# Universitat Politècnica de Catalunya - Numerical Geodynamic Modelling

## Course description

In recent decades numerical modelling has become an essential approach in geosciences in general and in geodynamics in particular. This is a very natural process since direct human observation scales are extremely limited in both time and space (depth) and rapid progress in computer technology offers every day new and exceptional possibilities to explore sophisticated mathematical models and this is true in every discipline, and even industrial applications. Numerical modelling in geosciences is widely used for both testing and generating hypotheses and strongly pushing geology from an observational, intuitive to a deductive, predictive natural science. Geo-modelling and geo-visualisation play a strong role in relating different branches of geosciences. Therefore, it has become necessary to have some knowledge about numerical techniques before planning and conducting state-of-the-art interdisciplinary research in any branch of geosciences. In this respect, geodynamics is traditionally ‘infected’ by numerical modelling and promotes the progress of numerical methods in geosciences.

## Learning Outcomes

By the end students are expected to be able to:

* Theory the basic principles of geodynamics, physical properties of rocks
* Model numerical techniques, initial and boundary conditions, and the differences between finite difference and finite element methods
* Software Gale ,Underworld and VISIT

## Lecturer

## Professor Sergio Zlotnik from Universitat Politècnica de Catalunya. Mainly engaged in numerical simulation research of geology and geophysics.

## Course topics

## Theme 1 - Intro to Geodynamics

This lesson is a simple introduction to geodynamics, emphasizing some important concepts and theories. Short history of geodynamics and numerical geodynamic modelling. A brief summary of models and numerical simulations in geodynamics, including basic equations of fluid mechanics, finite difference method, finite element method. Show some common models and software.

At the end of the mini-series, students should be able to:

* Get familiar with the basic processes.
* Get familiar with some geophysical observables used to constrain Geodynamic processes.
* Understand the role numerical modelling has in the study of geodynamic processes.

## Theme 2 - Physical processes

This lesson mainly introduces the basic physical processes in geodynamics. Focus on the fluid mechanics. Definition of a geological medium as a continuum. Field variables used for the representation of a continuum. Methods for definition of the field variables. Eulerian and Lagrangian points of view. Continuity equation in Eulerian and Lagrangian forms and their derivation. Advective transport term. Continuity equation for an incompressible fluid. Momentum equation. Viscosity and Newtonian law of viscous friction. Navier–Stokes equation for the motion of a viscous fluid. Stokes equation of slow laminar flow of highly viscous incompressible fluid and its application to geodynamics. Simplification of the Stokes equation in case of constant viscosity and its relation to the Poisson equation. Analytical example for channel flow.

At the end of the mini-series, students should be able to:

* Get familiar with the basic processes, models and conservation equations.
* To understand the basic function of the terms present on the equations (advection, diffusion, inertia, etc).
* To understand the assumptions and simplifications taken on Geodynamic modelling.

## Theme 3 - Numerical methods

This lesson mainly introduces numerical methods in geodynamics. Analytical and numerical methods for solving partial differential equations. Using finite differences to compute various derivatives. Discretisation of the heat conservation equation with finite differences. Conservative and non-conservative discretisation schemes. Explicit and implicit solution schemes of the heat conservation equation. Advective terms: upwind differences, numerical diffusion. Advection of temperature with markers. Subgrid diffusion. Thermal boundary conditions: constant temperature, constant heat flux, combined boundary conditions. Numerical implementation of thermal boundary conditions.

At the end of the mini-series, students should be able to:

* Understand the numerical solution of a simplified heat equation using Finite Differences (FD).
* Understand the concept of stability of a numerical scheme.

## Theme 4 - Physical properties

This lesson mainly introduces physical properties in geodynamics.Density of rocks and minerals. Thermal expansion and compressibility. Dependence of density on pressure and temperature. Equations of state. Solid-state creep of minerals and rocks as the major mechanism of deformation of the Earth’s interior. Dislocation and diffusion creep mechanisms. Rheological equations for minerals and rocks. Effective viscosity and its dependence on temperature, pressure and strain rate. Formulation of the effective viscosity from empirical flow laws.

At the end of the mini-series, students should be able to:

* Get familiar with basic concepts of rheology
* To understand the role of rheology in the computational cost of numerical simulations.
* Models for other physical properties of rocks
  + Density
  + Thermal expansivity
  + Thermal conductivity

## Theme 5 - Numerical Studies

This lesson mainly show numerical studies in geodynamics. Design of numerical models for different geodynamic processes: visco-elasto-plastic slab bending, retreating subduction, lithospheric extension, collision, slab detachment, intrusion emplacement, mantle convection with phase changes, core formation.

At the end of the mini-series, students should be able to:

* Thermal evolution of the Oceanic Lithosphere.
* Subduction dynamics and the origin of Andean orogeny.
* Coupled mantle dripping and lateral dragging controlling the lithosphere structure of the NW-Moroccan margin and the Atlas Mountains

## Theme 6 – Outlook, Question and Answer

Answer some students' questions. Introduce some recent research progress and research methods. Current and future directions of numerical geodynamic modelling development: 3D, FEM,GPU/cell-based computing, interactive computing, realistic physics, visualization challenges etc.

At the end of the mini-series, students should be able to:

* Q & A.
* Current cutting-edge technologies in geodynamics.
* Current challenges in geodynamics.

**Course Timetable**

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| **Date** | **Time (NZTZ)** | **Lecture topic** | **Lecturer** |
| **5 Dec** | **1800 - 2200** | Theme 1 - Intro to geodynamics | Sergio Zlotnik |
| **6 Dec** | **1800 - 2200** | Theme 2 - Physical processes | Sergio Zlotnik |
| **7 Dec** | **1800 - 2200** | Theme 3 - Numerical methods | Sergio Zlotnik |
| **8 Dec** | **1800 - 2200** | Theme 4 - Physical properties | Sergio Zlotnik |
| **9 Dec** | **1800 - 2200** | Theme 5 - Numerical studies | Sergio Zlotnik |
| **12 Dec** | **1800 - 2200** | Theme 6 – Outlook, question and answer | Sergio Zlotnik |
| **Pending** | **6 hours** | Presentation Discussion | Students (each group prepare for the presentation) |
| **Pending** | **6 hours** | Project Presentation | ZJU Professors |

**Assessment and Assignments**

Student presentations and all the markings are left to ZJU Professors