# GEOL 40290: Basin Analysis

**MODULE COORDINATOR**: Prof. Peter Haughton

**ADDITIONAL LECTURERS:** Dr Aggeliki Georgiopoulou
Dr Eoghan Holohan

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| **CREDITS:** 10 | **MODULE LEVEL**: 4 | **SEMESTER**: II |

**PRE-REQUISITES/PRIOR LEARNING**:

This module is suitable for students who have taken intermediate courses in sedimentology, stratigraphy and structural geology (for example UCD modules GEOL 20150, GEOL 30040, GEOL 30100, GEOL 30350)

**OVERVIEW OF MODULE:**

This module is in two parts: (a) Basin Analysis and (b) Structural Geology & Tectonics. It uses a combination of lectures, individual and team exercises, a four-day field course in the Clare Basin, and a seminar session. The first part covers the development of sedimentary basins and their fill, and the techniques that are used to unravel the history of basin filling. The second part outlines methods for the analysis and modelling of basin extension, fault system growth, fault-related fluid flow, salt tectonics, basin inversion, and fold-and-thrust systems, and it explores the architecture of mountain belts.

**LEARNING OUTCOMES:**

On completion of this module students should be able to:

1. Identify sequences stratigraphic surfaces and characteristics in outcrop, core and seismics;
2. Use wireline log data to infer lithology and the nature of fluids in uncored wells;
3. Integrate different types of data to provide reasoned interpretations of depositional environments, basin filling history and lithology prediction;
4. Quantitatively establish the kinematics of fault zones within sedimentary sequences.
5. Demonstrate an understanding of existing models of extensional basin evolution, related fault system growth, salt tectonics and basin inversion;
6. Describe the impact of faults/fractures on fluid flow within basins.

**ASSESSMENT:**

Continuous Assessment: 50%
*(Continuous assessment of lab books , a practical test and a seminar presentation)*

Examination: 50%
*(3-hour end of semester written examination)*

**BASIN FILL:**

*15 x 4 hour sessions, including lectures, lab work and a four-day field class.*

### Session 1:

**Lectures 1-2: Tectonics and basin formation** *(Prof. P.D.W. Haughton)*
Outline of main subsidence mechanisms, focussing on basins as containers for sediment and exploring the interaction between tectonics and basin filling. Contrasts between extensional rift basins, sag basins, flexural basins and strike-slip basins. Implications for subsidence patterns (spatial and temporal), thermal history and basin longevity.

**Practical 1: Basin diagnosis** *(Prof. P.D.W. Haughton)*
Selected data from a basin – but what type of basin is it?

### Session 2:

**Lectures 3-4: Introduction to wireline logs** *(Prof. P.D.W. Haughton)*
Objectives of wireline logging. Principles of petrophysics. Geological interpretation of resistivity, spontaneous potential, gamma, sonic, neutron, density and dipmeter logs. Identification of fluid types and properties; recognition and quantification of porosity and porosity types; sedimentological and burial history interpretation. Integration of log types.

**Practical 2: Wireline log interpretation** *(Prof. P.D.W. Haughton)*
Use of wireline logs to constrain depositional evolution and quantify porosity and determine water saturations.

### Session 3:

**Lecture 5: The accommodation:supply (A:S) balance** *(Prof. P.D.W. Haughton)*
The importance of the accommodation-supply balance for stratigraphy. What controls the clastic sediment supply? What is the evidence that global sea level has varied through time? Can a eustatic signal be isolated from relative sea level signals? How do eustatic variations combine with tectonic subsidence and supply and what are the implications for stratigraphy in different types of basins or within different parts of the same basin?

**Practical 3: Core-to-log matching exercise** *(Prof. P.D.W. Haughton)*
Core and wireline log data from a producing North Sea oilfield. The task is to (a) match the cores to the wireline logs and determine core-to-log shifts, and (b) interpret the reservoir interval.

### Session 4:

**Lecture 6: Sequence stratigraphy – an introduction** *(Prof. P.D.W. Haughton)*
Systems tracts and initial Exxon sequence stratigraphic model. Main types of sequence stratigraphic surfaces. Strengths and shortcomings of the original model.

**Practical 4: Romagna sequence stratigraphic correlation exercise** *(Prof. P.D.W. Haughton)*
A four borehole correlation in a coast-normal traverse across the Romagne Plain south of the Po delta.

### Session 5:

**Lecture 7: Practical sequence stratigraphy** *(Prof. P.D.W. Haughton)*
Parasequences, systems tracts and different approaches to sequence definition. How sequence stratigraphy is applied in practise; surface recognition in cores and outcrops across a range of depositional settings. Facies dislocations. Lowstand shorelines and incised valley fills.

**Practical 5: Sequence stratigraphic puzzles** *(Prof. P.D.W. Haughton)*
Short exercises illustrating the application of sequence stratigraphic principles in subsurface lithology prediction and interwell correlation.

### Session 6:

**Practical 6: Book Cliffs exercise** *(Prof. P.D.W. Haughton)*
A practical based on outcrop and subsurface information from one of the classic sequence stratigraphic datasets, the Book Cliffs in Utah, USA, a 100 km traverse from the coastal plain to offshore shelf. The focus is on correlation of parasequences and sequence stratigraphic surfaces, interpretation of the depositional evolution and tectonic vs. sea-level control on the stratigraphic architecture.

### Session 7:

**Lecture 8: Seismic stratigraphy – Principles** *(Dr A. Georgiopoulou)*
Concept of seismic reflectors and their relationship to fluid contacts, unconformities and stratal surfaces. Objectives and methodology of seismic stratigraphy. Analysis of seismic sequences using (a) Internal Reflection Configuration (e.g. amplitude, continuity, velocity), Sequence Relationships (terminational, transitional) and (c) External Geometry (e.g. sheet, drape, mud, infill). Interpretation and prediction of lithofacies.

**Lecture 9: Seismic stratigraphy – basin exploration scale** *(Dr A. Georgiopoulou)*
Potential and pitfalls of seismic stratigraphy in wildcat basins. Use of seismic stratigraphy in basin and prospectivity analysis illustrated by examples from both shallow and deep water basins.

**Practical 7: Porcupine clinoforms/Bahama Bank - Part 1** *(Dr A. Georgiopoulou)*
Application of techniques of seismic stratigraphy to basin analysis using examples from different basins and different geological settings.

### Session 8:

**Practical 7 (contd.): Porcupine clinoforms/Bahama Bank - Part 2** *(Dr A. Georgiopoulou)*
Application of techniques of seismic stratigraphy to basin analysis using examples from different basins and different geological settings.

### Session 9:

**Lecture 10: Carbonate sequence stratigraphy** *(Prof. P.D.W. Haughton)*
Outline of the principles behind the application of sequence stratigraphy to carbonate environments; contrasts between carbonate and clastic sediment production and supply and the way supply is coupled to sea level fluctuations. Sequence stratigraphy of main carbonate platform types.

**Practical 8: Carbonate sequence stratigraphy practical - Part 1** *(Prof. P.D.W. Haughton)*
A two-part exercise, combining core and petrographical data from a carbonate basin margin in order to reconstruct the stratigraphy and depositional evolution.

### Session 10:

**Practical 8 (contd.): Carbonate sequence stratigraphy practical - Part 2** *(Prof. P.D.W. Haughton)*
A two-part exercise, combining core and petrographical data from a carbonate basin margin in order to reconstruct the stratigraphy and depositional evolution.

### Session 11:

**Lecture 11: Diagenesis and reservoir quality** *(Prof. P.D.W. Haughton)*
Porosity-depth trends in sedimentary basins. Compaction and intergranular volumes. Diagenetic fluids. Common cement types and controls. Cement paragenesis.

**Practical 9: Wytch Farm reservoir quality exercise** *(Prof. P.D.W. Haughton)*
A petrographical reservoir quality based exercise using data from a producing well on the Wytch Farm oilfield in the south of England. Analysis of texture, pore systems, paragenesis and the controls on porosity and permeability.

### Field Class: Co Clare (four days) *(Prof. P.D.W. Haughton and Dr A. Georgiopoulou)*

A four-day field course to investigate the application of sequence stratigraphy of large sea cliffs in Co. Clare and to consider the applied significance of sequence and seismic stratigraphic workflows in industry.

### Session 12:

**Practical 10: Clare Wrap-up session** *(Prof. P.D.W. Haughton and Dr A. Georgiopoulou)*
Student-led summary of the previous weekends field work. Working as a group, they pull together key observations and interpretations on a whiteboard which is then captured digitally and posted to Blackboard. They then inspect recently drilled behind-outcrop cores and wireline logs from some of the localities they visited.

### Sessions 13-15:

**Practical 11: Kingdom-based 3D seismic interpretation exercise** *(Dr A. Georgiopoulou)*
Work station based practical exercise involving interpretation of faults and stratal surfaces in a 3D seismic volume from the Porcupine Basin, offshore Ireland.

**STRUCTURAL GEOLOGY:**

*8 x 4 hour sessions, including lectures and lab work.*

### Session 1:

**Lecture 1: Isostatic models of basin evolution.** *(Dr E.P. Holohan)*
Roles of isostatic and thermal adjustments in development of extensional basins (McKenzie model). Significance of depth-dependent stretching models –for e.g. "Steer's head" basin geometry. Pure shear vs simple shear models for lithosphere extension.

**Lecture 2: Flexural-Isostatic models of basin extension.** *(Dr E.P. Holohan)*
Role of faults and related flexure in development of extensional basins. Incorporation of fault interaction and basin subsidence (Flexural Cantilever Model). Application of flexural cantilever model to real basin development. Production of "steer's head" geometry at basin margins due to flexural uplift, erosion and thermal subsidence.

**Practical 1: Estimation of basin extension** *(Dr E.P. Holohan)*
Estimates of basin stretching factor for the Northern North Sea by using a variety of methods, including heave estimates, crustal thinning, thermal subsidence and fault populations.

### Session 2:

**Lecture 3: Geometric and kinematic coherence of fault systems** *(Dr E.P. Holohan)*
Scaling properties of faults. Simple fault growth models. Kinematic analysis of faults using displacement back-stripping methods.

**Lecture 4: Fault system growth** *(Dr E.P. Holohan)*
Fault growth rates and regional strain rates. Strain localisation within fault systems.

**Practical 2: Analysis of normal fault growth and interplay with sedimentation** *(Dr E.P. Holohan)*
Growth of faults and related sedimentation in the Taranaki Basin, New Zealand. Kinematic analysis of faults, as well as examination of fault displacement rates and relationship to sedimentary expansion index.

### Session 3:

**Lecture 5: Forms and Nomenclature of Salt Tectonics** *(Dr E.P. Holohan)*
Why and where salt moves. Salt diapirs - Rayleigh Taylor instabilities? Basic forms and terminology in salt tectonics. Internal structure and spacing of salt diapirs – roles of viscosity, thickness of salt and overburden.

**Lecture 6: Mechanisms of salt diapirism** *(Dr E.P. Holohan)*
Use of pre, syn and post kinematic sedimentary sequences to unravel salt tectonic history. Diapir growth – up-building vs down-building. Salt sheets - reactivation and segmentation. Discussion of driving mechanisms of diapirsim – buoyancy, differential loading, thermal convection and gravity spreading. Salt-related thin-skin tectonics in extension and compressional settings.

**Practical 3: Analysis/reconstruction of salt tectonics** *(Dr E.P. Holohan)*
Geometry and kinematics of salt diapirism and related faulting in the North Sea from seismic data.

### Session 4:

**Lecture 7: Faults as barriers** *(Dr E.P. Holohan)*
Principles of 2-phase flow through rocks. Fault rocks and their entry pressures. Examples of fault seals. Calculation of Shale Gouge Ratios on fault surfaces and their application to fault sealing. Relation between Shale Gouge Ratio and pressure differences across fault.

**Lecture 8: Faults as flow conduits** *(Dr E.P. Holohan)*
Principles of flow through fractures. Flow within planes or pipes? Stress sensitivity. Nature of mineral-bearing fluids and the effects of faults on mineralisation.

**Practical 4: Fault seal potential analysis using SGR triangle** *(Dr E.P. Holohan)*
Construction of Allan diagram for identification of juxtaposition seal and use the shale gouge ratio method to identify possible membrane seals along a fault through a sedimentary sequence. Estimation of oil column height and accumulation volumes for varying levels of SGR sealing cut-offs.

### Session 5:

**Lecture 9: The internal composition and structure of shear zones** *(Dr E.P. Holohan)*
Overview of strike-slip tectonics and associated basins. Kinematic indicators associated with brittle and ductile shear zones, transpression/transtension and faults. Geometry and kinematics of fault zones and origin and nature of fault rocks.

**Practical 5: Fault Rocks - structural/kinematic analysis** *(Dr E.P. Holohan)*
Hand specimen and thin section analysis of faults rocks in sandstone and shale sequences. Sandstone cataclasites, shaley gouge and granulation seams. Identification of kinematic indicators.

### Session 6:

**Lecture 10: Identification and Mechanisms of Inversion in Basins** *(Dr E.P. Holohan)*
Key signs such as exhumed sequences, reversed fault motion, hangingwall folds, unconformities. Significance of recognizing inversion for structural interpretation and prospectivity. Mechanisms - collisional tectonics, mantle plumes, strike-slip tectonics.

**Lecture 11: Examples and Analysis of Inversion.** *(Dr E.P. Holohan)*
Natural examples of varying degrees of inversion and associated structural styles, such as in the Celtic Sea, Wessex Basin and English Channel, North Sea, Western Alps and Irish Sea. Quantification of inversion by using null point, inversion ratio and displacement back-stripping.

**Practical 6: Analysis of Fault Inversion** *(Dr E.P. Holohan)*
Perform displacement back-stripping to determine the nature, extent and timing of inversion on major faults in the Southern Taranaki Basin, New Zealand. Using displacement/length data, discuss: (i) the impact of initial fault size on inversion; (ii) the geometric attributes of faults before and after their inversion.

### Session 7:

**Lecture 12: Internal geometry of thrust sheets.** *(Dr E.P. Holohan)*
Review of ramp-flat geometries, duplexes, antiformal stacks and imbricate systems. Side wall ramps and tear faults. The scaling properties of thrusts. Thrust-related folding.

**Lecture 13: The mechanical paradox of large overthrusts.** *(Dr E.P. Holohan)*
Simple mechanical models of thrust blocks. Gravity spreading, the effect of pore fluid pressures and tapered wedge (or critical wedge) models for thrust sheets. Examples of wedge taper data from nature and relationship to theory.

**Practical 7: Section balancing of thrust systems** *(Dr E.P. Holohan)*
Line balancing of thrusted sequences to test plausibility of cross-sections and estimate shortening. Using section data from the Jura Mountains and the Lewis Thrust (Rockies).

### Session 8:

**Lectures 14: Anatomy of orogenic belts** *(Dr E.P. Holohan)*
Although no single map or cross-section can provide a universal model of an orogenic belt, this lecture is intended to highlight that orogens have much in common, a fact which relates to the similarity in prevailing geometries and processes associated with mountain building. Much of this lecture is drawn from Chapter 22 of Twiss and Moores "Structural Geology".

**Practical 8: Structural analysis of the Moine Thrust system** *(Dr E.P. Holohan)*
Balancing of duplexes within the Moine thrust. Strain distribution within the Moine thrust system, using descriptions from two virtual field trips for areas straddling the system.