on sedimentation; Types of measurements; Marine geophysical technology: natural gas and oil; Utilization geological archives.

Unit-2: Physical Oceanography
General features of the ocean, Physical properties of seawater and their spatial distributions; Spatio- temporal scales and forcing mechanisms of oceanic motions; Conservation laws, Surface water circulation by wind stress, tides, waves, gyres etc.; Mixed layer depth; Coriolis force and geostrophic currents; Ekman transport and upwelling; Seasonal coastal and major currents in the Indian Ocean; Causes and frequency of Tsunami; Water mass formation, and global thermo-haline circulation; T–S plots; Heat budget of oceans; El Niño Southern Oscillations; Indian Ocean dipole; Measurement principles (including ocean acoustics) and their scientific applications.

Unit-3: Chemical Oceanography
General chemistry and thermodynamics of seawater; Dissolved chemical constituents, their spatial distributions and measurements; Atmosphere–ocean coupling and exchange of gases; Henry's law of gas solubility and its dependence on hydrographical properties of seawater; Penetration of anthropogenic CO2; Alkalinity and ocean acidification; pH scales; Organic matter degradation and redox reactions; Sources, sinks and internal cycling of various elements; Identification of oceanic processes using geochemical and isotope tracers.

Unit-4: Biological Oceanography
Basics of an ecosystem; Autotrophs and higher trophic levels; Planktonic and benthic ecology; Classification and global distributions of marine productivity; Redfield ratios of nutrients/micronutrients, and HNLC regions; Fe, N, P limitations; Depths of habitats and gametogenesis of forminifera; Vital effects; Human impacts on marine biota; Biological pump and its role in sequestration of atmospheric CO2 during glacial-interglacial cycles; Estimation of marine productivity using satellite imagery; Fish production and productivity in the Indian Ocean.

***Suggested Readings* :**

1. Talley, L. D., Pickard, G. L., Emery, W. J., Swift, J. H., 2005, Descriptive PhysicalOceanography: An Introduction (6 th revised Edition), Elsevier Academic Press.
2. Fundamentals of ocean acoustics, 2003, L.M Brekhovskikh, Yu.P.Lysanov, Springer
3. Emerson, S., and Hedges, J., 2008, Chemical Oceanography and the Marine CarbonCycle (1 st Edition), Cambridge University Press.
4. Zeebe, R. E., and Wolf-Gladrow, D., 2001, CO2 in Seawater: Equilibrium, Kineticsand Isotopes (1 st Edition), Elsevier Science.
5. Turekian, K. K., Holland, H. D., and Elderfield, H., 2003, The Oceans and MarineGeochemistry: Treatise on Geochemistry (1 st Edition), Pergamon.

EES 311: Mineralogy Laboratory (1)

***Prerequisites*:**EES 301 either credited or registered

***Learning Objectives*:**

Since minerals are the basic building blocks of earth materials, this course is designed togive the student a fundamental background in minerals, necessary to understand Earth processes. The students will learn the identification of minerals in hand samples and thinsections as well as identification of the crystallographic and optical properties of the minerals.

***Course Contents*:**

Unit-1: Physical Properties of Minerals
Color, luster, streak, form, cleavage, fracture, hardness, other relevant properties of specific minerals. Color and pleochroism, habit, relief, cleavage, extinction type and angle, interference figures, interference colors, and other properties etc.; Identification of rock-forming minerals using a polarizing microscope.

Unit-2: X-Ray Diffraction:
Sample Preparation, Analyses of X-Ray Diffractometer Measurements. Identification of Common Minerals of these Groups:

- Silicates: Neso-, inosilicates
- Silicates: Cyclo-, sorosilicates
- Silicates: Phyllo-, tectosilicates

Suggested Readings **:**

1. Mottana, A., Crespi, R., and Liborio, G., 1978, Simon and Schuster's Guide to Rocksand Minerals (6 th edition), Fireside Books.
2. Nesse, W. D., 2014, Introduction to Optical Mineralogy (4 th Edition), Oxford University Press.
3. Dana, J. D., 2008, Manual of Mineralogy and Petrology, Palala Press.
4. Mackenzie, W. S., and Adams, A. E., A Colour Atlas of Rocks and Minerals in ThinSection (2 nd Edition), Manson Publishing Ltd.
5. Klein, C., 2007, Minerals and Rocks: Exercises in Crystal and Mineral Chemistry, Crystallography, X-ray Powder Diffraction, Mineral and Rock Identification, and OreMineralogy (3 rd Edition), Wiley.

EES 312: Metamorphic Petrology Laboratory (1)

Prerequisites**:**Credited or registered in EES 304, EES 301

Learning Objectives**:**

In this course students will learn to identify different metamorphic rocks both mega- and microscopically. Emphasis will be given on identification of different mineral reaction textures. Additionally, laboratory exercises will also cover the computational methods to estimate P-T conditions in metamorphic rocks. Further, students will be introduced to thermodynamics based software to construct and interpret equilibrium phase diagrams.

Course Contents**:**

Unit-1: Classification and Nomenclature of Metamorphic Rocks:
Criteria for identification of equilibrium mineral associations; Relationships between textures, deformation for ordering metamorphic mineral associations.

Unit-2: Megascopic and microscopic study (textural and mineralogical):
Low grade metamorphic rocks: Serpentinites, albite-epidote-chlorite-quartz schists, slates, talc- tremolite-calcite-quartz schists.

Unit-3: Medium to high grade metamorphic rocks: Gneisses, amphibolites, hornfels, garnetiferous schists, sillimanite-kyanite-bearing rocks.

Unit-4: High Grade metamorphic rocks: Granulites, eclogites, diopside-forsterite bearing rocks.

Unit-5: Laboratory Exercises in Plotting Mineral Chemistry Data:
Determination of pressure-temperature conditions using various net-transfer and exchange reactions.

Unit-6: Preparation and Interpretation of Equilibrium Phase Diagrams:
DOMINO-THERAK, PERPLE_X and THERMOCALC.

Suggested Readings **:**

1. Vernon, R. H. and Clark, G. L, 2008, Principles of Metamorphic Petrology (1 stEdition), Cambridge.
2. Passchier, C., and Trouw, R. A. J., 2005, Microtectonics (2 nd Edition), Springer.
3. Popular equilibrium phase calculation software resources accessible via: **Link**

EES 313: Igneous Petrology Laboratory (1)

***Prerequisites*:**Students must have credited or be registered in EES 302

***Learning Objectives*:**

The aim of this course is to understand how igneous rocks are classified based on their mineralogy and textures, and how these can be used to interpret their cooling history. Upon completion of this course, the student will be able to identify igneous rocks and explain the processes by which the rock formed based on the textural associations of the mineral assemblages.

***Course Contents*:**

Unit-1: Review of Mineralogy:
Identification of the primary and secondary igneous minerals in hand specimen and thin section; Identification of these minerals within a rock.

Unit-2: Classification of Igneous Textures and Structures:
Grain shape and size; Grain fabric; Relationship between the grains of various minerals; Interpretation of cooling history based on textural analyses; Structures of igneous rocks.

Unit-3: Megascopic and Microscopic Study of the Following Rock Groups:

- Non-feldspathoidal basic rocks
- Silica-saturated intermediate rocks
- Acidic rocks
- Feldspathoidal mafic rocks (basic and ultrabasic)
- Feldspathoidal felsic rocks (intermediate with basic variants)
- Lamprophyres and ultrabasic rocks of extreme compositions
- Pyroclastic rocks

Unit-4: Laboratory Exercises:
Modal and normative mineralogy; Calculation of normative mineralogy; Bivariant and Triangular plots for mineral chemistry, major element, trace element, and isotopic data analyses.

***Suggested Readings* :**

1. Williams, H., Turner, F. J., and Gilbert, C. M., 1982, Petrography (2 nd Edition), Freeman Publications.
2. Philpotts, A. R., 2015, Petrography of Igneous and Metamorphic Rocks, CBSPublications.
3. Cox, K. G., 1979, The Interpretation of Igneous Rocks, Springer.

EES 314: Structural Geology Lab (1)

***Prerequisites*:**credited or registered in EES 304

***Course Contents*:**

Unit-1: Basic idea of topographic maps, Topographic sheets of various scales. Interpretation of topographic maps.

Unit-2: Interpretation of geological maps with unconformity, fault, fold and igneous bodies. Construction of structural cross-sectionon.

Unit-3: Stereographic projections of planes and lines

Unit-4: True dip and apparent dip problems, 3-point problems, fold problems, fault problems and their solutions through graphical methods and stereographic projection methods.

Suggested Readings **:**

1. Ragan, D. M. (2009) Structural Geology: an introduction to geometrical techniques(4th. Ed.) Cambridge University Press
2. Marshak, S and Mitra G. (1988) Basic Methods in Structural Geology, Prentice Hall.

EES 315: Environmental Chemistry Laboratory (1)

Prerequisites**:**MTH, CHM, and PHY 100 level courses; credited or registered in EES 305

Learning Objectives**:**

This course is designed to complement the material covered in environmental science theory courses. The courses intends to introduce the student to analytical techniques, including instrumental methods that are essential for determining the state of the environment and provide hands on experience in techniques that can be built upon for use in contemporary research of environmental systems.

Course Contents**:**

Unit-1: General inorganic properties (pH, TDS, alkalinity, salinity) of natural waters and waste waters. Determination of hardness of groundwater, river/stream waters and RO water by titration method.

Unit-2: Solubility of dissolved oxygen in surface waters at varying temperature and salinity by titration methods.

Unit-3: Determination of chemical and biological oxygen demand in natural and polluted/waste water.

Unit-4: Determination of dissolved/labile nutrients (N, P, Si) and contaminant abundances in natural/waste waters, aerosols and soils.

Unit-5: Determination of inorganic anions/cations in water samples using ion chromatography.

Unit-6: Determination of water, carbonate and organic matter contents in a soil sample.

Unit-7: Evaluation of the relationships between cation exchange capacity of soils and their organic matter contents, in a depth profile.

Unit-8: Determination of aerosol (PM 10 and PM 2.5) concentrations at various locations — sampling and gravimetry and analyzing temporal trends (using actual measurements/synthetic data sets) OR Aerosol optical depth by sunphotometry and preparing Langley plots.

Unit-9: Monitoring ambient meteorological parameters – wind speed, wind direction, temperature, and relative humidity. Preparation of wind rose plots (using measurements/synthetic data sets).

Unit-10: Monitoring ambient gaseous pollutants – O_3 , SO_2 , NO_x , and CO. Analyzing temporal trends (using measurements/synthetic data sets).

***Suggested Readings* :**

1. Douglas A. S, Holler, F. J., and Stanley R. C., 2006, Principles of InstrumentalAnalysis, Thomson Brooks/Cole.
2. Gopalan, R., Anand, A., Sugumar, R., and Wilgred, 2009, A Laboratory Manual forEnvironmental Chemistry, I K International Publishing House.
3. Newmann, M. E., 2005, Environmental Chemistry: A Laboratory Manual, Taylor andFrancis E-book.

EES 316: (Lab) Chemical Petrology & Geochemistry (1)

***Prerequisites*:**credited or registered in ESS 306, EES 303

***Course Contents*:**

Geochemical variation diagrams and its interpretations: bivariate and trivariate plots to delineate the control of different compositional variables: Harker variation diagram, AFM diagram, MgO diagram. Chemical variation diagrams based on major, trace and REE: the alkali-lime index, iron enrichment index, aluminium saturation index and alkalinity index diagrams. Norm calculation for silica undersaturated and silica oversaturated rocks. Plottingof modal data in IUGS classification diagram for plutonic rocks (Streckeisen diagram).

EES 317 : Sedimentology Laboratory (1)

***Prerequisites*:**EES 307, either credited or registered

***Learning Objectives*:**

Approximately 75% of the Earth's surface is covered by sedimentary rocks. This course will help students learn to identify and characterize both clastic and chemical sedimentary rocks at macro- and microscopic scales. Besides, students will be introduced to the study of sedimentary textures, structures, and paleocurrent and facies analyses as tools for environmental reconstructions.

***Course Contents*:**

Study of Hand Specimens:
Megascopic examination of hand specimens of sediments/soils and sedimentary rocks; Hand specimen study and analyses of photographs of primary, secondary (chemical), biogenic and organo- sedimentary structures.
Textural Analyses of Sediments:
Size analyses, plotting of grain size data and statistical analyses.
Paleocurrent Analysis:
Exercises using sets of directional data to understand spatial variation in vectorial data.
Study of Thin Sections:
Study of thin sections of siliciclastic and carbonate sedimentary rocks.

***Suggested Readings* :**

1. Lindholm, R. C., 1987, A Practical Approach to Sedimentology, Springer.
2. Tucker, M. E., 2011, Sedimentary Rocks in the Field - A practical guide, Wiley-Blackwell.
3. Adams, A. E., Mackenzie, W. S., and Guilford, C., 2015, Atlas of Sedimentary RocksUnder the Microscope, Prentice Hall.

EES 319: Introductory Field & Project Work (3)

Prerequisites (Desirable): *All EES 300 level courses credited or registered*

***Learning Objectives*:**

This course is intended to complement the material covered in EES theory courses. Earth scientists use a number of field methods to decipher Earth history and understand the processes that occur on and beneath the Earth’s surface. This course will introduce students to the basic practices of field geology and impress upon them the importance of making rigorous field observations in the Earth and environmental sciences.

***Course Contents*:**

Pre-Field Work:

Understanding remote sensing images and satellite data; Learning to read a toposheet; Using a GPS, brunton, and clinometer; Maintainance of a field notebook.

Field Work:

Day 1
Use of topographical sheets; Identification of topographical features in the field that are marked on toposheets; Orientation of toposheet with the geographical north; Location ofposition in the toposheet using the method of back bearings; Introduction to Global Positioning System (GPS).

Days 2 to 4
Practice for determination of locations; Identification of outcrops and rock units, study of hand samples in the field; Documentation of outcrops; Determination of dip and strike; Tracing units along strike; Plotting of data in the toposheet to prepare a map.

Days 5 to 7
Identification of gap areas to complete the locality map, collection of samples; Understanding and
summarizing the sequence of events; Synthesis of data from different spatial locations; Geological cross-sections and inference of geological history; Interim field report.

Post-Field Work:

Preparing a final field report; Preparation of maps and logs using software ROCKWARE andGEO-ORIENT; Complete documentation of all samples collected.

Suggested Readings **:**

1. Compton, R. R., 1982, Geology in the Field, John Wiley and Sons.
2. Coe, A. L., 2010, Geological Field Techniques, Wiley-Blackwell.
3. Lisle, R. J., Brabham, P., Barnes, J. W., 2011, Basic Geological Mapping(5th Edition), Wiley Publications.

EES 320 : Introduction to Geophysics (4)

Prerequisites**:**All 100 and 200 level EES, MTH, and PHY courses

Learning Objectives**:**

This course is a general introduction to the study of the physics of the solid Earth, including the dynamics of both the Earth's surface and its deep interior. Geophysics provides tools and methods which can image the subsurface through measurements which are mostly made remotely from the Earth’s surface. It describes the subsurface of the Earth in physical terms — density, electrical resistivity, magnetism, conductivity, and heat flow. Upon completion of this course the student will learn to appreciate the application of geophysics for understanding the physical conditions of the Earth’s multi-layered interior.

Course Contents**:**

Unit-1: An Introduction to Geophysical Methods
Introduction; The problem of geophysical expression, lateral or vertical variation of the Earth, geophysical surveys, signal processing, interpretation of the geophysical data, and application of different geophysical methods.

Unit-2: Gravity and the Earth
The nature and characteristics of the gravitational field of the Earth; The Earth’s size, shape and figure - geoid and spheroid; Potential field equations and derivation; Newton's

gravitational law, Green’s theorem, Helmholtz equation, Laplace's and Poisson's Equations; Effect of rotation on Earth's shape; Gravity field of the Earth; International gravity formula; Reduction of gravity data; Gravimeters; Global gravity anomalies; Isostasy; Satellite geodesy, temporal variations, tidal friction.

<u>Unit-3:</u> Geomagnetism
History of Magnetism; Basic physics of magnetics; Magnetic field of the Earth; Rock magnetism, magnetic potential of the Earth in terms of spherical harmonic coefficients; Origin of magnetic field – internal and external origin; Temporal variations – secular and diurnal; Magnetic field strength; International Geomagnetic Reference Field (IGRF); Origin of dipole field; Dynamo theory.

<u>Unit-4:</u> Paleomagnetism
Introduction to paleomagnetism; Polar wandering; Euler pole and continental drift; Geomagnetic polarity; Seafloor spreading and continental drift; Filtering (magnetic) data; Modelling and interpretation of magnetic anomalies.

<u>Unit-5:</u> Geoelectromagnetism
Basic electrical and electromagnetic concepts; Principles of magnetotelluric (MT) method; Sources of MT, dead band; Principle of induction coil and fluxgate magnetometers, MT Data Acquisition, MT parameters viz., impedance, skew, ellipticity, tipper; MT processing, modelling and interpretation; Study of the interior of the Earth from magnetotelluric studies.

<u>Unit-6:</u> Seismology and the Internal Structure of the Earth
Elastic theory; Snell's law; Seismic waves and the ray parameter; Surface waves, body waves, free oscillations; Global seismicity; Magnitude and intensity; Seismograph, seismogram, seismic phases; Earthquake mechanisms; Travel-time curves, inversion, velocity structures; Velocity and internal structure of the Earth; Surface wave dispersion and free oscillations; Seismic tomography.

<u>Unit-7:</u> Geothermics
Mechanism of heat transport in the Earth; Head conduction equation, heat flow density; Heat flow measurements; Temperature distribution (geotherm); Factors contribution to heat flow; Oceanic and continental heat flow; Global heat flow maps; Thermal structure of mid-ocean ridges and trenches; Mantle convection — hotspots and mantle plumes; Heat flow measurements and simple estimates of thermal history from diffusivity values, Solutions of diffusion equation. Outline of Geophysical Exploration

Suggested Readings **:**

1. Musset, A. E., and Khan, M. A., 2000, An Introduction to Geological Geophysics,Cambridge University Press.
2. Lowrie, W., 2011, Fundamentals of Geophysics (2nd Edition), Cambridge UniversityPress.
3. Fowler, C. M. R., 2004, The Solid Earth – An Introduction to Global Geophysics (2ndEdition),Cambridge University Press.
4. Dobrin, M. B., and Savit, Carl, H., 1988, Introduction to Geophysical Prospecting (4th Edition), McGraw Hill International.
5. Telford, W. M., Geldart, L. P., Sheriff, R. E., 1990, Applied Geophysics (2nd Edition),Cambridge University Press.

EES 401 : Paleontology (3)

***Prerequisites*:**All EES 100 and 200 level courses

***Learning Objectives*:**

Extinct plants and animals make up 99% of all species that ever lived, and this course provides an opportunity to obtain insights on this larger perspective of the tree of life. This is an introductory course that provides insights into the fossil record against a background of ecological and evolutionary change. The empirical record of both biological and environmental change will be considered over different time scales. Apart from developing a conceptual understanding of the nature of the fossil record, the course will summarize the scientific evidence for the origin of life, history of life, mass extinctions, and related topics.

***Course Contents*:**

Unit-1: The Fossil Record
Introduction to the scope of paleontology and palaeobiology; What is a fossil? Fossilization potential of an organism; Process of fossilization; Taphonomy and quality of the fossil record; Factors required for extraordinary preservation and Lagerstatten; The quality of the fossil record; Variations in fossils; Species concepts and speciation; Taxonomy and phylogeny; Functional morphological analysis.

Unit-2: Systematics and Evaluation
Why Systematics? Evolution and Classification, molecular systematics, codes of systematic nomenclature; Macroevolution and the tree of life, fossil form and function.

Unit-3: Diversity of Fossil Life
The origin of life; Protists, Metazoans - origin and classification; Sponges and corals; Spirulians — lophopherates and molluscs; Arthropods; Brachiopods; Trilobites; Echinodermisand hemichordates; Fish and basal tetrapods; Dinosaurs and mammals; Microfossils- Foraminifera, Front plants; Trace fossils; Diversification of life trends and radiations.

Unit-4: Fossils in Time and Space
The diversification of life; Evolution and extinction, causes of extinction and study of faunal and floral changes across the major mass extinctions.

Unit-5: Palaeobiology
Introduction to estimation and times of origins (fossils & molecular clocks); Punctuated equilibrium, ecosystem evolution; Explaining the Cambrian explosion; Framework of litho- and biostratigraphy, use of fossils, palaeobiogeography, palaeoecology, paleoenvironment and palaeoclimates; Palaeoclimate reconstructions using fossils; Stratigraphic palaeontology, biostratigraphy and correlation.

***Suggested Readings* :**

1. Prothero, D. R., 2013, Bringing Fossils to Life: An Introduction to Palaeobiology (3rdEdition), McGraw Hill.
2. Benton, M. J., and Harper, D. A. T., 2009, Introduction to Palaeobiology and theFossil Record Wiley-Blackwell.
3. Clarkson, E. N. K., 1993, Invertebrate Paleontology and Evolution (3rd Edition),Chapman and Hall.
4. Foote, M. J., and Miller, A. I., 2007, Principles of Paleontology, W. H. Freeman.

EES 402 : Global Climate Change (2)

***Prerequisites*:**All EES 300 level courses

***Learning Objectives*:**

This course provides an introduction to the science of climate change. The climate system evolves in time under the influence of its own internal dynamics and due to changes in external factors that are called forcings. The course is divided into four parts: (i) Understanding the drivers and factors shaping the Earth’s climate; (ii) Meteorological consequences of climate variability and change; (iii) human influence on climate variability and change; (iv) Global emission scenarios and climate change globally and regionally. Upon completion of this course, students will learn the different aspects of the science of climate change as well as specific regional issues of climate change with reference to

SouthAsia.

***Course Contents*:**

Unit-1: Introduction to Climate Change Science
Climate system and its key elements — Geosphere, cryosphere, hydrosphere, atmosphere and biosphere; Key concepts in climate science; Indicators of climate change (global and regional surface temperature, sea-level, ocean acidification, ice-sheets and glaciers, greenhouse gas concentrations, extreme events); Drivers of climate change; Observations.

Unit-2: The Earth's Changing Climate
Forcing: Natural - Variation in Earth's orbit; Variation in solar output; Climate change due to atmospheric constituents (volcanic eruptions, mineral dust); Anthropogenic - Increase in greenhouse gases, aerosols; Land use change.
Feedback mechanisms in the climate systems: Air-sea interactions, cloud-albedo, carbon cycle and accumulation of CO2 in the atmosphere; Description of various effects of atmospheric greenhouse gas accumulation in the climate system; Aerosols (direct, semi-direct, and indirect effects).
Millennium scale climate change and variability: Proxies and archives, reconstruction from tree rings, lake sediments and speleothems; Concept of Medieval Warming Period and the Little Ice Age, droughts and mega-droughts, PAGES2K temperature reconstructions (global).

Unit-3: Radiative Forcing and Budget
Concept of Radiative forcing (RF), natural (solar irradiance, volcanic) and anthropogenic (green house gases, ozone and stratospheric water vapor, aerosols and cloud effects, land surface change) RF; Time evolution of RF; Uncertainty associated with RF; Future RFs.

Unit-4: Climate Model Chain and Evaluations
Earth system models, atmospheric general circulation model, regional climate models and their characteristics; Techniques (evaluation, multi-model ensemble) of assessing climate models; Regional climate downscaling skills and added value; Climate sensitivity and climate feedbacks.

Unit-5: Global Climate Change Projections
Climate model ensembles and source of uncertainty from emission to projection, projected changes for next century (temperature and energy budget, water cycle, circulation, ocean, and cryosphere); Abrupt climate change.

Unit-6: Regional Climate Projections and Impacts
Regional meteorology; Regional climate model high-resolution climate validation and projection for India; Regional projection focus on monsoon - ENSO, atmospheric circulation; Agriculture, water resources, energy, health; Climate extremes (frequency, occurrence, and intensity), sea level rise, glaciers.

***Suggested Readings* :**

1. Dessler, A., 2012, Introduction to Modern Climate Change, Cambridge UniversityPress.
2. Ruddiman, W. F., 2001, Earth's Climate: Past and Future, W. H. Freeman & Co Ltd.
3. Pant, G. B., and Rupa Kumar, K., 1997, Climate of South Asia, Wiley.
4. McGuffie, K., and Henderson-Sellers, A., 2014, The Climate Modelling Primer (4 th Edition), Wiley.

EES 403 : Economic Geology (3)

***Prerequisites*:**All 100 and 200 level EES courses

***Learning Objectives*:**

This course deals with the fundamental principles of the genesis of ore minerals and discusses the classic examples of the world-class ore mineral deposits covering all the important metals. The objectives of this course are to familiarize the student with common terminologies in economic geology and mineral exploration, understand why and how minerals are concentrated in certain parts of the Earth. On completion of this course, students will be able to comprehend ore forming processes and would have developed skills in interpreting the genesis of ore deposits, besides obtaining insights into mineral economics.

***Course Contents*:**

Unit-1: Introduction
The importance of ores to our society; Ore and gangue, tenor and grade, ore bodies and lodes; Resources and reserves.

Unit-2: Processes of Formation of Economic Mineral Deposits
Endogenous Processes – Magmatic, contact metasomatism, skarn, greisen, pegmatitic and hydrothermal processes, metamorphic enrichment. Exogenous Processes – Sedimentation, chemical and bacterial precipitation, colloidal deposition and evaporation. Weathering Processes — Oxidation and supergene enrichment.

Unit-3: Metallic Ores
Oxides of Fe, Mn, Cr, W; Sulphides of Cu, Pb, Zn; Metallogenic provinces and epochs.

Unit-4: Ore Minerals:
Their texture and structure, development in open space and polycrystalline aggregates.

Unit-5: Field and Laboratory Studies of Ores
Remote sensing, sampling methods; Distribution, morphology and deposition of ore bodies; Physical characteristics; Optical characteristics; Ore microscopy; Experimental ore petrology; Fluid inclusions; Trace element and isotopic studies of ores. 2312

Unit-6: Ore Associations and Classical Examples

- Ores associated with ultramafic and related mafic plutions – Sudbury type Fe-Ni-Cu sulphides,apatite rich and Ti-V bearing magmatites, Fe-Ti oxides and anorthosites.
- Ores associated with felsic plutonic rocks – porphyry deposits of Cu-Mo, griesen and skarndeposits of W and Sn, pegmatite bodies.
- Ore association with acidic and mafic volcanic rocks, including those in greenstone belts – Kabaldatype, Kuroko type, and Cypruss type.
- Strata bound ore deposits associated with non-volcanic meta-sedimentary rocks – Bog iron and ironstone deposits, Banded Iron Formations (BIFs), laterite and karst deposits of Fe, Mn, Al and Ni,placer depostis of Au, Sn, W, oxidation and supergene enrichment, sulphide enrichment, ocean floordeposits of Mn-Ni-Cu-Co.
- Rare Earth deposits

Unit-7: National and International Mineral Economies
Environments of ore formation; Importance of minerals in national economy; Basic pattern ofmineral economy and changing mineral requirements; Strategic minerals and their supplies in time of peace and war; Problems related to the marketing of minerals; Developing substitutes to take care of shortages and production costs of minerals; Internal controls and trade restrictions; World resources and production of important minerals; Importance of steel fuels in modern economy; Impact of atomic energy over conventional fuels; Conservation of resources.

***Suggested Readings* :**

1. Evans, A. M., 2015, Ore Geology and Industrial Minerals –An Introduction (3 rdEdition), Blackwell Science.
2. Guilbert, J. M. and Park, Jr. C.F., 2007, The Geology of Ore Deposits, Waveland Press, Inc.
3. Stanton, R. L., 1972, Ore Petrology, McGraw Hill.
4. Mookherjee, A., 2000. Ore Genesis – A Holistic Approach, Allied Publishier.
5. Robb, L., 2004 Introduction to Ore-Forming Processes, Wiley – Blackwell.

6. Swakins, F. J., 1984, Metal Deposits in Relation to Plate Tectonics, Springer –Verlag.
7. Misra, K. C., 2000 Understanding Mineral Deposits, Springer – Netherlands.

EES 404 : Basin Analysis and Geology of Fuels (3)

***Prerequisites*:**All EES 100 and 200 level courses, credited or registered in EES 307

***Learning Objectives*:**

Mineral and fossil fuels constitute an essential resource for energy production. This course endeavors to introduce students to various aspects of these resources such as the nature, distribution, occurrence, genesis, and the reserves in India. In the case of petroleum, the aspects covering reservoir rocks, migration, trapping mechanisms and plate tectonic associations will be discussed. Additionally, non-conventional hydrocarbons such as gas hydrates and their potential will be introduced. In coal geology some aspects of organic petrology will be covered. Further the potential for coal-bed methane will also be discussed. Lastly, the methods of exploration for atomic minerals will be introduced here.

***Course Contents*:**

Unit-1: Facies Models for Sedimentary Environments and Sequence Stratigraphy

Unit-2: Petroleum Geology
Petroleum - Its different states of natural occurrence, chemical composition and physical properties of crude in nature, origin of petroleum, maturation of kerogen; Biogenic and thermal effect; Reservoir rocks - General attributes and petrophysical properties; Classification of reservoir rocks - fragmental reservoir rocks and chemical reservoir rocks; Concept of flow unit; Migration of oil and gas - Geologic framework of migration, short and long distance migration, primary and secondary migration; Geologic factors controlling hydrocarbon migration, forces responsible for migration, migration routes and barriers; Hydrocarbon traps - Definition, anticlinal theory and trap theory, classification of hydrocarbon traps, time of trap formation and time of hydrocarbon accumulation; Cap rocks — definition and general properties; Formation water characteristics as oil exploration leads; Plate tectonics and global distribution of hydrocarbon reserves; Classification of Indian basins and petroleum geology of Assam, Bengal, Cauvery, Krishna-Godavari, Cambay and Bombay offshore basins; Natural gas hydrates and its potentialities.

Unit-3: Coal Geology
Coal and its properties - Different varieties and ranks of coal; Origin of coal; Types of depositional processes; Coalification processes and its causes; Sediments closely associated with coal (coal balls, tonsteins, seat-earths, under-clays, fire-clays and soils); Lithotypes, microlithotypes and macerals, Maceral analysis of coal; Mineral and organic matter in coal; Application of coal geology in hydrocarbon exploration; Coal-bed methane - Maturation of methane in coals, coal as a reservoir, fundamentals of coal bed methane exploration and production; Methods of coal prospecting and estimation of coal reserves; Application of coal petrography, proximate and ultimate analyses, industrial evaluation of coal characteristics with reference to coal classification; Geology and coal petrography of different coalfields and lignite fields of India; Uses of coal for various industries e.g. carbonization, liquefaction, power generation, gasification and coal-bed methane production.

Unit-4: Nuclear Geology
Radioactivity and radioactive decay, growth and decay mechanisms (α β γ decay), decay units and dosage, neutron activation; Mineralogy of U and Th bearing economic minerals, geochemistry of U-Th and their distribution in ore bodies through geologic time; U and Thmetallogenic provinces of India; Detectors of radioactivity - Geiger, proportional and scintillation counters and spectrometers.

***Suggested Readings* :**

1. Selley, R. C., and Sonnenberg, S. A., 2014, Elements of Petroleum Geology (3 rdEdition), Academic Press.

2. Chilinger, G. V., Buryakovsky, L. A., Eremenko, N. A., and Gorfunkel, M. V., 2005,Developments in Petroleum Science-Geology and Geochemistry of Oil and Gas (Volume 52), Elsevier Science.
3. North, F. K., 1985, Petroleum Geology, Springer Netherlands.
4. Chandra, D., Singh, R. M., and Singh, M. P., 2000, Textbook of Coal (IndianContext), Tara Book Agency.
5. Singh, M. P., 1998, Coal and organic Petrology, Hindustan Publishing Corporation.
6. Aswathnarayana, U., 1985, Principles of Nuclear Geology, Routledge.
7. Dahlkamp, F. J., 1993, Uranium Ore Deposits, Springe-Verlag.

EES 405 : Evolution of the Indian Plate (4)

***Prerequisites*:**Credited or registered in All EES 300 and 400 level courses

***Learning Objectives*:**

This course offers a synthesis of the developmental history of the Indian plate through the Precambrian (~3.5 b.y. to 540 m.y.) and the Phanerozoic (540 m.y. to recent). An overview of the major geological provinces of the Indian plate and their geodynamic contexts in termsof cratonization, rifting, volcanism, and collision orogenesis is presented. Finally, the evolutionary trajectory of the Indian continent is traced from the initial formation of continental nucleii in the Archaean to its present state, as manifested in the geology and morpho-tectonics of the Indian plate.

***Course Contents*:**

Unit-1: Introduction
Physiography of the Indian subcontinent; Geological terrains of the Indian continent.

Unit-2: Precambrian
Archaean cratons - Bastar, Singhbhum, Dharwar, Aravalli; Proterozoic mobile belts, Purana basins of Peninsular India (Vindhyan, Cuddapah)

Unit-3: Phanerozoic
Gondwanaland and the Late Palaeozoic — Basinal stratigraphy, tectonics and sedimentation,Mesozoic basins of India; Jurassic-Cretaceous volcanism - Rajmahal and Deccan volcanic provinces, Cenozoic basins of India, Collision orogenesis and the evolution of Himalaya

***Suggested Readings* :**

1. Valdiya, K. S., 2010, The making of India – Geodynamic evolution (2 nd Edition), Springer.
2. Ramakrishana, M., and Vaidyanadhan, R., 2008, Geology of India, Geological Society of India.

EES 406 : Geohydrology (4)

***Prerequisites*:**All 100 level CHM, EES and PHY courses.

***Learning Objectives*:**

The emphasis of the course will be on groundwater, although some aspects of surface waterhydrology will also be addressed. It will cover the basic empirical knowledge of the occurrence and movement of groundwater, focusing on some of the quantitative aspects as well as on groundwater chemistry. Students will also learn what affects wells have on the steady-state system. They will know how to apply pumping-test data to determine aquifer properties and will obtain a basic understanding of the chemical constituents in groundwater and surface waters. In addition, students will acquire knowledge of the behavior of various pollutants in groundwater systems.

***Course Contents*:**

Unit-1: Introduction:
The water cycle, budgets; water properties, atmospheric water and precipitation; Interception, evaporation and transpiration; Soil moisture and infiltration; Groundwater; Snowhydrology, water balance; Runoff and hydrographs; Flooding; Basins, hill slopes, and erosion; Rivers and streams –hydraulics, sediments, geometries; hydrology and climate; Surface-groundwater interactions.

Unit-2: Properties of Aquifers:
Porosity and specific yield; Darcy's law; Hydraulic conductivity; Water-table; Types of aquifers, Groundwater maps; Transmissivity, storativity; Principles of groundwater flow; Hydraulic head; Velocity; Groundwater flow equations; Flow nets; Refraction of flow lines; Computer aided drafting of flow nets: Demonstration of FLOWNET; Calculation of steady state flow in confined and unconfined aquifers; The vadose zone; Groundwater recharge; Regional groundwater flow; Principles of salt- water intrusion.

Unit-3: Groundwater Occurrences
Groundwater regions of India; Occurrence of groundwater in igneous, sedimentary and metamorphic terrains as well as unconsolidated sediments; Methods of well construction, well casing and screens; Development and disinfection of wells.

Unit-4: Groundwater Flow to Wells
Drawdown, cone of depression; Estimation of drawdown in pumped confined aquifers and pumped leaky (semiconfined) aquifers; Drawdown in unconfined aquifers; Determining aquifer parameters from pump-test data, Steady-state and transient conditions, confined aquifers; Time-drawdown methods - Theis method; Jacob time-drawdown straight line method; Jacob distance-drawdown straight line method; AQTESOLV and other computer programs; Slug Tests; Well efficiency; Well specific capacity; Estimating aquifer transmissivity from specific capacity data; Effects of well interference and aquifer boundaries; Estimation of distance to a hidden source of recharge.

Unit-5: Water Chemistry
Water sampling; Aqueous chemistry of ionic compounds (minerals) major, minor and trace constituents; Methods of analyses of above ions in water sample; Groundwater and carbonate rocks; Specific conductance as a measure of concentration; Eh-pH controls; Cation exchange; Methods of chemical data presentation; Introduction to water quality; Chemical composition of natural waters; Atmospheric precipitation; Groundwater; River waters; Lakes and reservoirs; Sea-water; Sources of groundwater contamination; Water quality standards for drinking, agricultural and industrial purposes; Ground water monitoring; Plotting chemical data using a computer; Transport of pollutants in ground water; Advection and dispersion; Sorption and diffusive mass transfer; Aquifer remediation; Groundwater restoration.

Unit-6: Managing Water Resources:
Reservoirs, desalination, controlling demand and waste, protecting the environment, hydropolitics; Integrated water resources management, system analysis in water resources management, case studies - Ganges-Brahmaputra Delta, Godavari, Krishna, Cauvery rivers.

***Suggested Readings* :**

1. Freeze, A. R., and Cherry, J. A., 1979, Groundwater, Prentice Hall.
2. Walton, W. C., 1970, Groundwater Resource Evaluation, McGraw-Hill.
3. Karanth, K. R., 2014,Groundwater Assessment Development and Management,McGraw-Hill.
4. Subramanya, K., 1994, Engineering Hydrology, McGraw-Hill.
5. Todd, D. K., and Mays, L. W., 2004, Groundwater Hydrology (3 rd Edition), Wiley.

EES 407 : Remote Sensing and GIS (4)

***Prerequisites*:** All EES 300 level courses

***Learning Objectives*:**

Satellite remote sensing is a powerful tool to acquire information about the surface of any object. Thus, the information obtained through satellite imagery can be used for geological mapping, monitoring of natural resources and climate and weather prediction. In this course, the theory of electromagnetic radiation, principles of spectroscopy, data acquisition systems will be discussed in details. Emphasis will be given on the different image processing techniques and preparation of digital maps from the satellite data.

Course Contents:

Unit-1: Introduction
Structure of the course, development of remote sensing techniques, fundamental principles, advantage and limitations of remote sensing.

Unit-2: Electromagnetic Radiation
The nature, principle and sources of electromagnetic radiation, the blackbody radiation, the electromagnetic spectrum, energy available for remote sensing, atmospheric window for remote sensing.

Unit-3: High Altitude Photography
Interaction between light and matter, color science, film technology; Aerial photography - vertical and oblique photography.

Unit-4: Spectroscopy of Rocks and Minerals Introduction, basic principles of spectroscopy, electronic process and vibrational processes, spectral reflectance of minerals.

Unit-5: Multispectral Digital Imaging System
Introduction to digital images, imaging sensors and tubes, optical mechanical line scanner, CCD linear array scanner, digital camera, description of space borne image sensors.

Unit-6: Thermal Remote Sensing
The Earth`s radiant energy, surface, radiant temperature and kinetic temperature, Planck'slaw and emissivity, interpretation of thermal imagery.

Unit-7: Microwave Remote Sensing
Introduction to microwave, passive and active microwave remote sensing, RADAR technology, interferometry.

Unit-8: Remote Sensing based on Gravity
Gravity of Earth and other planetary bodies, GRACE mission; Space borne gravity data for hydrology, geodesy and solid Earth science.

Unit-9: Distortion and Quality of Photographs and Images
Geometric distortion, distortions related to a) sensors, b) spacecraft, c) Earth's rotation;Factors affecting image quality; Projection, mosaic resampling of satellite images.

Unit-10: Digital Image Processing of Satellite Images
Introduction to digital image processing, radiometric and geometric corrections; Principle component analysis, band ratio and colour enhancement of images.

Unit-11: Geological Application of Remote Sensing Data
Digital image processing and satellite imagery for geomorphology, tectonics, coastal and deltaic landforms, monitoring vegetation patterns and desertification, lithology and geological mapping, mineral and oil exploration.

Unit-12: Environmental Application of Remote Sensing Data
Detailed description of SPOT and JERS images; Geobotany, geohydrology and water quality using remote sensing data; Remote sensing of the atmosphere.

Unit-13: Integration of Remote Sensing Data with other Geo-data
Introduction to GIS, transformation of remote sensing data and other data in GIS format.

Unit-14: Indian Remote Sensing Program
Remote sensing program by Indian Space Research Organization; INSAT, IRS, Oceansat,Resourcesat and Cartosat data and their applications; Future directions.

Suggested Readings **:**

1. Sabins, F. F., 2007, Remote Sensing: Principles and Interpretation (3 rd Edition), Waveland Press.
2. Rencz, A. N., 1999, Remote Sensing for the Earth Sciences: Manual of RemoteSensing (3 rd Edition), Wiley.
3. Gupta, R. P., 2013, Remote Sensing Geology (2 nd Edition), Springer-Verlag.
4. Jenson, J., 2007, Remote Sensing of the Environment: An Earth ResourcePerspective (2 nd Edition), Prentice Hall.

EES 408 : Sustainability Informatics (SI) (4)

Learning Objectives**:**

Sustainability informatics is an inter-disciplinary research field focused on the role of computer and information sciences in enabling human society to thrive for the long term on planet earth.At the completion of this course, student understand areas of ICT applications towards sustainable development. Student will be able to independently use various ICT tools, information bases to arrive at the realistic assessment and futuristic planning for a given ecosystem, ensuring that the principles and objectives of sustainable development are achieved.

Course Contents**:**

Unit-1: Sustainability Informatics (SI): Introduction, Definition, scope and importance, andtrans- disciplinary nature of SI.

Unit-2: ICT and Sustainable Development Goals (SDGs).

Unit-3: Theory and Practices in Informatics for biology (biotechnology, ecology, biodiversity), geosciences, chemistry, environment, meteorology, and climate sciences.

Unit-4: Roles of statistics and data analysis, classification & presentation of statistical data

Unit-5: Modeling concepts and Estimation and hypothesis testing on means and otherstatistics

Unit-6: Regression, Time Series, Spatial statistics, multivariate analysis and Map analysis

Suggested Readings **:**

1. Link
2. Environmental Informatics for Sustainable Development, at Link
3. Sustainability development practices using GeoInformatics (2020) at Link

EES 410 : (Lab) Geohydrology
(with EES406)

Prerequisites**:**credited or registered in EES 406

Course Contents**:**

Preparation and interpretation of water level contour maps, hydrographs. Chemical quality data and water classification. Numerical problems related to: permeability, groundwater flow and well hydraulics.

EES 411 : (Lab)-Paleontology (1)

***Prerequisites*:**credited or registered in ESS 401

***Course Contents*:**

Study of fossils showing various modes of preservation
Study of diagnostic morphological characters, systematic position, stratigraphic position and age of various invertebrate, vertebrate and plant fossils

EES 412 : Practices in Sustainability Informatics (Lab) (2)

***Learning Objectives:*:**Expansion of EES 408

***Course Contents*:**

Expansion of EES 408

Exercises & Examples, review & pilot project development in Integrated Assessment Modeling, BigData, Databases, Metadata: Standards, Quality, Tools and applications, Metadata, Data Quality & Data Control, Fitness-for-use, publishing, discovery, ease of using, e-BPR, Statistical and analysis tools for Earth, environment & sustainability scientists & practitioners

EES 413 : (Lab)-Economic Geology (1)

***Prerequisites*:**credited or registered in ESS 403

***Course Contents*:**

Hand specimen study of important ores
Study of optical properties of ore minerals.

EES 414 :Atmospheric Sciences (3)

***Prerequisites*:** MTH, PHY and CHM 100 level courses and EES 100 and 200 level courses

***Learning Objectives*:**

This course is designed as a first level course for undergraduate students; upon the completion of this course, the student will be able to understand the evolution of the Earth's atmosphere, tools to observe it, and its properties. Additionally the students will learn to formulate and apply equations to solve problems on atmospheric dynamics, radiation and thermodynamics. Finally the sub-disciplines of atmospheric science and their inter-relationships will be discussed.

***Course Contents*:**

Unit-1: Introduction
Significance of studying atmospheric sciences in the regional and global contexts, prediction of weather and climate change, identification and remediation of environmental threats; Recent trends and emerging frontiers.

Unit-2: Earth's Atmosphere
Sun and its origin, evolution of the Earth and its atmosphere - elements and compounds, spectrum of radiation of the sun and Earth, Sun Earth relationships - seasons, heat budget, latitudinal heat budget.

Unit-3: Atmospheric Observations
Overview of meteorological observations, measurement of temperature, humidity, pressure, wind and precipitation, high altitude observations, weather RADAR and satellites, vertical structure and composition of the atmosphere.

Unit-4: Atmospheric Motion
Wind systems and the atmosphere, forces that drive the winds - pressure gradient; Coriolis, centrifugal, friction, scales of atmospheric motion; Global circulation of single cell and three cell models - observed distribution of pressure and winds, monsoons, westerlies and waves in the westerlies.

Unit-5: Atmospheric Radiation
Quantitative description of radiation, blackbody radiation, Planck's function, local thermodynamic equilibrium, budget of solar radiation, terrestrial radiation, absorption and emission by atmospheric gases, scattering by air molecules and particles, absorption by particles, Beer-Lambert's law, radiative energy balance, simplified models of the greenhouse effect.

Unit-6: Atmospheric Thermodynamics
Basic definitions, gas laws, hydrostatic balance; First law of thermodynamics, moisture in the atmosphere, measure and description of moist air, isobaric cooling, adiabatic and pseudo adiabatic processes, hydrodynamic stability - air parcel and slice methods, vertical mixing, vertical stability in the atmosphere, stability analysis and conditions, Second law of thermodynamics, Carnot cycle and ClausiusClapeyron equation.

Unit-7: Atmospheric Chemistry
Chemical structure, reactivity, and lifetime of chemicals; Overview of tropospheric and stratospheric chemistry - Ozone depletion.

Suggested Readings **:**

1. Wallace, J. M., and Hobbs, P. V., 2006, Atmospheric Science: An introductorySurvey, Academic Press.
2. Ahrens, C. D., 2015, Essentials of Meteorology: An Invitation to the Atmosphere, Stamford Brooks/Cole Cengage Learning.
3. Frederic, J., 2008, Principles of Atmospheric Science, Jones and Bartlett Publishers.
4. Seinfeld, J., and Pandis, S N., 2006, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change (2 nd Edition), Wiley-Interscience.

EES 415 :RS-GIS &Geoinformatics Laboratory (4)

Prerequisites**:** Credited or registered in EES 407

Learning Objectives**:**

The course aims to understand the basic theory and applications of RS-GIS software and sets of appropriately designed exercises.

Course Contents**:**

Practical exposure to RS-GIS software
Model case studies of different geological, geomorphological and environmental problems with the help of RS-GIS

Suggested Readings **:**

1. Same as EES 407

EES 416 :Aerosol Science (3)

Prerequisites**:** MTH and PHY 100 level courses, CHM and EES 100 and 200 level courses

Learning Objectives**:**

This course is a first course in aerosol science for senior undergraduates and graduate students. Upon the completion of this course the students will be able to understand the importance of aerosols in the atmosphere, terminology used in aerosol science,fundamentals of the dynamics and mechanics of aerosols, size distributions, particle deposition and adhesion, and the theoretical basis for aerosol sampling and collection on tofilter substrates.

***Course Contents*:**

Unit-1:Introduction and Aerosol Characterization
Definitions and terminology, parameters for determining particle behavior, particle size, shape and density, aerosol concentrations, number, size, and mass distribution functions (moment distributions), log-probability graphs, Hatch-Choate conversion equations, statistical accuracy.

Unit-2:Uniform Particle Motion
Newton and Stokes laws, settling velocity, mechanical mobility, slip correction factor, equivalent diameters, settling at high Reynolds numbers, stirred settling, and instruments based on settling velocity.

Unit-3: Straight Line Acceleration and Curvilinear Motion
Relaxation time, stopping distance, curvilinear motion, impaction, cascade and virtual impactors, time- of-flight instruments.

Unit-4: Diffusion, Thermal and Radiometric Forces
Diffusion coefficients, Brownian displacement, diffusion/diffusion batteries, thermophoresis, thermophoretic precipitators, radiometric forces.

Unit-5: Coagulation, Condensation, and Evaporation
Monodisperse coagulation, polydisperse coagulation, kinematic coagulation, homogenous nucleation, Kelvin effect; Condensational growth – growth laws, transported limited growth, aerosol phase, reaction-limited growth, heterogeneous condensation, nucleated condensation evaporation.

Unit-6:Experimental Methods for Aerosol Sampling and Characterization
Microscopy; Condensation particle counters; Filtration – single fiber efficiency, deposition mechanisms, filter efficiency, pressure drop, membrane filters; Optical measurement instruments- definitions, extinction, scattering, visibility - nephelometers, transmissometers; Electrical properties based instruments – electric fields, mobility, charging mechanisms, corona discharge, charge limits, electrostatic precipitators, differential mobility analyzer.

Unit-7: Atmospheric Aerosols
Biogenic and anthropogenic aerosols, general features of ambient aerosol size distributions background aerosol, urban aerosol, chemical composition of urban aerosols.

***Suggested Readings* :**

1. Hinds, W. C., 1999, Aerosol Technology: Properties, Behavior, and Measurement ofAirborne Particles, John Wiley and Sons.
2. Friedlander, S. K., 2000, Smoke, Dust, and Haze: Fundamentals of Aerosol Dynamics, Oxford University Press.
3. Seinfeld, J. H., and Pandis, S. N., 2006, Atmospheric Chemistry and Physics: FromAir Pollution to Climate Change, Wiley-Interscience.

EES 418 :Indian Monsoon and Its Variability (3)

***Prerequisites*:** EES 305, ESS 404, EES 410

***Learning Objectives*:**

This course is designed for UG/PG students to provide a comprehensive knowledge of the Indian monsoon and its variability on different spatial and temporal time scales. The physics and dynamics of the monsoon variability involve a basic understanding of air-sea interaction, and their teleconnection with oscillations such as the El Nino-Southern Oscillation (ENSO).

An in depth exploration of the background, the present understanding about nature of the system responsible for the monsoon mechanism, which leads to its variability, will be elucidated. Skill of the state of art models in simulating and predicting the variability of the monsoon will be assessed, and problems and prospects of improvement of predictions will be considered. In addition, the impact of the Indian monsoon on agriculture and the economy will be discussed.

***Course Contents*:**

Unit-1: Introduction to Monsoon
Indian summer and winter monsoon, nature of winter and summer monsoon variability, present understanding of the underlying mechanisms; Interannual variability, onset over Kerala and advances, active and break spells; Convection and rainfall in the tropics - Organization over different spatial scales, conditional instability of the first and second kind; Variation of temperature, pressure and density with height in the atmosphere; Relationship between wind and pressure in rotating systems.

Unit-2: Basic System Responsible for the Monsoon
Fundamental processes in seasonal cycle; Gigantic land-sea breeze, different hypotheses for the basic system responsible for the summer monsoon; Inter Tropical Convergence Zones (ITCZs) and the Indian monsoons; Role and characteristic behavior of ITCZ during summer and winter monsoon.

Unit-3: Variation of Convection/Rainfall over the Ocean
Air-sea interaction; SST-rainfall relationship; Heat lows; ITCZ and monsoonal regions of the world; Seasonal transitions (onset and retreat) - spring to summer, advance and retreat on summer monsoon; Summer to winter transitions.

Unit-4: Intraseasonal Variation and Intraseasonal Oscillation
Active-weak spells and breaks in the monsoon.

Unit-5: El Nino and Southern Oscillation
Walker circulation, Hadley cell, Southern Oscillation index and its variability, Bjerknes theory and feedbacks; Definition of Nino regions, teleconnections, understating El-Nino, what causes El Nino and its underlying mechanism? Impact of the Asian Monsoon on ENSO.

Unit-6: Indian Ocean and the Indian Monsoon
Role of SST on monsoon; Indian Ocean Dipole (IOD) mode variability and association with winter and summer monsoon.

Unit-7: Interannual Variation of the Indian Summer Monsoon Rainfall
Links to events over the Indian and Pacific Ocean; Land surface processes; Circulation; IOD and ENSO link.

Unit-8: Monsoon Variability, Agriculture and Economy
Effect of monsoon rainfall variability (droughts and floods) on agriculture production; Relationship between variation of rice production and variation of rainfall; Agricultureproduction link to Gross Domestic Product.

Unit-9: Monsoon Prediction: Problems and Prospects
Short, medium and long-range monsoon prediction using statistical approach; Coupled model prediction of monsoon and their skills, and limitations in monsoon forecasting.

***Suggested Readings* :**

1. Fein, J. S., and Stephens, P. L., 1987, Monsoons, Wiley.
2. Hastenrath, S., 1991, Climate Dynamics of the Tropics, Kluwer Academic Publishers.
3. Wang, B., 2006, Asian Monsoon, Springer Praxis.
4. Asnani, G. C., 1993, Tropical Meteorology (3 Vol. set), Asnani Publishers.
5. Pant, G. B., and Rupa Kumar, K., 1997, Climate of South Asia, Wiley.Rao, Y. P., 1976, Southwest Monsoon. Meteorological Monograph (synoptic meteorology). No.1, India Meteorological Department, New Delhi.

6. Asanani, G. C., De, U. S., Hatwar, H. R., and Mazumdar, A. B., 2011, Monsoon Monograph (vol 1) India Meteorological Department, Ministry of Earth Sciences Govt.of India.

EES 420 :Mineral Exploration (3)

***Prerequisites*:** credited or registered in EES 320, EES 403

***Learning Objectives*:**

The objective of this course is to introduce students to mineral Exploration and mining principles. The course will include basic principles of geophysical and geochemical methods of mineral exploration, ore reserve estimation.

***Course Contents*:**

Unit-1: Introduction:
Introduction: Classification of mineral deposits for prospecting. Mineral deposits and their possible host rocks, geological prospecting, Stages of exploration: RP, LAP, PI, ML, Diamond drilling, bore hole survey, logging. Pitting, Trenching, Channel, Chip, drill core, bulk/ Muck/ Grab/ Car /Stack sampling, sample reduction, accuracy.

Unit-2: Geochemical Prospecting:
Geochemical Prospecting: Pedogeochemical Prospecting, Lithogeochemical Prospecting, Hydrogeochemical Prospecting, Biogeochemical Prospecting, Geobotanical Prospecting, Atmogeochemical Prospecting.

Unit-3: Geophysical prospecting:
Magnetic method, Gravimetric method, Geo-electrical method, Seismic method, Electromagnetic method, Radioactive method, Telluric and Magnetotelluric method. Reserves and reserve estimation of mineral deposit, UNFC classification Ore beneficiation, General techniques of ore beneficiation, beneficiation of sulfide ores Pb-Zn and Cu and Iron ores.

***Suggested Readings* :**

1. Haldar, S.K., 2013. Mineral Exploration – Principles and Applications. ElsevierPublication.
2. Clark, G.B. (1967). Elements of Mining. 3rd Ed. John Wiley and Sons.
3. Arogyaswami, R.P.N. (1996). Courses in Mining Geology. 4th Ed. Oxford-IBH.
4. Moon, C.J., Whateley, M.K.G. and Evans, A.M. (2006). Introduction to Mineral Exploration,Blackwell Publishing.

EES 422 : Statistics & Analytics for Earth, Environmental Sciences and Sustainable Development Sciences (3)

***Learning Objectives*:**

Statistical analysis is essential to the fields of earth, environment and sustainability science. It allows students, researchers and practitioners to gain understanding of issues through data intestine researching and developing potential solutions. The applications of statistical methods in these areas are numerous and varied. This course aims to equip students with these methods and the state of the art tools.

***Course Contents*:**

Unit-1:
Roles of statistics and data analysis, classification & presentation of statistical data.

Unit-2:
Modeling concepts and Estimation and hypothesis testing on means and other statistics.

Unit-3:
Regression, Time Series, Spatial statistics, multivariate analysis and Map analysis.

Unit-4:
Discrete data analysis and point processes.

Unit-5:
Design of experiments and directional data.

Unit-6:
Data visualisation, summary statistics, correlation, selection parametric statistics (t-tests, general linear models), selected non parametric methods, and statistical influence.

Unit-7:
Statistical and analysis tools for earth, environment & sustainability scientists & practitioners.

Suggested Readings **:**

1. Scheunemeyer and Drew (2011) Statistics for earth and environmental scientists. AJohn Wiley & Sons Inc Publications.
2. Abbas F.M. Alkarkhi, Wasin A.A. Alqaraghuli, in Applied Statistics for Environmental Science with R, 2020.
3. Schabenberger, O. and Gotway, C. (2005) Statistical Methods for Spatial DataAnalysis Chapman & Hall/CRC.
4. Peter J. Diggle, Paulo J. Ribeiro, Jr (2007) Model-based geostatistics, Springer. Cressie, N. (1993). Statistics for Spatial Data (Revised Ed.). John Wiley & Sons, Inc.
5. Chiles, J. P. and Delfiner, P. (1999) Geostatistics: Modeling Spatial Uncertainty. Wiley. Davis, J.C., Statistics and Data Analysis in Geology, 3rd Edition, John Wiley& amp; Sons, Inc.

EES 424: Isotope Geochemistry (3)

Prerequisites (Desirable): *credited or registered in EES 303, EES 307, EES 302, EES 306*

Learning Objectives:

Isotope geochemistry is a powerful tool to explore a number of earth surface processes in both modern and ancient earth and environmental systems. Recycling of various elements in the Earth's upper crust, hydrosphere and atmosphere through various biogeochemical processes alters their physical states; however their isotope compositions still retain clues on their source signatures and quantitative information on these cycling processes. Under closed system conditions, radiogenic isotopes additionally act as time clocks. This course enables students to understand the evolutionary trajectories of various physical, chemical, biological processes in Earth systems.

Course Contents:

1. Isotopes and Radioactivity:
2. Basics of atomic and nuclear physics; Synthesis, relative abundances and stability of various nuclides; Radioactivity, radioactive decay modes; Radiation detection and environmental protection.
3. Instrumentation:
4. Alpha, beta, gamma counters; Mass spectrometers; Methods of internal spike addition, isotope dilution and standard sample bracketing; Isotope fractionation correction by single/double normalization and double/triple isotope spiking.
5. Isotope Dating:
6. Growth and decay of radiogenic daughters; Basic assumptions of dating; Isochron dating, and related analytical uncertainties and geological errors; Dating using radioactive parent only (10Be, 14C and 36Cl), parent–daughter couple (40K–40Ar, 87Rb–87Sr, 147Sm–143Nd, 176Lu–176Hf, 187Re–187Os, 238U–206Pb), decay series disequilibria (238U–234U–230Th–236Ra), radiogenic daughter only (Pb–Pb and Ar–Ar) and extinct parent (26Al, 41Ca, 53Mn,

60Fe, 107Pd, 129I, 146Sm, 182Hf); Ages of crystallization and last metamorphism; Sediment depositional ages; Model ages; Exposure ages; Archaeological ages.

7. Radiogenic Isotope Geochemistry:
8. Compatibility; Crust–mantle differentiation; Crustal evolution; Crust recycling in subduction zones; Pb-paradox; Chemical weathering versus physical erosion; Mixing theory; Sediment provenance; Zircon effect; Ocean circulation; Strantium isotope chronostratigraphy.
9. Stable Isotope Geochemistry:
10. Mass dependent and independent isotope fractionations; Use of traditional and non-traditional stable isotopes in exploration of Earth's climate, hydrology, oceanography, and other biogeochemical processes, Evolution of atmospheric gases.
11. Noble Gas Geochemistry:
12. Production and abundance; Isotope composition and behavior of noble gases; Noble gas–water interactions; Cycling in continental and oceanic crusts; Applications in oceanography and terrestrial rocks.

Suggested Readings :

1. Allègre, C. J., 2005, Isotope Geology, Cambridge University Press.
2. Faure, G., and Mensing, T. M., 2004, Isotopes – Principles and Applications, Wiley.
3. White, W. M., 2015, Isotope Geochemistry, Wiley-Blackwell.
4. Holland, H. D., and Turekian, K. K., 2011, Treatise or Geochemistry (2nd Edition), Elsevier Science.
5. Zeebe, R. E., and Wolf-Gladrow, D., 2001, CO2 in Seawater: Equilibrium, Kinetics and Isotopes (1st Edition), Elsevier Science.
6. Hoefs, J., 2015, Stable Isotope Geochemistry (7th Edition), Springer.

EES 426: Marine Biogeochemical Cycles (3)

Prerequisites (Desirable): *credited or registered in EES 306, EES 308*

***Learning Objectives*:**

The growing interest of our scientific community to explore the contemporary and past oceans using geochemical and isotope data of marine samples requires a comprehensive understanding of various elemental sources to, and sinks within the oceans, and elemental behavior during particle–seawater interactions. The designed course contents enable students to trace various natural marine biogeochemical processes, environmental factors, and human perturbations on the cycling of various elements.

***Course Contents*:**

Oceanic Influxes:

Riverine/eolian transfer of continental materials, submarine ground water discharge and hydrothermal/cosmic supply; Invasion of atmospheric gases; Boundary exchange; Modification of riverine flux of non-conservative elements in estuaries; Chemistry of marine aerosols; Particle dissolution at air–sea interface; Benthic fluxes; Low/high temperature particle–seawater interactions; Relative magnitudes of various influxes.

Internal Cycling:

Oceanic residence times of dissolved constituents, their physical transport through water advection, isopycnal/diapynal mixing, reversible scavenging; Two box model; Bulk saturation state of seawater; mineral precipitation in microenvironments; Carbon partitioning in biological, carbonate and solubility pump; Organic matter remineralization, and associated consumption/production of dissolved gases and authigenic minerals.

Oceanic Outfluxes:

Outgassing at air–sea interface; Biotic/abiotic precipitation of different minerals, their growth rates, spatial distributions and removal from water column via particle scavenging; Diagenesis at sediment–seawater interface; Overall oceanic budgets of major nutrients (C, N, P and Si) and key trace elements.

Human Perturbations and Past Variations in Global Biogeochemical Cycles:

Coastal eutrophication and hypoxia; Ocean acidification; Sea level rise; Geochemical and isotope records of various marine and terrestrial archives; Reconstructions of past pCO_2 levels, marine productivity, oxygenation, temperature, and oceanic/atmospheric circulation.

***Suggested Readings* :**

1. The Open University, 2005, Marine Biogeochemical Cycles, 2nd edition, Elsevier Butterworth-Heinemann Ltd.
2. Libes, S., 2009, Introduction to Marine Biogeochemistry (2nd edition), Elsevier Academic Press.
3. Emerson, S., and Hedges, J., 2008, Chemical Oceanography and the Marine Carbon Cycle (1st Edition), Cambridge University Press.
4. Zeebe, R. E., and Wolf-Gladrow, D., 2001, CO_2 in Seawater: Equilibrium, Kinetics and Isotopes (1st Edition), Elsevier Science.
5. Turekian K. K., Holland, H. D., and Elderfield, H., 2003, The Oceans and Marine Geochemistry: Treatise on Geochemistry (1st Edition), Pergamon.

EES 427: Conservation of Nature & Natural Resources (3)

Learning Objectives:

This course is aimed at revising the students knowledge about biodiversity, ecosystems, roles of ecosystem services and conservation of nature, especially biotic ecosystem. On completion of the course, the student should be well prepared to work with nature conservation. Student will be able to (a) discuss fundamental values for the preservation of biological diversity, (b) account for different forms of human influence on natural ecosystems, (c) combine physical planning with nature conservation, (d) justify instructions given in management plans and their equivalents, etc.

Course Content

1. Understanding of ecology, ecosystem, trophic chain, ecosystem balance & sustainability
2. Natural resilience: definition, factors of influence, mitigation methods and processes
3. Natural Resources Accounting: Definition, Concept, Practices, Methods and Standards
4. The human influence on the landscape, including social and ethical considerations associated with nature-preserving actions
5. Biodiversity and characterisation of different habitat types according to Natura 2000 and other standards
6. Identification and rectifying of decreased biological diversity and other damages to terrestrial and aquatic ecosystems
7. Practical measures of nature conservation: Local, National, Global
8. Evidence-based nature conservation
9. Basic exercises in GIS and applications in nature conservation.
10. Survey, Assessment, Analysis, Ecological modelling & Forecasting etc.
11. This course requires for students to be in field for a minimal period of 20 hrs (3 working days) e.g.marine & coastal ecosystem, land based ecosystems etc.

Suggested Readings:

1. Hart, Adam (University of Gloucestershire). Applied ecology - monitoring, managing and conserving. Oxford University Press, 2017.
2. Sutherland (2019) Nature Conservation Handbook. Blackwell Publishing.

3. Scott et al. (2020) Shepherding Nature: The Challenge of Conservation Reliance. Cambridge University Press.

EES 428: Environmental Impact Assessment & Environmental Planning (3)

Learning Objectives:

This subject prepares students for environmental management role by imparting with them the principles of human impact on environment can be assessed. The principles will be placed with the legal and social contexts of EIA and environmental planning. At the completion of the course students are, (a) understand nuts-n-bolts of EIA processes, (b) able to critique effectively documents related to an EIA, (c) apply knowledge in better environmental planning.

Course Content

1. Introduction, Definition, scope and importance, multi-disciplinary nature of EIA and environmental planning.
2. Overview & review of the EIAs in India vis-a-vis Global scenario, Global guidelines and norms for EIA & its uptake in India.
3. MoEF notification and guidelines for EIA, National Environmental Policy 2006.
4. Scoping exercise for EIA
5. EIA Process and Procedures
6. Issues with regards to EIA clearance including forest & marine clearances
7. Risk analysis for EIA
8. Environmental Management Plan (Environmental Planning)
9. Verification of EIA by environmental audits
10. Environmental clearance processes
11. R&R issues (social and technical), social impacts assessment (SIA)
12. Case studies, Group discussions, and prototype EIA development
13. International Association for Impact Assessment (IAIA)

Suggested Readings:

1. Environmental Impact Assessment, Canter Larry W.,McGraw-Hilleducation Edi (1996)
2. Environmental Impact Assessment Methodologies, by Y.Anjaneyulu, B.S. Publication, Sultan Bazar, Hyderabad.
3. Environmental planning and sustainable development by Vara Saritha and Manoj Kumar Karnena, Orange Books Publications (2021).

EES 429: Earth Surface Processes (3)

Prerequisites (Desirable): *All EES 300 level courses*

***Learning Objectives*:**

The Earth’s surface consists of several interacting morpho-tectonic elements on which the climate system dynamics is superposed. This endogenic-exogenic coupling at different spatio-temporal scales exercises a first order control on the development of the Earth’s surface and its gross characteristics. Against this backdrop, large scale physiographic and morpho-tectonic features, weathering and regolith development, sediment routing systems and drainage basins will be explored. Fundamental geomorphic concepts involving relationships between scale, pattern, and process will be introduced. Critical Earth surface processes related to hill-slopes, fluvial, aeolian, costal, and glacial geomorphic settings will be described. Lastly, the importance of human transformations of these process domains during the Anthropocene will be analyzed.

***Course Contents*:**

Introduction to the Earth's Surface:

Sources of energy, energy flows and relative energy of surface processes, mass conservation and geomorphic transport laws (Bretherton Diagram).

Geomorphic Concepts:

Spatial and temporal scales; Hierarchy and multi-scale process, magnitude-frequency concepts; Sensitivity, equilibrium, threshold, equifinality, non-linearity and complexity; Diffusion equation, advection equation and application to modelling of Earth surface process.

Fundamentals of Earth Surface Systems:

Development of large scale topography and its role in Earth surface processes; Tectonics-climate coupling; Weathering rates and the Critical Zone processes; Bedrock to sediment routing systems; Quantitative characteristics of drainage basins, sediment and solute fluxes in drainage basins; Sediment yield and landscape models.

Specific Earth Surface Processes:

Hill slopes and catchment erosion processes; Fluvial, aeolian and coastal processes and landforms; Complexity of large river systems.

Geosphere and Cryosphere processes:

Polar ice sheets, Himalayan cryosphere, ice melt dynamics, spatio-temporal considerations, glacial and periglacial processes, thermal structure, climate change impacts on the cryosphere.

The Anthropocene:

Human transformations of Earth; Atmosphere-Geosphere-Biosphere interactions, concept of Anthropocene and human impacts on oceans, rivers and terrestrial biosphere.

***Suggested Readings* :**

1. Anderson, R. S., and Anderson, S. P., 2010, Geomorphology: The Mechanics and Chemistry of Landscapes, Cambridge University Press.
2. Allen, P. A., 1997, Earth Surface Processes, Blackwell Publishing.
3. Pelletier, J., 2008, Quantitative Modeling of Earth Surface Processes, Cambridge University Press.
4. Summerfield, M. A., 2012, Global Geomorphology (2nd Revised Edition), Prentice Hall.
5. Wilcock, P. R., and Iverson, R. M., 2003, Prediction in Geomorphology, AGU Publications.