Geology and Mechanics
ALERT Summerschool
Innsbruck, 16.-20. September 2013

Dimitrios Kolymbas

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General concept

Viewed from the aspect of Continuum Mechanics, Geology is the most fascinating exhibition of large deformations of solid materials and the accompanying pattern formation. The latter is dominated by the phenomenon of localisation of deformation, think of shearbands and faults. The scale invariance of the relevant deformation mechanisms implies that the same phenomena are observed in a large range of scales. What is observed and studied by Soil Mechanics in the small is also observed by geologist in large scales. It proves (cf. the law of BYERLEE) that sand is an appropriate solid material to model large deformations of geological strata. This fact is scientifically exploited by the so-called sandbox models, where geological folding and faulting is modeled in the laboratory with sand. The trapdoor problem, a widespread benchmark of soil mechanics, exhibits exactly the same patterns as the formation of grabens and ring structures in the lithosphere. An important feature in Soil Mechanics is the fact that fragmentation of sand bodies is always manifested by the formation of rigid blocks that slide relative to each other. The analogon in large scale is the motion of continents relative to each other with the accompanied friction and earthquakes. Also vulcanism has a counterpart in the small scale of Soil Mechanics, the so-called sand-volcanos.
The above stated effects are highly interesting and can cross-fertilize scientists from various disciplines.

It is desirable to have inspiring lectures to open new views about concepts, challenges, tasks and possibilities. Lengthy equations or tables would be boring.

Overlapping presentations are not necessarily to be avoided. It is nice to get questions illuminated by different persons.

Tentative programme

The available time is a full week, Monday to Friday. Taking 4 teaching units each day (09:00-10:30, 11:00-12:30, 14:00-15:30, 16:00-17:30) we have to cover 20 teaching units.

Provided the weather is good we organize a geologic excursion to the Alps, to be guided by Dr. Gunther Heißel. The excursion is scheduled for Thursday, but it would be nice to leave the option for Wednesday, in case the weather forecast for Thursday is rain.

	Mo	Tu	We	Th	Fr
09:00-10:30	Kolymbas	Lewis	Corti	Excursion	Le Pourhiet
11:00-12:30	Marques	Lewis	Corti	Excursion	Pomella
14:00-15:30	Couples	Kaus	Engl	Excursion	Koyi
16:00-17:30	Couples	Gerya	Klinkmüller	Excursion	–

Contents

Dimitrios Kolymbas, Links of Soil Mechanics and Geology: Why can we simulate the deformations of rock strata with sand? Which are the scaling properties of sand? How can we describe the mechanical behavior of sand by means of equations? Some problems of Soil Mecanics with applications in Geology: (i) Trapdoor problem, and (ii) tidal deformation. How does Soil Mechanics treat localization of deformation and shear banding?

Fernando Marques, Counter intuitive processes in Geology: Many are the processes in the geological nature that do not happen the way we thought (intuitively) that they would happen. This is the case of, for example: (1) the rotation of elliptical rigid bodies in simple shear, under certain common geological boundary conditions. (2) Shear strain localization in rock experiments with polymineralic aggregates. (3) The effects of strain rate on the folding and unfolding of elastic single layers embedded in a viscous matrix. (4) The formation of transform faults orthogonal to rifts. (5) The relationship between plate velocity and mountain building.

Gary Couples, Role of Simulations and Experiments in Understanding Folding and Flexure: Folding (which can be defined as the process of causing planar rock layers to become non-planar) occurs in almost all geological settings. In sedimentary basins, folding is strongly dependent on the stacking of differing rock layers that has been caused by depositional variations. The role of the contrasts in material properties between layers, and the related role of layer interfaces, are both important in governing the ultimate configuration of the fold, and its internal distribution of strain, and hence physical properties. This lecture will describe how numerical simulations and experiments contribute to our understanding of the operative processes, with a particular emphasis on the major importance of layer interfaces.

Gary Couples, Millimetres to Basins: Linking Deformed Textures to Large-Scale Fluid Flow: When Geomaterials undergo permanent strain, their textures become altered. The texture can be defined as the spatial arrangement of the solid components, typically the grains and any cements, but equally describes the pore space configuration. Deformations can result in distributed textural changes, or they may be concentrated in a localisation feature. An exciting research area focuses on using textural images to predict physical properties, such as those controlling fluid flow. This lecture will examine the role of textural analysis in workflows designed to predict fluid flows at several scales, and assess the value of such predictive approaches.

Helen Lewis, Poro-Mechanics in the Wild: Nature provides remarkable demonstrations of the principle of effective stress. In sedimentary basins, the energy associated with high pore pressure is comparable to the strain energy of deforming rocks, and equal attention needs to be given to the driving role of pore fluids in controlling deformations. This lecture will show that the main physical characteristics of sedimentary basins are predicted by an analysis based on appreciation of Geomaterial characteristics: the development of seals that retain high pore pressures, the eventual failure of such seals, and the ways that rocks in sealed pressure compartments evolve along some surprising paths.

Helen Lewis, Role of Simulations and Experiments in Understanding Fault Zones: Natural faults (which are displacement discontinuities) occur at a range of sizes, and with varying expressions in terms of the distribution of rock deformation. Some faults seem well-approximated as frictional sliding surfaces, whereas others seem to demand a description in terms of a process zone. This lecture will focus on the use of simulations, and some experiments, that provide opportunities to improve our understanding of the physical processes that operate during faulting. Simulations provide full-volume, time-varying specifications of the complete mechanical state associated with faulting. The simulation outcomes can be converted into spatial distributions of properties that govern aspects such as fluid flow associated with faults, and seismic reflection images of faults.

Boris Kaus, Forward and inverse modelling of geological processes: Over the last two decades, computer simulations have become a powerful tool to help understand how geological processes work. Yet modelling such processes remains challenging, particularly in 3D. This lecture will give an overview of recent progress on modelling 3D lithospheric deformation as well as on modelling of fluid and magma flow through a deformable poro-viscoelastoplastic rock (applied to magma migration in the Earth). Moreover, some of the remaining computational challenges will be discussed. One of these challenges is that most geological data have formed over millions of years. Most geological questions are thus by definition inverse problems. Yet, until recently comparatively little research was done on inverse modelling of geological processes. I will give a summary of work-in-progress in this direction.

Taras Gerya, Continuum mechanics and numerical modelling of plate tectonic processes: Plate tectonic processes shape out Earth's surface and interior and are often counter-intuitive and difficult to observe, understand and model. At present, continuum mechanics and numerical modeling are broadly used as the research tools in geodynamic studies aimed at deciphering physical controls and dynamics of plate tectonics on Earth. This talk discusses in short one of the most simple numerical techniques used in geodynamic modeling (staggered finite differences combined with marker in cell approach) and presents related examples of 2D and 3D numerical studies for some of the major plate tectonic processes such as subduction, continental collision and mid-oceanic spreading. The emphasis is on explaining how numerical models may help training our scientific intuition and give deep insights into some of the standing plate tectonics enigmas.

Giacomo Corti, Analogue modelling of geodynamic processes: Review of analogue modelling works on faulting and deformation in different environments (strike-slip, extension and shortening) and a different scale (crustal-scale, lithospheric scale). Comparison with selected natural examples from different geodynamic environments (East Africa, Central America, Mexico, Russia, Italy).

Daniela Engl, Slope instabilities - field observations, mechanical explanation and analysis tools: Slope instabilities are widespread in hilly terrains and alpine regions all over the world. They are found in all types of geological environments, in various types of soil and rock, and with a wide range of sizes and volumes, from small-scale to large-scale and shallow-seated to deep-seated. The mechanisms of slope deformation are very variable and depend on multiple factors, such as the rheology of the involved materials, slope geometry, structural predisposition, ect. Field observations give valuable evidences of the internal structure of slope instabilities. A sound knowledge about slope architecture is essential for reliable geotechnical analyses. This talk highlights typical field observations of slope instabilities, their mechanical interpretation and subsequently presents simple but powerful tools for slope analysis.

Matthias Klinkmüller, A brief history of analogue modeling of crustal scale processes: Analogue modeling represents not only a very old method to illustrate deformation of earth's crust, but also a very sophisticated approach to quantify large scale deformation on planet earth that is manifested in stunning mountain ranges like the Himalayas or the Alps. Since the beginning of analogue modeling more than 200 years ago, geologists have used a multitude of different materials like clay, cloth and sand. The lecture gives an overview over the past 200 years and the latest achievements about what can be done using sand as an analogue material to better understand deformation processes of the upper crust of planet earth and the application and development of observation techniques.

Laetitia Le Pourhiet, Mohr Coulomb non associated flow rule and its relevance for the rheology of fault zones at different scales: In the first part of the lecture I will present the Mohr-Coulomb non associated elasto-plastic flow rule. This flow rule is used in the field of geosciences to introduce brittle rheology, i.e. faults in the mechanical models of the earth crust in the first 15-50 km beneath earth surface. This model has the advantage above more complex models that it produces drop of effective friction from ?0=0.85 at peak to ?ss=0.64 in a characteristic shear strain of 7-8%, which are close to the characteristics found for most rocks in the laboratory. In a second part, I will discuss application of the model in the understanding of the dynamics and structure of natural fault zones from outcrop scale to crustal scale.

Hanna Pomella, The tectonic evolution of the Alps: The tectonic history of the European Alps is very complex, as they are the product of two orogenies, a Cretaceous followed by a Tertiary one. Based on a crustal scale cross section, reaching from the Northern Alpine Foreland to the Po plain in the South, an overview of the Geology and the tectonic evolution of the Alps will be presented. The tectonic nappes involved comprise European Basement and sedimentary cover units, Penninic nappes, as well as Apulian Basement and cover nappes, separates by some of the most important fault structures of the Alps. In the central part the section cross-cuts the Tauern Window following the course of the planned Brenner Base Tunnel.

Hemin Koyi, Salt structures and their significance as radioactive waste disposal sites: In this lecture, a brief description of salt structures will be given (their geometry, kinematics and dynamic evolution) and the triggering mechanisms will be outlined. Several natural examples will be used to illustrate these structures. One particular example will be discussed in detail to illustrate the structural complexities of salt formations and their suitability as repositories for hazardous waste.