Earth and Environmental Sciences

I Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits (AL/3)
EES 101	Earth Materials and Processes	2	1	6	0	0	9	3	O to F	3

II Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits (AL/3)
EES 102	Introduction to Environmental Sciences	2	1	6	0	0	9	3	O to F	3

III Semester

	Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits (AL/3)
DC	EES201	Atmospheric Sciences	3	0	6	0	0	9	3	O to F	3
	EES203	Geochemistry	3	0	7.5	0	0	11.5	3	O to F	4
MD	MTH201	Multivariable Calculus	3	1	4.5	0	0	8.5	4	O to F	3

IV Semester

	Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits (AL/3)
DC	EES202	The Evolution of the Earth	3	0	6	0	0	9	3	O to F	3
	EES204	Oceanography	3	0	6	0	0	9	3	O to F	3
	EES206	Introduction to Earth and Environmental Sciences Laboratory	0	0	1	3	0	4	3	O to F	1
MD	CHM222	Classical Thermodynamics	3	1	4.5	0	0	8.5	4	O to F	3

DC: Departmental Compulsory Course; **MD**: Mandatory Course from Other Department

V Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
EES 301	Mineralogy	3	0	6	0	0	9	3	O to F	3
EES 303	Structural Geology	3	0	6	0	0	9	3	O to F	3
EES 305	Geohydrology	3	0	6	0	0	9	3	O to F	3
*** ***	Open Elective I	3	0	6/7.5	0	0	9/10.5	3	O to F	3/4
EES ***	Department Elective I	3	0	7.5	0	0	7.5	3	O to F	4
EES 311	Mineralogy Laboratory	0	0	1	3	0	4	3	O to F	1
EES 313	Structural Geology Laboratory	0	0	1	3	0	4	3	O to F	1
Total Credits		**15**	**0**	**33.5/35**	**6**	**0**	**51.5/53**	**21**		**21/22**

VI Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
EES 302	Igneous Petrology	3	0	6	0	0	9	3	O to F	3
EES 304	Environmental Chemistry	3	0	6	0	0	9	3	O to F	3
EES 306	Solid Earth Geophysics	3	0	6	0	0	9	3	O to F	3
*** ***	Open Elective II	3	0	6/7.5	0	0	9/10.5	3	O to F	3/4
EES ***	Department Elective II	3	0	7.5	0	0	7.5	3	O to F	4
EES 312	Igneous Petrology Laboratory	0	0	1	3	0	4	3	O to F	1
EES 314	Environmental Chemistry Laboratory	0	0	1	3	0	4	3	O to F	1
EES 316	Basic Field Geology	1-week field work							O to F	2
Total Credits		**15**	**0**	**33.5/35**	**6**	**0**	**51.5/53**	**21**		**20/21**

VII Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
EES 401	Sedimentology and Principles of Stratigraphy	3	0	6	0	0	9	3	O to F	3
EES 403	Metamorphic Petrology	3	0	6	0	0	9	3	O to F	3
EES 405/647	Data Analyses and Statistics for Geosciences	3	0	7.5	0	0	10.5	3	O to F	4
*** ***	Open Elective III	3	0	6/7.5	0	0	9/10.5	3	O to F	3/4
EES ***	Departmental Elective III	3	0	7.5	0	0	10.5	3	O to F	4
EES 411	Sedimentology Laboratory	0	0	1	3	0	4	3	O to F	1
EES 413	Metamorphic Petrology Laboratory	0	0	1	3	0	4	3	O to F	1
Total Credits		**15**	**0**	**35/36.5**	**6**	**0**	**56/57.5**	**21**		**19/20**

VIII Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
EES 402/614	Earth Surface Processes	3	0	7.5	0	0	10.5	3	O to F	4
EES 404	Geodynamics*	3	0	6	0	0	9	3	O to F	3
EES 406	Global Climate Change**	3	0	6	0	0	9	3	O to F	3
*** ***	Open Elective IV	3	0	6/7.5	0	0	9/10.5	3	O to F	3/4
EES ***	Departmental Elective IV	3	0	7.5	0	0	10.5	3	O to F	4
EES 414	Geodynamics Laboratory*	0	0	1	3	0	4	3	O to F	1
EES 416	Global Climate Change Laboratory**	0	0	1	3	0	4	3	O to F	1
EES 408	Advanced Field Geology#	10-15 days of field work					9	9	O to F	3
EES 410	Field Work in Environmental Sciences#	10-15 days of field work					9	9	O to F	3
Total Credits		**12**	**0**	**28/29.5**	**3**	**0**	**54/55.5**	**24**		**18/19**

Students should register for either one of these two courses

Students should register for both the * or both the ** courses

IX Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
EES 505/645	Remote Sensing and GIS	3	0	7.5	3	0	13	5	O to F	4
EES ***	Departmental Elective V	3	0	7.5	0	0	10.5	3	O to F	4
HSS 503$	Law Relating to Intellectual Property and Patents$	1	0	2.5	0	0	3.5	1	S/X	1
EES 501	MS Thesis	-	-	-	-	-	30	-	O to F	12
Total Credits		**7**	**0**	**17**	**3**	**0**	**57**	**9**		**21**

$Students can credit this course during any semester of their BS-MS study

Students can credit this course in the 9th or 10th semester

X Semester

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
EES 502/503	Contemporary Environmental Issues	1	0	2	0	6	9	7	O to F	3
EES 501	MS Thesis	-	-	-	-	-	40	-	O to F	16
Total Credits		**1**	**0**	**2**	**0**	**0**	**49**	**7**		**19**

Electives and Ph.D. courses

Course No.	Course Title	Lec Hr	Tut Hr	SS Hr	Lab Hr	DS Hr	AL	TC Hr	Grading System	Credits
EES 320/321	Introduction to Paleontology	3	0	7.5	0	0	10.5	3	O to F	4
EES 322/323	Economic Geology	3	0	7.5	0	0	10.5	3	O to F	4
EES 324/325	Geology of Fuels	3	0	7.5	0	0	10.5	3	O to F	4
EES 420/421	Science of Sustainability	3	0	7.5	0	0	10.5	3	O to F	4
EES 422/423/602	Marine Biogeochemical Cycles	3	0	7.5	0	0	10.5	3	O to F	4
EES 424/425/604	Aerosol Science	3	0	7.5	0	0	10.5	3	O to F	4
EES 426/427/631	Greenhouse Gas Budgets and Climate Change	3	0	7.5	0	0	10.5	3	O to F	4
EES 510/511/601	Isotope Geochemistry	3	0	7.5	0	0	10.5	3	O to F	4
EES 512/513/603	Mineral Thermodynamics	3	0	7.5	0	0	10.5	3	O to F	4
EES 514/515/605	Indian Monsoon and its Variability	3	0	7.5	0	0	10.5	3	O to F	4
EES 615	Reconstructing Quaternary Continental Environments and Climates of South Asia	3	0	7.5	0	0	10.5	3	O to F	4
EES 629	Advanced Mineralogy	3	0	7.5	0	0	10.5	3	O to F	4
EES 630	Climate Change and Extreme Events	3	0	7.5	0	0	10.5	3	O to F	4
EES 643	Advanced Structural Geology	3	0	7.5	0	0	10.5	3	O to F	4

EES 101: Earth Materials and Processes (3)

Learning Objectives

This is an undergraduate level course to introduce students to the basic concepts of Earth Science. The course gives an introduction to the dynamic planet Earth, explains the natural principles and processes that govern how its interior works and couples with the external system. In essence, this course provides a beginner's guide to planet Earth. Upon the completion of this course the student will have an understanding of the co-evolution of the Earth and life.

Course Contents

An introduction to Earth Sciences:
Disciplines of Earth science; Earth system science and its role in global environmental management and sustainability.

Concept of Time in Earth and Environmental Systems:
Early history of the Universe; Geologic time; Relative versus absolute age; Spatio-Temporal scales in Earth and Environmental Sciences.

Interior of the Earth:
Continental and oceanic crust; Mantle and its discontinuities; Convection in the mantle; Core; Earth's internal heat; Earth's magnetic field; Gravity and shape of Earth; Conductive heat flow and simple geotherms; Total heat loss from Earth; Earth's surface topography as a product of coupling of endogenic-exogenic processes;

Plate Tectonics:
Lithospheric plates; Plate movement and earthquakes; Divergent boundaries; Continental rifting; Convergent plate boundaries; Transform faults and hotspots; What drives plate tectonics; Tectonics on a sphere – the geometry of plate tectonics; Past plate motions; The rock cycle.

Earth Materials, Energy, and Resources:
Mineralogy – Definition and physical properties of minerals; Basic crystallography; Important mineral groups; Formation, exploration, and production of ore deposits; National mineral resources and policies.

Petrology – Volcanoes and their products; Classification of igneous rocks; Sediments and the sedimentary cover; Classification of sedimentary rocks; Metamorphism and associated changes; Classification of metamorphic rocks.

Resources and Reserves – Energy resources, oil and natural gas, coal; Alternative fossil fuels; Ore deposits and plate tectonics; Exploration techniques; Finding new mineral deposits.

Hydrological Resources – Hydrological cycle and water budgets; Aquifer properties; Groundwater; Groundwater flow; Groundwater-surface water interactions.

Coupled Earth and Environmental Systems in the Indian Context (Case Histories):

Glacier climate coupling; Toxic elements and environmental health; Trace gas issues over India; Energy issues of India; Groundwater pollution and contaminant transport; River dynamics and floods.

Earth-Environmental Data Sets:

Spatio-temporal variabilities – Data from ground observational systems and satellites.

Selected Readings

1. Press, F., and Siever, R., 2001, Understanding Earth (3rd Edition), Freeman and Co. Ltd.
2. Grotzinger, J., and Jordan, T., 2014, Understanding Earth (7th Edition), Freeman and Co. Ltd.
3. Fowler, C. M. R., 2004, The Solid Earth: An introduction to Global Geophysics (2nd Edition), Cambridge University Press.

EES 102: Introduction to Environmental Sciences (3)

Learning Objectives

This course seeks to introduce students to the importance of life and the environment, both natural and anthropogenic. Insights into basic causes of, and possible solutions to, important environmental problems, and skills for defining and furthering environmentally sound action will be provided. Attainment of these goals requires an integrative study of Earth and environmental systems, and environmental ethics. This is a course that emphasizes the physical and chemical interactions between the Earth and environmental systems, to better understand the present day environmental issues and their solution.

Course Contents

Introduction to Environmental Sciences:

Environmental science - meaning, scope, and importance; Environmental dynamics: time dependence of concentration, field, transport, introductory concepts in fluid dynamics, chemical thermodynamics and kinetics; System, its components, feedback; Environmental factors; Understanding why human population growth is the underlying environmental problem and what its implications are on environmental systems. Valuing the Environment - Concepts and methods; Economic growth, the environment and sustainable development.

Abiotic and Biotic Environment:

Global environment and its segments - atmosphere, hydrosphere, lithosphere, biosphere and inter-relationships. Ecological principles; Concepts of species, populations, communities and ecosystems, dynamics of biological populations, interactions between species, food chains and food webs, energy flow in ecosystems; Interaction between biotic and abiotic environments. Introduction to Biogeochemical cycles: definition and description, Carbon, Nitrogen, and Sulfur cycles; Anthropogenic impacts on these cycles.

Natural Resources:

Mineral, water, land, and forest resources – use, overexploitation, and conservation (examples - rainwater harvesting and wasteland reclamation, wildlife management); Sources of energy from the natural environment - Fossil fuels and nuclear energy; Concentration, storing and transporting energy; Renewable and nonrenewable energy supplies.

Contemporary Environmental Issues:

<u>Atmospheric Pollution</u>: Types of pollutants - primary and secondary; Major phenomenon - Ozone depletion, smog formation, and acid rain – geospatial and time scales, causes and effect; Physics of thermal radiation, radiative forcing, and global warming potential. Distinction between greenhouse-effect and global warming, Pollution prevention strategies, International treaties to reduce pollution, e.g., Kyoto Protocol, Montreal Protocol, and later developments.

Water Pollution: Water pollution - Types, general properties and dynamics of water pollutants; Contaminant transport, thermal pollution, groundwater pollution (e.g., nitrate, heavy metals, organics) and contaminant transport; Groundwater remediation; Acid mine drainage; Sewage treatment.

Soil Degradation: Soil erosion and desertification, major impacts of soil degradation, soil conservation techniques.

Solid Waste Management: Types and sources of solid waste; Control of solid waste, methods of solid waste treatment; Solid wastes from mines and their disposal methods.

Radiation and Noise pollution: Noise - measurement, classification and hazards; Sources, effects, and controls of radioactive pollution.

Selected Readings

1. Cunningham, W. P., and Cunningham, M. A., 2010, Environmental Science - A Global Concern (11th Edition), McGraw Hill Publications.
2. Harnung, S. E., and Johnson, M. S., 2012, Chemistry and the Environment (1st Edition), Cambridge University Press.
3. Botkin, D, B., and Keller, E. A., 2010, Environmental Science - Earth as a Living Planet (7th Edition), John Wiley and Sons Inc.
4. Harrison, R. M., 2006, An Introduction to Pollution Science, The Royal Society of Chemistry.

EES 201: Atmospheric Sciences (3)

Prerequisite (Desirable): *EES 101, EES 102*

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

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.

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, Composition and structure of the atmosphere - pressure and wind systems, vertical structure of pressure, density, temperature, wind and moisture. Sun Earth relationships - seasons, heat budget, latitudinal heat budget.

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.

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.

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 Clausius Clapeyron equation – application to the atmosphere.

Atmospheric Motion:

Fundamental and apparent forces of atmospheric motion – Momentum equation – pressure gradient, Coriolis, gravitational, centrifugal and frictional forces -

geostrophic and gradient flow, thermal wind. Equation of continuity – hydrostatic balance. Energy conservation equation, Circulation, vorticity and divergence. Scales of atmospheric motion - microscale, mesoscale, synoptic scale and planetary scale circulations. Global circulation of single cell and three cell models - observed distribution of pressure and winds, monsoons, westerlies and waves in the westerlies.

Atmospheric Chemistry:

Chemical structure, reactivity, and lifetime of chemicals; Overview of tropospheric and stratospheric chemistry - Ozone depletion.

Selected Readings

1. Wallace, J. M., and Hobbs, P. V., 2006, Atmospheric Science: An introductory Survey, 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 (2nd Edition), Wiley-Interscience.

EES 202: The Evolution of the Earth (3)

Prerequisite (Desirable): *EES 101, EES 102, EES 203*

Learning Objectives

This is an undergraduate level course to introduce students to the basic concepts of Earth Science and Earth's evolution with time. The course gives an introduction to the dynamic planet Earth, explains the natural principles and processes that govern how its interior works and couples with the external system. In essence, this course provides a beginner's guide to planet Earth Upon the completion of this course the student will have an understanding of the co-evolution of the Earth and life.

Course Contents

Earth Systems:

Earth as a Planetary System, Structure of the Earth, Plate Tectonics, Is the Earth unique? Interacting Earth Systems

The Crust:

Crustal Types, Continent Size, Seismic Crustal Structure, Heat-Flow Distribution, Exhumation and Cratonization, Unraveling Pressure–Temperature–Time Histories, Processes in the Continental Crust, Crustal Composition, Crustal Provinces and Terranes, Crustal Province and Terrane Boundaries Super continents.

Tectonic Settings:

Ocean Ridges, Tectonic Settings Related to Mantle Plumes, Continental Rifts, Cratons and Passive Margins, Arc Systems, Orogens, Uncertain Tectonic Settings, Mineral and Energy Deposits, Plate Tectonics with Time.

The Mantle:

Seismic Structure of the Mantle, Mantle Upwellings and Geoid Anomalies, Temperature Distribution in the Mantle, The Lithosphere, The Low-Velocity Zone, The Transition Zone, The Lower Mantle, Plate-Driving Forces, Mantle Plumes, Mantle Geochemical Components, Convection in the Mantle.

The Core:

Core Temperature, Composition of the Core, Age of the Core, Generation of the Earth's Magnetic Field, Origin of the Core, Where Do We Go from Here?

The Atmosphere and Oceans:

General Features of the Atmosphere, The Primitive Atmosphere, The Secondary Atmosphere, The Carbon Cycle, The Precambrian Atmosphere, The Origin of Oxygen, Phanerozoic Atmospheric History, The Oceans, Paleoclimates.

Living Systems:

Origin of Life, First Fossils, Origin of Photosynthesis, Tree of Life, Stromatolites, Appearance of Eukaryotes, Origin of Metazoans, Neoproterozoic Multicellular Organisms, Evolution of Phanerozoic Life Forms, Biologic Benchmarks, Mass Extinctions.

Crustal and Mantle Evolution:

Earth's Thermal History, Earth's Primitive Crust, Earth's Oldest Rocks and Minerals, Crustal Origin, How Continents Grew, Continental Growth Rates, Secular Changes in the Crust, Secular Changes in the Mantle, Evolution of the Crust–Mantle System.

The Supercontinent Cycle and Mantle-Plume Events:

Supercontinent Cycle, Supercontinents Mantle Plumes and Earth Systems, Mantle-Plume Events Through Time, What Causes a Mantle-Plume Event? Mantle-Plume Events and Supercontinents, A Plume–Supercontinent Connection?

Selected Readings

1. Condie, K.C., Earth as an evolving planetary system (3rd Edition), Elsevier
2. Press, F., and Siever, R., Understanding Earth (3rd Edition), Freeman and Co Ltd

EES 203: Geochemistry (4)

Prerequisite (Desirable): *EES 101, EES 102*

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 aqueous systems 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

Introduction:

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

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.

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.

Radiogenic Isotope Geochemistry:

Physics of the nucleus and the structure of nuclei; Basics of radiogenic isotope geochemistry; Decay systems and their applications; Principles of radiometric geochronology; Cosmogenic and fossil isotopes; Applications of radiogenic isotopes to the Core-Mantle-Crust system.

Mixing and Dilution:

Binary mixtures; Dilution; Evaporative concentration; Ternary mixtures; Isotopic mixtures of one element; Isotopic mixtures of two elements.

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; Non-traditional stable isotope systematics. Applications of stable isotope systems to the Ocean-Atmosphere-Hydrosphere system.

Selected Readings

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

EES 204: Oceanography (3)

Prerequisite (Desirable): *EES 101, EES 102, EES 201, EES 203*

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/environmental conditions on various Earth surface processes can be learnt from marine fossil/geochemical/isotope records.

Course Contents

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; Spatial distributions of sedimentary constituents (detrital sediments, gas hydrates and other authigenic/biogenic minerals), their formation/degradation, settling/accumulation over seafloor, and post-depositional disturbances; Roles of lysocline/CCD, productivity, monsoon, atmospheric/ocean circulation pattern/strength, and orbital controls on sedimentation; Reconstruction of past climate–ocean interactions and oceanic properties using geochemical and isotope records from the Indian Ocean.

Physical Oceanography:

River runoff; Sub-marine groundwater discharge; Physical properties of seawater and their spatial distributions; Spatio-temporal scales and forcing mechanisms of oceanic motions; 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; Water masses of the northern Indian Ocean; Heat budget of oceans; El Niño Southern Oscillations; Indian Ocean dipole.

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; N loss by denitrification and anammox; Denitrification in the Arabian Sea; Lysocline and carbonate compensation depth; Oxygen minimum zones; Sources, sinks and internal cycling of various elements; Advection–diffusion–scavenging model; Exploration of contemporary oceanic processes using geochemical and isotope tracers.

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, and nutrient utilization by traditional/non-traditional stable isotopes; Fish production and productivity in the Indian Ocean.

Selected Readings

1. Talley, L. D., Pickard, G. L., Emery, W. J., Swift, J. H., 2005, Descriptive Physical Oceanography: An Introduction (6th revised Edition), Elsevier Academic Press.

2. Emerson, S., and Hedges, J., 2008, Chemical Oceanography and the Marine Carbon Cycle (1st Edition), Cambridge University Press.
3. Lalli, C. M., and Parsons, T. R., 1997, Biological Oceanography: an introduction (2nd Edition), Elsevier Butterworth-Heinemann Ltd.
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 206: Introduction to Earth and Environmental Sciences Laboratory (1)

Prerequisite (Desirable): *EES 101, EES 102*

Learning Objectives

The objective of this laboratory course is to introduce students to the practical aspects of all the varied components of Earth and environmental sciences. This will allow the students to gain hands-on experience on the various wide-ranging activities that are performed in the laboratory and in the field. This will also give the students the opportunity to appreciate the interdisciplinary nature of Earth and Environmental Sciences.

Course Contents

1. Identification of basic rock forming minerals in hand specimen
2. Identification of major igneous, metamorphic, and sedimentary rocks in hand specimens
3. Mapping techniques and practices
4. Basic exercises in structural geology using Stereonets
5. Basic geophysical data interpretation techniques
6. Proximate analyses of coal
7. Sampling for fine particles in air and determining their mass concentration
8. Testing water for potability
9. Determining alkalinity in natural waters
10. Soil moisture profiling

Selected Readings

1. Laboratory manual and handouts, as required, will be provided

EES 301: Mineralogy (3)

Prerequisite (Desirable): *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 a fundamental 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

Introduction:

Structure of the course, introduction to the subject and history of mineralogy.

Crystallography:

Definition of mineral and crystal; Fundamental laws of crystallography; Introduction to crystallography and the seven crystal systems; Pattern, symmetry operations in plane lattices; Symmetry operations in space lattices - axes of rotation, mirror , center of symmetry, roto-inversion; Bravais Lattices; Crystal forms and their nomenclature; 32 point group symmetries in Hermann Mauguin Notations; Miller's Indices; Nature of X-rays, X-ray crystallography; Derivation of the space groups using X-ray Crystallography; Bragg Equation and its application in mineralogy.

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.

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.

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, birefregence; Interference figures.

Descriptive Mineralogy of Common Rock Forming Minerals:

- Ortho and ring silicates - Olivines, Garnets, Epidote, Beryl and Tourmaline
- Chain silicates - Pyroxene group and Amphibole group
- Sheet silicates - Mica group
- Framework silicate - Feldspars
- Non-silicates - Native elements, sulfides, and sulfosalts; oxides, hydroxides and halides with emphasis on the Spinel group; Carbonates, sulfates and phosphates.

Mineralogy in the Indian Context:

Occurrences of various minerals in India.

Introduction to Igneous Petrology:

Bowen's Reaction Series; Mineralogy and petrology of igneous rocks.

Selected 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 Forming Minerals (3rd Edition), Mineralogical Society of Great Britain and Ireland.
3. Klein, C., and Butrow, B., 2008, The 23rd edition of the Manual of Mineral Science (4th Edition), John Wiley and Sons.
4. Wenk, H.-R. and Bulakh, A., 2016, Minerals – Their Constitution and Origin (2nd Edition), Cambridge University Press.

5. Nesse, W. D., 2011, Introduction to Mineralogy (2^{nd} Edition), Oxford University Press.

EES 302: Igneous Petrology (3)

Prerequisite (Desirable): *All EES 200 courses, EES 301, EES 311*

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

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.

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.

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 H_2O 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.

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.

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.

Layered Mafic Intrusions:

Igneous layering; Examples of layered mafic intrusions; Processes of crystallization, differentiation and layering in these complexes.

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.

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.

Subduction Related Igneous Activity:

Island arc volcanism, rocks suites, and magma series; Chemistry of island arcs; Spatial and temporal 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.

Continental Alkaline Magmatism:

Continental rift-associated alkaline magmatism; Carbonatites; Highly potassic rocks; Mantle metasomatism and mantle xenoliths.

Granitoids and Anorthosites:

Petrography, chemistry and petrogenesis of granitiods; Granitoid classification; Chemical discrimination of tectonic granitoids; Origin of the continental crust; Archaean anorthosites; Proterozoic anorthosites; Lunar anorthosites.

Selected Readings

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

EES 303: Structural Geology (3)

Prerequisite (Desirable): *All EES 200 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

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.

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 and ductile deformation.

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.

Faults:

Different types of faults, recognition of faults, measurement of fault displacements, fault geometry, orientation of stress fields and fault kinematics, paleostress from the fault slip data, fault bend folds, fault propagation folds.

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.

Kinematics of Folding:

Folding mechanisms, buckling and shear folding of single layers, multilayer folding, formation of kink and Chevron fold.

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.

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.

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.

Structural Geology and Plate Tectonics:

Introduction to plate tectonics, different types of tectonic boundaries, development of structures at active plate margins.

Selected 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.

EES 304: Environmental Chemistry (3)

Prerequisite (Desirable): *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

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.

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.

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.

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.

Global Biogeochemical Cycles:

Carbon cycle – the short and long term carbon cycles, atmospheric and marine Carbon; Carbon cycle 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.

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.

Selected 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 System Science: 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 305: Geohydrology (3)

Prerequisite (Desirable): *All 200 level EES courses*

Learning Objectives

The emphasis of the course will be on groundwater, although some aspects of surface water hydrology 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

Introduction:

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

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.

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.

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.

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.

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.

Selected 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 (3rd Edition), Wiley.

EES 306: Solid Earth Geophysics (3)

Prerequisite (Desirable): *All 200 level EES courses, EES 303, EES 313*

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

The Earth:

Surface features, continents, continental margins, oceans; Continental drift, evidence that continents "drift", computer-assisted reconstructions to support continental drift hypothesis, paleomagnetism and continental drift, seafloor spreading, Vine Matthews Morley hypothesis, conservative margins, destructive margins, hotspots, triple junctions, Euler's rotation theorem.

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.

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.

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.

Paleomagnetism:

Introduction to paleomagnetism; Polar wandering; Euler pole and continental drift; Geomagnetic polarity; Seafloor spreading and continental drift; Filtering (magnetic) data; Modeling and interpretation of magnetic anomalies.

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.

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.

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.

Selected 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 (2^{nd} Edition), Cambridge University Press.
3. Fowler, C. M. R., 2004, The Solid Earth – An Introduction to Global Geophysics (2^{nd} Edition), Cambridge University Press.
4. Dobrin, M. B., and Savit, Carl, H., 1988, Introduction to Geophysical Prospecting (4^{th} Edition), McGraw Hill International.
5. Telford, W. M., Geldart, L. P., Sheriff, R. E., 1990, Applied Geophysics (2^{nd} Edition), Cambridge University Press.

EES 311: Mineralogy Laboratory (1)

Prerequisite (Desirable): *EES 301 either credited or registered*

Learning Objectives

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

Course Contents

Physical Properties of Minerals:

Color, luster, streak, form, cleavage, fracture, hardness, other relevant properties of specific minerals.

Crystallography:

Symmetry and Crystal System; Crystal Classes; Stereographic Projections; Identification of Miller's indices, symmetry, crystal angles of various important crystal forms across the 32 crystal classes.

Optical Mineralogy:

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.

X-Ray Diffraction:

Sample Preparation, Analyses of X-Ray Diffractometer Measurements.

Identification of Minerals of these Groups:

- Native elements and sulfides
- Oxides, hydroxides, halides and carbonates
- Sulfates, tungstates, phosphates, vanadates
- Silicates: Neso-, inosilicates
- Silicates: Cyclo-, sorosilicates
- Silicates: Phyllo-, tectosilicates
- Mineraloids

Selected Readings

1. Mottana, A., Crespi, R., and Liborio, G., 1978, Simon and Schuster’s Guide to Rocks and Minerals (6th edition), Fireside Books.
2. Nesse, W. D., 2014, Introduction to Optical Mineralogy (4th 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 Thin Section (2nd 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 Ore Mineralogy (3rd Edition), Wiley.

EES 312: Igneous Petrology Laboratory (1)

Prerequisite (Desirable): *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

Review of Mineralogy:

Identification of the primary and secondary igneous minerals in hand specimen and thin section; Identification of these minerals within a rock.

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.

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

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.

Selected 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, CBS Publications.
3. Cox, K. G., 1979, The Interpretation of Igneous Rocks, Springer.

EES 313: Structural Geology Laboratory (1)

Prerequisite (Desirable): Credited or registered in EES 303

Learning Objectives

Preparation of geological maps is of primary importance to understand the spatial patterns of rocks in the Earth's crust. In this course, students will be exposed to the different measurement techniques of geological features that are used to prepare geological maps.

Course Contents

Measurement of Structural Data:

Measurement of structural data of foliation and lineations.

Stereographic Exercises:

Strike and dip of planar structures, pitch and plunge of linear structure, pictorial representation of structures, borehole plotting on stereonet.

Preparation of Geological Maps:

Representations of planar and linear structures on map, drawing cross sections of maps, balanced cross section of orogenic belts.

Mohr's Circle:

Construction of stress and strain, strain analysis of deformed pebbles, minerals, fossils.

Computational Techniques:

Introduction of different software for drawing maps, stereographic projections and grain size analyses.

Selected Readings

1. Marshak, S., and Mitra, G., 2006, Basic Methods of Structural Geology (2nd Edition), Prentice Hall.
2. Lisle, R. J., 2014, Geological Structures and Maps, A Practical Guide (3rd Edition), Butterworth-Heinemann.
3. Ramsay, J. G., and Huber, M. I., 1983, The Techniques of Modern Structural Geology (Volume 1): Strain Analysis, Academic Press, London.

EES 314: Environmental Chemistry Laboratory (1)

Prerequisite (Desirable): *Credited or registered for EES 304*

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

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.

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

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

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

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

6. Determination of water, carbonate and organic matter contents in a soil sample.
7. Evaluation of the relationships between cation exchange capacity of soils and their organic matter contents, in a depth profile.
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.
9. Monitoring ambient meteorological parameters – wind speed, wind direction, temperature, and relative humidity. Preparation of wind rose plots (using measurements/synthetic data sets).
10. Monitoring ambient gaseous pollutants – O_3, SO_2, NO_x, and CO. Analyzing temporal trends (using measurements/synthetic data sets).

Selected Readings

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

EES 316: Basic Field Geology (2)

Prerequisite (Desirable): *All EES 200 level courses*

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:

<u>Day 1</u>

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

<u>Days 2 to 4</u>

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.

<u>Days 5 to 7</u>

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 and GEO-ORIENT; Complete documentation of all samples collected.

Selected 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 (5^{th} Edition), Wiley Publications.

EES 320/321: Introduction to Paleontology (4)

Prerequisite (Desirable): *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

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.

Systmatics and Evaluation:

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

Diversity of Fossil Life:

The origin of life; Protists, Metazoans - origin and classification; Sponges and corals; Spirulians – lophopherates and molluscs; Arthropods; Brachiopods; Trilobites; Echinodermis and hemichordates; Fish and basal tetrapods; Dinosaurs and mammals; Front plants; Trace fossils; Diversification of life trends and radiations.

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.

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.

Selected Readings

1. Prothero, D. R., 2013, Bringing Fossils to Life: An Introduction to Palaeobiology (3rd Edition), McGraw Hill.
2. Benton, M. J., and Harper, D. A. T., 2009, Introduction to Palaeobiology and the Fossil 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 322/323: Economic Geology (4)

Prerequisite (Desirable): *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

Introduction:

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

Processes of Formation of Economic Mineral Deposits:

Endogenous Processes – Magmatic, contact metasomatism, skarn, griesens, pegmatitic and hydrothermal processes, metamorphic enrichment.

Exogenous Processes – Sedimentation, chemical and bacterial precipitation, colloidal deposition and evaporation.

Weathering Processes – Oxidation and supergene enrichment.

Metallic Ores:

Oxides of Fe, Mn, Cr, W; Sulphides of Cu, Pb, Zn; Metallogenic provinces and epochs.

Ore Minerals:

Their texture and structure, development in open space and polycrystalline aggregates.

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.

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 skarn deposits of W and Sn, pegmatite bodies.
- Ore association with acidic and mafic volcanic rocks, including those in greenstone belts – Kabalda type, 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 floor deposits of Mn-Ni-Cu-Co.

- Rare Earth deposits

National and International Mineral Economies:

Environments of ore formation; Importance of minerals in national economy; Basic pattern of mineral 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.

Selected Readings

1. Evans, A. M., 2015, Ore Geology and Industrial Minerals –An Introduction (3rd Edition), 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 – Verlaj.
7. Misra, K. C., 2000 Understanding Mineral Deposits, Springer – Netherlands.

EES 324/325: Geology of Fuels (4)

Prerequisite (Desirable): *All EES 100 and 200 level courses*

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

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.

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.

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 Th metallogenic provinces of India; Detectors of radioactivity - Geiger, proportional and scintillation counters and spectrometers.

Selected Readings

1. Selley, R. C., and Sonnenberg, S. A., 2014, Elements of Petroleum Geology (3rd Edition), 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 (Indian Context), 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 401: Sedimentology and Principles of Stratigraphy (3)

Prerequisite (Desirable): *All 200 and 300 level EES courses*

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

Development of Concepts in Sedimentology:

The context of sedimentology; Weathering, erosion, transportation; Sedimentation in the backdrop of the interaction of plate tectonics and hydrological cycle; Soil formation and sediment production, regolith, chemical index of alteration.

Textural Properties of Sediments and Sedimentary Rock:

Grain Size and scale, grain size distributions; Porosity and permeability; Grain orientation and fabric.

Fluid Flow and Sediment Transport:

Fluid gravity flows – Classification, velocity distribution in turbulent flows; Sediment transport under unidirectional flows, Hjulstrom’s diagram, Shield’s criterion; Bedforms and structures under unidirectional flow – Flow regime concept, bedform stability diagrams.

Primary Sedimentary Structures:

Primary structures and their directional significance, bedding, cross-bedding – planar, trough, HCS, Herring bone, normal and inverse graded beds; Bedding plane markings, biogenic sedimentary structures - Stromatolites and Ichnofossils; Penecontemporaneous Deformation Sturctures (PCD).

Depositional Sedimentary Environments:

Classification; methods and data integration for environmental reconstruction - vertical faces associations.

Facies:

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.

Terrigenous Clastic Sediments:

Sediment connectivity and transport systems, conglomerates, breccia, sandstone, compositional versus textural maturity of sediments; Sedimentology of mudstones.

Carbonate Rocks:

Importance of limestone, carbonate continuum and carbonate minerals, carbonate geochemistry, controls on carbonate deposition; Carbonate sediment factories, bio- and organo-mineralisation, warm and cool water carbonates, pelagic carbonates, reefs and build-ups; Carbonate diagenesis.

Biogenic Sedimentary Rocks:

Chert and siliceous sediment, phosphates, and organic-rich sediments; Chemical and non-epiclastic sedimentary rocks – Iron-rich sedimentary rocks and evaporates; Volcanoclastic sedimentary rocks – fragmentation, eruption column characteristics non-genetic classification of pyroclastic rocks.

Siliciclastic Diagenesis:

Compaction and cementation; Authigenesis, recrystallization and replacement; Diagenesis and porosity.

Tectonics of Sedimentary Basins:

Basin classification – intraplate (pre- and post- rift), Divergent and convergent – margin basins, collision and post – collision basins, strike–slip basins; mechanisms of basin formation; The uniform stretching model.

Concepts in Lithostratigraphy and Biostratigraphy:

Index fossils, FAD/LAD, bio stratigraphic zonation and correlation, time significance of biostratigraphic events; Geophysical and chemostratigraphic correlation - well logging, seismic stratigraphy, chemostratigraphy.

Magnetostratigraphy and Geochronology:

Principles of magnetostratigraphy and development of GPTS (Global Polarity Time Scale), Geochronological techniques as applied to the Quaternary record (Carbon-14, luminescence, amino-acid dating and Oxygen isotope stratigraphy) and pre- Quaternary (Ar-Ar), U-Pb, fission track dating.

Selected Readings

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

EES 402/614: Earth Surface Processes (4)

Prerequisite (Desirable): *All EES 200 and 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.

Selected 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.

EES 403: Metamorphic Petrology (3)

Prerequisite (Desirable): *All 200 and 300 level EES courses*

Learning Objectives

The study of metamorphic rocks encompass 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

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.

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.

Metamorphic Textures:

Classification and types of textures; Interpretation of porphyroblast–inclusion relations.

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.

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.

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.

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.

Selected Readings

1. Winter, J. D., 2010, An Introduction to Igneous and Metamorphic Petrology (2nd Edition), 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 (8th Edition), Springer.

EES 404: Geodynamics (3)

Prerequisite (Desirable): *All EES 200 and 300 level courses*

Learning Objectives

The course provides an opportunity to learn the basic concepts of deformation of solids, rheology of Earth materials, and flow in porus media. Thereafter, a global perspective of plate tectonic and geodynamic processes, including the nature of plate boundaries and the forces that drive those processes will be provided. Finally this will enable students to understand the tectonic processes that lead to different deformation domains of the Earth.

Course Contents

Introduction:

Structure of Earth, historical perspective, continental drift, sea floor spreading and the birth of plate tectonics, impact of plate tectonics; Interior of the Earth.

Stress and Strain in Solids:

Body forces and surface forces, stress in two dimensions, pressure in the deep interiors of planets, stress measurement, basic ideas about strain, strain measurements.

Heat Transfer:

Introduction, Fourier's law of heat conduction, measuring the Earth's surface heat flux, the Earth's surface heat flow, continental geotherm, radial heat conduction in a sphere or spherical shell.

Gravity:

Introduction, gravitational acceleration external to the rotationally distorted earth, centrifugal acceleration and the acceleration of gravity, the gravitational potential and the geoid, moments of inertia, surface gravity anomalies, Bouguer gravity formula, forces required to maintain topography and the geoid.

Rock Rheology:

Introduction, elasticity, diffusion creep, dislocation creep, shear flows of fluids with temperature- and stress-dependent rheologies, mantle rheology, rheological effects on mantle convection, mantle convection and the cooling of the Earth, crustal rheology, viscoelasticity, elastic–perfectly plastic behavior.

*Flow in Porus Media***:**

Equations of conservation of mass, momentum, and energy for flow in porous media, one-dimensional advection of heat in a porous medium, thermal convection in a porous layer.

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.

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.

The Mechanism of Plate Tectonics:

Contracting Earth hypothesis, expanding Earth hypothesis, calculation of the ancient moment of inertia of the Earth, calculation of the ancient radius of the Earth implications of heat flow, convection in the mantle the vertical extent of convection, the forces acting on plates, driving mechanisms of plate tectonics, mantle drag mechanism, edge-force mechanism, evidence for convection in the mantle, the mechanism of the supercontinent cycle.

Chemical Geodynamics:

Radioactivity and geochronology, geochemical reservoirs, two-reservoir model with instantaneous crustal differentiation, noble gas systems, isotope systematics.

Implications for Geodynamics:

Implications of plate tectonics, environmental change, economic geology, natural hazards.

Selected Readings

1. Kearey, P., Klepeis, K.A., and Vine F. J., 2009, Global Tectonics (3rd Edition), John Wiley and Sons.
2. Donald, L. G., and Turcotte, S., 2000, Geodynamics (3rd Edition), Cambridge University Press.

3. Fowler, C. M. R., 2005, The Solid Earth: An Introduction to Global Geophysics (2nd Edition), Cambridge University Press.

EES 405/647: Data Analysis and Statistics for Geosciences (4)

Prerequisite (Desirable): *All EES 200 and 300 level courses*

Learning Objectives

This course will introduce the various data analysis tools, discuss the mathematical background behind these tools, and illustrate the choice and application of these tools in the analyses of geoscience data. This course will help develop critical thinking skills, particularly in the use of quantitative data across different temporal and spatial scales.

Course Contents

Statistics and Data Analysis:

Description of data, directional data - circular data, spherical data; Vector and matrix notation, probability theory, probability distributions – common discrete and continuous distributions; Statistical concepts and paradigms, samples versus the population; Normality and error analysis, exploratory data analysis, estimation, bias, causes of variance.

Estimation and Hypothesis Testing on Means and other Statistics:

Introduction, independence of observations; Central limit theorem; Sampling distributions, t-distribution, confidence interval estimate on a mean, confidence interval on the difference between means, hypothesis testing on means, Bayesian hypothesis testing; Nonparametric hypothesis testing, Bootstrap hypothesis testing on means; Testing multiple means via analysis of variance, multiple comparisons of means, nonparametric ANOVA; Paired data; Kolmogorov-Smirnov goodness-of-fit test.

Statistical Modelling:

Introduction; Steps in statistical modelling, model assumptions, designed experiments, replication.

Regression:

Correlation and covariance, simple linear regression, multiple regression, other regression procedures; Nonlinear models.

Multivariate Analyses:

Multivariate graphics; Principal component analyses; Factor analyses; Cluster analyses; Discriminant analyses.

Design of Experiments:

Sampling designs; Design of experiments; Field studies and design; Missing data.

Time Series:

Time Domain; Frequency Domain; Wavelets; Auto regressive model (AR1) and persistence.

Spatial Statistics:

Three-dimensional data visualization; Spatial association, the effect of trend; Semi-variogram models, Kriging, space-time models.

Selected Readings

1. Schuenemeyer, J., and Drew, L., 2001, Statistics for Earth and Environmental Scientists, Wiley.
2. Emile-Geay, J., 2014, Data analysis in the Earth & Environmental Sciences, E-book accessible via http://dx.doi.org/10.6084/m9.figshare.1014336.
3. Ross, S. M., 2004, Introduction to Probability and Statistics for Engineers and Scientists, Elsevier.
4. Davis, J. C., 1986, Statistics and Data Analysis in Geology, John Wiley.
5. Hardle W., 2003, Applied Multivariate Statistical Analysis, Springer.

EES 406: Global Climate Change (3)

Prerequisite (Desirable): *All EES 200 and 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 South Asia.

Course Contents

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.

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 CO_2 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).

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.

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.

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.

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.

Selected Readings

1. Dessler, A., 2012, Introduction to Modern Climate Change, Cambridge University Press.
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 (4th Edition), Wiley.

Report

1. IPCC AR5 report: Climate Change 2013: The Physical Science Basis

EES 408: Advanced Field Geology (3)

Prerequisite (Desirable): *All EES 200 and 300 level courses*

Learning Objectives

Advanced geological mapping is a field based course with strong emphasis on detailed observations and the development of mapping skills of relatively complex geological terrains. The students will learn how to prepare a detailed geological map of a small area. The course involves the study of both natural outcrops in the field and pre-field studies of satellite imagery of the region, involving image processing techniques and GIS software.

Course Contents

Introduction:

Outline and approach, safety, field behavior, geological heritage.

Field Equipment:

Brunton compasses and clinometers, hand lenses, tapes, map cases, field notebooks, sketching and drawing tools, Global Positioning System (GPS), geochemical field kits and probes.

Methods of Geological mapping:

Strategy for the mapping programme, mapping by following contacts, traversing, exposure mapping, mapping in poorly exposed regions, superficial deposits, drill site locations, geophysical aids to mapping.

Field Measurements and Techniques:

Measuring strike and dip of planar structures - plotting strike and dip, measuring linear features, folds, faults, thrusts, joints, unconformities, map symbols, specimen collection, and field photography.

Mappable Rock Units and Lithology:

Lithostratigraphy and sedimentary rocks, sedimentary formations, rock descriptions, identifying and naming rocks in the field based on the mineralogy, texture, collection of samples, sampling design.

Cross-sections:

Method of apparent dips, down-plunge projection method, balanced cross-sections, and columnar sections block diagrams, models.

Preparation of Geological Report:

Geological Report - introduction, main body of the report, conclusions, text illustrations, references, appendices.

Selected Readings

1. Clarke, S. M., 2016, Advanced Geological Mapping: A Field Guide, John Wiley & Sons.
2. Lisle, R. J., 2014, Geological Structures and Maps, A Practical Guide (3rd Edition), Butterworth-Heinemann

EES 410: Field Work in Environmental Sciences (3)

Prerequisite (Desirable): *All EES 200 and 300 level courses*

Learning Objectives

This field work is intended to consolidate and build upon the learning in Environmental Sciences theory and laboratory courses. This course intends to provide hands-on training in problem definition, field-site selection, sampling/monitoring methodology, physico-chemical characterization, data analyses and interpretation. Upon the completion of this course, the student will be able to develop research protocols/Standard Operating Procedures for running a field station, maintaining a field log, data generation and recording, and the preparation of scientific reports of their findings.

Course Contents

Introduction:

Air, water, and soil/sediment sampling in the ambient environment, choice of mutually compatible sampling methods, substrates/sampling vessels/equipment, and analytical techniques; Problem definition; Chemodynamic studies - baseline studies, comparative studies.

Site Selection:

Geomorphological features, logistics/accessibility, personnel safety, prevailing meteorology, supporting documentation and photography. [Indicative list of sites: Bhopal Upper and/or Lower lake; Betwa river banks, Bhojpur; Open sewers/waste water discharge sites in and around Bhopal; Mandideep industrial area; Salkanpur Lake; In and around Dow Chemicals (Bhopal Gas tragedy) site; Kerwa dam]

Sampling Methodology and Field Instrumentation:

Development and/or identification of standard operating protocols, pre-sampling preparation, artifact free sample collection and handling, storage and transportation.

Sample Characterization:

Selection of appropriate standard operating protocols, pre-conditioning, sample preparation, physico-chemical measurements, data retrieval and recording.

Data Analyses and Interpretation:

Description, presentation – summary tables, plotting techniques, preliminary statistics (if appropriate) and interpretation; Overall findings and conclusions.

Selected Readings

1. Nichols, A. L. (Coordinating Editor), 1998, Aerosol Sampling Guidelines, The Royal Society of Chemistry.
2. Douglas A. S., Holler, F. J., and Stanley R. C., 2006, Principles of Instrumental Analysis, Thomson Brooks/Cole.

Papers

1. Standard Operating Protocols (CPCB, India, US EPA, DRI, IMPROVE), as appropriate Instruments technical manuals/operating procedures, and reports, as appropriate

Notes

1. Field sampling/monitoring will be conducted over a period of 10-15 days

EES 411: Sedimentology Laboratory (1)

Prerequisite (Desirable): *EES 401 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, grain shape, orientation, packing properties.

Paleocurrent Analysis:

Exercises using sets of directional data to understand spatial variation in vectorial data.

Study of Thin Sections:

Study of thin sections of clastic sedimentary rocks; Arenites, arkoses, and wackes; Study of grain mounts of dense minerals; Study of thin sections and stained thin sections of carbonate sedimentary rocks.

Selected 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 Rocks Under the Microscope, Prentice Hall.

EES 413: Metamorphic Petrology Laboratory (1)

Prerequisite (Desirable): *Credited or registered in EES 403*

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

Classification and Nomenclature of Metamorphic Rocks:

Criteria for identification of equilibrium mineral associations; Relationships between textures, deformation for ordering metamorphic mineral associations.

Megascopic and microscopic study (textural and mineralogical):

Low grade metamorphic rocks: Serpentinites, albite-epidote-chlorite-quartz schists, slates, talc-tremolite-calcite-quartz schists.

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

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

Laboratory Exercises in Plotting Mineral Chemistry Data:

Determination of pressure-temperature conditions using various net-transfer and exchange reactions.

Preparation and Interpretation of Equilibrium Phase Diagrams:

DOMINO-THERAK, PERPLE_X and THERMOCALC.

Selected Readings

1. Vernon, R. H. and Clark, G. L, 2008, Principles of Metamorphic Petrology (1st Edition), Cambridge.
2. Passchier, C., and Trouw, R. A. J., 2005, Microtectonics (2nd Edition), Springer.
3. Popular equilibrium phase calculation software resources accessible via http://ees2.geo.rpi.edu/MetaPetaRen/Software/Software.html

EES 414: Geodynamics Laboratory (1)

Prerequisite (Desirable): *Credited or registered in EES 404*

Learning Objectives

The course aims to understand the basic theory and applications of geodynamics using numerical models and computational techniques. The theoretical knowledge will be utilized to model the key dynamic processes such as subduction, lithospheric extension, collision, slab break-off, intrusion emplacement, mantle convection and planetary core formation through a set of appropriately designed exercises.

Course Contents

Continuity Equations:

Continuum, continuity equation, Eulerian and Lagrangian points – what is the difference? Derivation of the Eulerian continuity equation, derivation of the Lagrangian continuity equation, comparing Eulerian and Lagrangian continuity equations.

Stress and Strain:

Equations related to stress conditions and associated strain in lithospheric plates, Mohr's Circle constructions.

The Heat Conservation Equations:

Heat generation and consumption, Fourier law of heat conduction, simplified temperature equations, heat diffusion time scales.

Gravity:

Density and gravity of rocks and minerals, equations of state, gravitational potential, geoid.

Flow Laws Related to Rock Elasticity and Melting:

Diffusion creep, dislocation creep, viscous fluid, effective viscosity, mantle rheology and channel flow.

Design of 2D Numerical Geodynamical Models:

Elasto-plastic slab bending, lithospheric extension, continental collision, slab breakoff, intrusion emplacement into the crust.

Selected Readings

1. Fowler, C. M. R., 2005, The Solid Earth: An Introduction to Global Geophysics (2nd Edition), Cambridge University Press.
2. Garya, T. V., 2009, Introduction to Numerical Geodynamic Modeling, Cambridge.

EES 416: Global Climate Change Laboratory (1)

Prerequisite (Desirable): *Credited or registered in EES 406*

Learning Objectives

In this course students will understand the procedure for extraction of data from different data formats and the availability and usage of data. They will analyze the global temperature record for the historical period and evaluate long-term trends and shorter-term fluctuations in these records. Further, they will analyze the evidence of the impact of climate forcing and mechanisms of natural variability on the global surface temperature. The ultimate goal is to help them understand the nature of the difficulties encountered in trying to extrapolate recent temperature trends into the future, and the need for models to make reasoned projections of temperature change.

Course Contents

1. Understanding different data types e.g. observation, model (historical and projection).
2. Use of “netcdf” (binary) data format to fetch data for the desired local region.
3. Understand and analyze floods, droughts, volcanoes, and El Nino in the observation temperature data.
4. Plot Climate trends (temperature).
5. Plot Climate projections (temperature).
6. Understand Regional climate variations (e.g. temperature and precipitation anomaly distribution, monsoon circulation).
7. Description and interpretation of graphical information.
8. Explore the significance of global climate change patterns of a desired region.

9. Introduce students to the difficulties encountered in trying to extrapolate recent temperature trends into the future, and the need for models to make reasoned predictions of temperature change.

Selected Readings

1. Dessler, A., 2012, Introduction to Modern Climate Change, Cambridge University Press.
2. Storch, H., and Zwiers, F. W., 2002, Statistical Analysis in Climate Research, Cambridge University Press.

Reports

1. IPCC AR5 report: Climate Change 2013: The Physical Science Basis.

EES 420/421: Science of Sustainability (4)

Prerequisite (Desirable): *All EES 100 and 200 level courses*

Learning Objectives

This course will introduce ideas of sustainability at the global scale across Earth systems and the drivers for sustainability. The course will then explore the methods necessary for designing and implementing changes in various manufacturing process to increase sustainability. Special emphasis will be placed on assessing the connections between economic activities, the natural environment, and our society.

On the 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

Background:

Status and trends - 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.

Introduction:

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.

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.

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.

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.

*Industrial Ecosystems***:**

Environmental impact assessment, policy implications**,** eco-industrial parks, development of industrial symbiosis, socio-economic dimensions of industrial symbiosis.

Selected 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.

EES 422/423/602: Marine Biogeochemical Cycles (4)

Prerequisite (Desirable): *All EES 100, 200, and 300 level courses*

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.

Selected 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 424/425/604: Aerosol Science (4)

Prerequisite (Desirable): *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 to filter substrates.

Course Contents

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.

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.

Straight Line Acceleration and Curvilinear Motion:

Relaxation time, stopping distance, curvilinear motion, impaction, cascade and virtual impactors, time-of-flight instruments.

Diffusion, Thermal and Radiometric Forces:

Diffusion coefficients, Brownian displacement, diffusion/diffusion batteries, thermophoresis, thermophoretic precipitators, radiometric forces.

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.

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.

Atmospheric Aerosols:

Biogenic and anthropogenic aerosols, general features of ambient aerosol size distributions background aerosol, urban aerosol, chemical composition of urban aerosols.

Selected Readings

1. Hinds, W. C., 1999, Aerosol Technology: Properties, Behavior, and Measurement of Airborne 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: From Air Pollution to Climate Change, Wiley-Interscience.

EES 426/427/631: Greenhouse Gas Budgets and Climate Change (4)

Prerequisite (Desirable): *All 200 level CHM, EES, MTH and PHY courses*

Learning Objectives

This course is a lead-in course towards the greenhouse gas budgets through atmospheric perspective, including a number of case studies and scientific reviews on closely related topics. Upon the successful completion of this course, the students will be able to acquire a foundation to understand how one can 'quantify' distribution of greenhouse gases and climate change as well as their multitude of relationships among driving factors. Additionally they will get an overview of different approaches that are currently available/used.

Course Contents

Climate and trace gas composition of the atmosphere:

Solar variability, radiative forcing and overall radiation balance; Energy flows in the Earth system; the global temperature record; anthropogenic perturbation of the Earth radiation balance and its mathematical formulations; greenhouse gases and enhanced greenhouse effect; atmospheric lifetimes; global carbon cycle and its compartmental model; climate sensitivity; radiation-induced feedbacks in the climate system; climate model scenarios under various radiative forcings and their uncertainties

Global greenhouse budgets:

Greenhouse gases, measurements and its interpretations; global emissions; terrestrial carbon uptake; ocean uptake; scientific reviews and current knowledge; different approaches to estimate global budgets- introduction to top-down and bottom-up modeling approaches; physical, mathematical and statistical aspects of different approaches; atmospheric transport and surface flux mechanisms; introduction to various measurement platforms and tools; Case studies.

Atmospheric transport modeling:

Different model types; the Eulerian and Lagrangian box models; 3D atmospheric transport modeling and numerical solutions; mass balance equations and practical applications; co-ordinate systems; initial and lateral boundary conditions; Atmospheric diffusion equations in terms of GHG mixing ratios; advection treatment; chemical kinetics; Statistical modeling/analysis techniques (basic); Case studies

Optimal estimation of the state (specific to GHG):

Introduction to inverse problem; Baye's theorem; tools for inverse modeling; Case studies and scientific reviews.

Selected Readings

1. Seinfeld, J. H., and Pandis, S. N., 2006, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, Wiley-Interscience.
2. McGuffie, K., and Henderson-Sellers, A., 2014, The Climate Modelling Primer (4th Edition), Wiley.

EES 502/503: Contemporary Environmental Issues (3)

Prerequisite (Desirable): *All EES 400 level courses*

Learning Objectives

To create awareness about and provide a fundamental understanding of a selection of environmental issues, relevant literature, and mitigation strategies with a special emphasis on India. This course will be conducted as a reading/seminar course and will require the submission of a term paper and oral presentation.

Course Contents

- Hydroelectric projects and their environmental impacts
- Groundwater: Mining and depletion; Strategies for deep aquifers resources; Arsenic contamination
- Climate change impacts on river discharge regimes, reservoir storages, and the Glacial Lake Outburst Floods (GLOFS)
- Acid mine drainage
- Urban heat island
- Urban air pollutants – gas and particle
- Landfill and solid waste
- Urban waste water management
- Industrial accidents
- Radioactive waste management
- Deforestation and desertification
- Biodiversity hotspots and conservation paleobiology

Selected Readings

1. Slattery, M., 2014, Contemporary Environmental Issues, Kendall Hunt Publishing.
2. Publications of the Centre for Science and Environment (CSE), India, as suggested by the Instructor.

EES 505/645: Remote Sensing and GIS (4)

Prerequisite (Desirable): *All EES 200, 300 and 400 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

Introduction:

Structure of the course, development of remote sensing techniques, fundamental principles, advantage and limitations of remote sensing.

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.

High Altitude Photography:

Interaction between light and matter, color science, film technology; Aerial photography - vertical and oblique photography.

Spectroscopy of Rocks and Minerals:

Introduction, basic principles of spectroscopy, electronic process and vibrational processes, spectral reflectance of minerals.

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.

Thermal Remote Sensing:

The Earth`s radiant energy, surface, radiant temperature and kinetic temperature, Planck’s law and emissivity, interpretation of thermal imagery.

Microwave Remote Sensing:

Introduction to microwave, passive and active microwave remote sensing, RADAR technology, interferometry.

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.

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.

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.

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.

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.

Integration of Remote Sensing Data with other Geo-data:

Introduction to GIS, transformation of remote sensing data and other data in GIS format.

Indian Remote Sensing Program:

Remote sensing program by Indian Space Research Organization; INSAT, IRS, Oceansat, Resourcesat and Cartosat data and their applications; Future directions.

Selected Readings

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

EES 510/511/601: Isotope Geochemistry (4)

Prerequisite (Desirable): *All EES 400 courses*

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

Isotopes and Radioactivity:

Basics of atomic and nuclear physics; Synthesis, relative abundances and stability of various nuclides; Radioactivity, radioactive decay modes; Radiation detection and environmental protection.

Instrumentation:

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.

Isotope Dating:

Growth and decay of radiogenic daughters; Basic assumptions of dating; Isochron dating, and related analytical uncertainties and geological errors; Dating using radioactive parent only (^{10}Be, ^{14}C and ^{36}Cl), parent–daughter couple (^{40}K–^{40}Ar, ^{87}Rb–^{87}Sr, ^{147}Sm–^{143}Nd, ^{176}Lu–^{176}Hf, ^{187}Re–^{187}Os, ^{238}U–^{206}Pb), decay series disequilibria (^{238}U–^{234}U–^{230}Th–^{236}Ra), radiogenic daughter only (Pb–Pb and Ar–Ar) and extinct parent (^{26}Al, ^{41}Ca, ^{53}Mn, ^{60}Fe, ^{107}Pd, ^{129}I, ^{146}Sm, ^{182}Hf); Ages of crystallization and last metamorphism; Sediment depositional ages; Model ages; Exposure ages; Archaeological ages.

Radiogenic Isotope Geochemistry:

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.

Stable Isotope Geochemistry:

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.

Noble Gas Geochemistry:

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.

Selected 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, Tretise or Geochemistry (2^{nd} Edition), Elsevier Science.
5. Zeebe, R. E., and Wolf-Gladrow, D., 2001, CO2 in Seawater: Equilibrium, Kinetics and Isotopes (1^{st} Edition), Elsevier Science.
6. Hoefs, J., 2015, Stable Isotope Geochemistry (7^{th} Edition), Springer.

EES 512/513/603: Mineral Thermodynamics (4)

Prerequisite (Desirable): *All EES 400 level courses*

Learning Objectives

Estimation of pressure-temperature (P-T) conditions of rocks is of fundamental importance for understanding the tectonic processes and large-scale vertical movement of materials at great depth within the Earth. In the last four decades, considerable progress has been achieved in understanding the tectono-thermal evolution of rocks by using systematic analysis of compositional properties and phase relations of their mineral assemblages. This course aims to use the concept of classical thermodynamics and solution models to understand the nature of mineral reactions using modern computational techniques.

Course Contents

Introduction:

Rock forming minerals and chemical thermodynamics.

Overview of Mineralogy:

Systematic classifications of minerals, determination of structural formulae based on the chemical analyses; Silicate Minerals - classification, chemical structure, mode of occurrence.

Introduction to Thermodynamics:

Free energy in the form of heat and work, first and second laws of thermodynamics, entropy, enthalpy, and third law of thermodynamics, Gibbs free energy and mineralogical phase rule, phase transformation and polymorphism, elementary phase diagrams for common rock forming minerals.

Thermodynamics of Solutions:

Concept of solid solution in mineralogy, conservative and non-conservative components of solutions, chemical potential, chemical equilibrium, fugacity and activity of a component in solution.

Thermal Pressure, Earth's Interior and Adiabatic Processes:

Thermal pressure, adiabatic temperature gradient, temperature gradients in the Earth's crust, mantle and core, isotropic melting in the Earth's interior, the Earth's mantle and core: linking thermodynamics and seismic velocities.

Element Formation in Geological Systems:

Fractionation of major elements, exchange equilibrium and distribution coefficient, temperature and pressure dependence of distribution coefficient, compositional dependence of distribution coefficient, trace element fractionation between mineral and melt, metal-silicate fractionation - magma ocean and core formation; Pressure dependence of metal-silicate partition coefficients.

Thermodynamics for Igneous Systems:

Lever rule for igneous system, correlation of mineral paragenesis and Gibbs free energy in binary and ternary systems, introduction to MELTS family of algorithm.

Thermodynamics of Metamorphic Systems:

Definition, condition and type of metamorphism, primary mineral assemblage and mineral paragenesis in metamorphic rock, graphical representation of mineral para-genesis and free energy of metamorphic reactions, examples of metamorphic phase diagrams.

Introduction to Computational Phase Equilibrium:

Forward and Backward modelling of igneous and metamorphic reaction textures, calculation of Gibbs free energy of complex chemical systems using computational software THERMOCALC, PERPLEX and Domino-Theriak

Selected Readings

1. PatiñoDouce, A., 2011, Thermodynamics of the Earth and Planets, Cambridge University Press.
2. Ganguly, J., 2010, Thermodynamics in Earth and Planetary Science, Springer.
3. Ganguly, J., and Saxena, S., 2012, Mixtures and Mineral Reactions, Springer.
4. Philpotts, A., and Auge, J., 2009, Principles of Igneous and Metamorphic Petrology (2nd Edition), Cambridge.

EES 514/515/605: Indian Monsoon and its Variability (4)

Prerequisite (Desirable): *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

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.

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.

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.

Intraseasonal Variation and Intraseasonal Oscillation:

Active-weak spells and breaks in the monsoon.

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.

Indian Ocean and the Indian Monsoon:

Role of SST on monsoon; Indian Ocean Dipole (IOD) mode variability and association with winter and summer monsoon.

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.

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; Agriculture production link to Gross Domestic Product.

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.

Selected 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.

Reports

1. Rao, Y. P., 1976, Southwest Monsoon. Meteorological Monograph (synoptic meteorology). No. 1, India Meteorological Department, New Delhi.
2. 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 615: Reconstructing Quaternary Continental Environments and Climates of South Asia (4)

Learning Objectives

This course aims to provide an inter-disciplinary perspective to studying past continental sedimentary environments and climates of the Indian Sub-Continent. Going beyond the instrumental records of historical time scales requires the use of proxy data that is embedded in natural archives such as ice cores (glaciers), lake sediments, tree rings, speleothems and others. Apart from laying the foundations required for understanding multiple approaches to environmental and climate reconstructions of the continental sedimentary record, overviews of the stratigraphy and sedimentation patterns of some selected Quaternary domains of the Indian Sub-continent will be presented. Case histories from the Himalayan lake sediments and glaciers, Thar lake sediments, the large river systems of the Indo-Gangetic Plains, speleothems, and tree rings shall be used to elucidate the paleao-climatology of the continental records of the South Asian monsoonal regime.

Course Contents

Depositional Sedimentary Environments:
Sedimentary Environments, as a product of the complexity of earth surface processes, nature of changing sedimentary record through the Cenozoic, incompleteness of stratigraphic records; Tectonics, climate and eustasy – their role in sediment accumulation; Fluid flow and sediment transport, clastic sediments, sediment routing systems and concepts of sediment connectivity; Carbonate sediments and depositional settings; Lithification and diagenesis; Facies analysis, seismic facies analysis; Sedimentary basins- formation mechanisms and tectonic classification

Reconstruction of Quaternary Paleoclimates:
Overview of climate science; Climate archives, data and models; dating climate records; CO_2 and the long term climate; Orbital scale climate change; Insolation control on monsoons and ice sheets; Deglaciation, Last Glacial maximum (LGM) and climate since last deglaciation; millennial oscillations of climate; Humans and Pre-Industrial climate; Climate change in the last millennium.

Case Histories of Quaternary Climate Reconstructions:

Overview of the Cenozoic Sedimentary basins of India with a focus on Himalayan, Indo-Gangetic Plains (IGP) and Thar Quaternary Sequences; Review of monsoonal history over the last 18000 years; Himalayan lake and Ice core records; Lake records of Thar and its margins; Fluvial and Lake records of the IGP; Millenial scale monsoonal reconstructions from tree rings and speleothem records from the Indian Sub-continent; Inter-regional comparisons of Holocene climate changes in India and other Asian monsoonal systems.

Selected Readings

1. Nichols, G., 2009, Sedimentary and Stratigraphy (2nd Edition), Wiley – Blackwell.
2. Prothero, D. R., and Schwab, F., 2014, Sedimentary Geology – An Introduction to Sedimentary Rocks and Stratigraphy (3rd Edition), WH Freeman and Company.
3. Jones, N. P., and Jones, B., 2015, Origin of Carbonate Sedimentary Rocks, Wiley.
4. Bradley, R. S., 2015, Palaeoclimatology: Reconstructing Climates of the Quaternary (3rd Edition), Elsevier.
5. Ruddimann, W. F., Earth’s Climate – Past and Future (3rd Edition), W H Freeman and Company.

EES 629: Advanced Mineralogy (4)

Learning Objectives

Minerals are the basic building blocks of Earth. This advanced course is designed for PhD students to provide an understanding of classification, structure, properties and thermodynamics of rock forming minerals.

Course Contents

Introduction:

Structure of the course, introduction to the subject and history of mineralogy.

Crystal and Mineral Chemistry:

Introduction to crystal chemistry - ionic radii and coordination number; Bonding: Ionic and Chemical bonding, coordination polyhedra, radius ratio, and Pauling’s rules;

Isomorphism, polymorphism, twinning, phase transformations and crystalline defects; Mineralogical Phase Rule, Binary and Ternary phase diagrams (binary eutectic, peritectic, solid solutions, exolution).

Descriptive Mineralogy of Common Rock Forming Minerals:

- Ortho and ring silicates - Olivine, Garnets
- Chain silicates - Pyroxene group and Amphibole group
- Sheet silicates - Mica group
- Framework silicate - Feldspars
- Non-silicates - Native elements, sulfides; oxides, hydroxides and halides with emphasis on the Spinel group; Carbonates, sulfates and phosphates.

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.

Introduction to Computational Phase Equilibrium:
Forward and Backward modeling of stable mineral assemblages, calculation of Gibbs free energy of complex chemical systems.

Selected 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 Forming Minerals (3rd Edition), Mineralogical Society of Great Britain and Ireland.
3. Nesse, W. D., 2011, Introduction to Mineralogy (2nd Edition), Oxford University Press.

EES 630: Climate Change – Extreme Events (4)

Learning Objectives

This course provides an introduction to climatic phenomena and dynamics, the future climate change and its assessment. Introduction to extremes and the methods of analysis of extreme events and the assessment of the climate change impacts on extreme events and the adaptation and mitigation of climate change impacts.

The course exposes students to climatology concepts and climate dynamics of the past, present and future, methods for the assessment of climate change, methods of analysis of extreme events, the impact of climate change, the adaptation and mitigation of climate change impacts on extreme events.

Course Contents

Introduction to climate

Weather and climate; energy and climate system; circulation and wind; climate change; impacts of climate variability and change on phenomena's like El Nino/La Nina, monsoons, teleconnections; global warming.

Introduction to Extreme

What is extreme; types of extreme (i) Global scale - solar storm, ice age, global warming (ii) Synoptic scale – ozone hole, El-Nino/La Nina, monsoons, heat waves (iii) Mesoscale – floods, droughts, cyclones, Fog; (iv) Microscale – clear air turbulence, hail, lightning, avalanche.

Climate change and extreme events

Relation between climate change and extreme events; hydrological extremes - drought, flood; temperature extremes - heat waves, cold waves, forest fire); tropical cyclones, glaciers, permafrost; statistics for extreme events - spatial and temporal variability of extreme events, methods of extreme events evaluation.

Future extreme events

Methods and models assessment of extreme analysis, Scenario-based climate predictions and projections, Global Climate Models (GCMs), Regional Climate Models (RCMs); projected changes in weather and climate extremes (temperature, precipitation, wind).

Adaptation and mitigation of climate change impacts on extremes events

Impact on agriculture; human health; analysis of extreme-events impact; managements of extreme events; vulnerability assessment; risk; uncertainty; adaptation and mitigation measures.

Selected Readings

1. Dessler, A., 2012, Introduction to Modern Climate Change, Cambridge University Press.
2. Ruddiman, W. F., 2001, Earth's Climate: Past and Future, W. H. Freeman & Co Ltd.
3. C. Donald Ahrens, Essentials of Meteorology (selected chapters)
4. McGuffie, K., and Henderson-Sellers, A., 2014, The Climate Modelling Primer (4th Edition), Wiley.

Report

1. Intergovernmental Panel on Climate Change, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, Cambridge University Press, 2012
2. IPCC AR5 report: Climate Change 2013: The Physical Science Basis

EES 643: Advanced Structural Geology (4)

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

Stress Strain and rock failure:

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 and ductile deformation.

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.

Advanced Fabric Analyses:

Strain analyses from quartz C-axis, deformed pebble; anisotropy of magnetic susceptibility

Advanced Mohr's Circle Analyses:

Understanding 3D stresses and failure using Mohr's circle; Stresses around a bore hole. Stresses around a tunnel.

Application of Structural Geology in Oil and Gas Exploration:

Fault seal analyses; Balanced cross-section; Interpretation of complex structure from seismic; Discrete fracture network modelling.

Geomechanics:

Origin of pore ppressure, over pressure, pore pressure prognosis, fracture pressure, upper bound, lower bound fracture presure, mud window calculation. hydraulic fracturing, natural and induced fracturing in CBM and Shale gas. fracturing and permeability.

Advanced methods:

Basics of analogue and numerical modeling, application of Finite Element Analysis, Geogenic Electromagnetic Radiation (EMR) technique for stress calculations.

Selected 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.