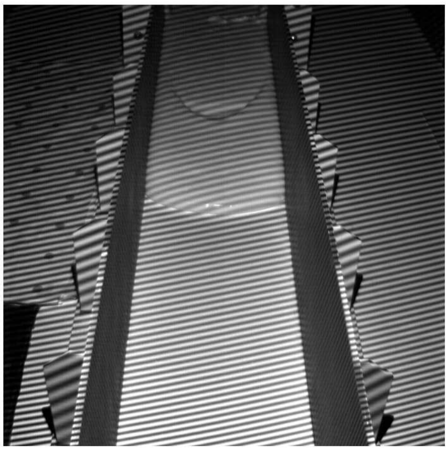
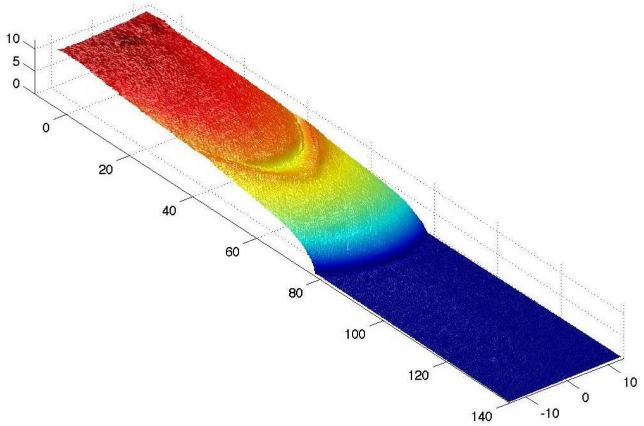
Program

Viscoplasticity: from Theory to Application

15–18 October 2007

Monte Verità, Ticino, Switzerland





Program

General information

Welcome to our workshop "Viscoplasticity: from theory to application" and thank you for coming to Monte Verità to participate and share your experience. We hope you enjoy the presentations and you take the opportunity to make new friends and research collaborators.

This workshop would not be possible without the financial support from the *Centro Stefano Franscini* (CSF) [1] and the Swiss National Science Foundation. We are very grateful for this support.

All lectures will be given in the auditorium. LCD projector (beamer), overhead projector, blackboards, two laptops (Windows Pentium 3 and Apple G4), and two slide projectors are available for presentations. The best solution is to load your presentation on one of the auditorium laptops prior to presentation time.

Christophe Ancey, Neil Balmforth, and Ian Frigaard

1. The Centro Stefano Franscini (CSF) is the international conference centre of the Swiss Federal Institutes of Technology (ETHZ and EPFL). It has been named after the Federal Councillor Stefano Franscini, a native of Ticino who, in 1854, played an important part in establishing the first Federal Institute of Technology in Switzerland (ETHZ). Every year, the centre hosts 20 to 25 conferences concerning all disciplines (sciences and humanities) taught at academic level. Monte Verità belongs to the Canton Ticino and it is managed by a foundation, the *Fondazione Monte Verità*.

Internet

What IT infrastructure does the centre offer?

Hardware	Description
Wired Network (LAN)	100 Mbit/s internal network with 40 connections in all conference rooms. 3 Mbit/s downstream, 600 kbit/s upstream connection to the web provided by the ETH with the possibility to connect the own laptop on DHCP.
Wireless Network (WLAN)	In the whole hotel: 2 Mbit/s connection to the web provided by the Swisscom with costs. In the hotel: 2 Mbit/s connection to the web provided by the ETH for the CSF workshops.
Computer room	4 desktop computers (2 Windows P4 and 2 Apple G4), with 15" TFT screen, CD-Writer, DVD-Player, Internet connection, USB and FireWire connection on the desk and the standard software. 2 laptops (Windows PIII and Apple G4) for the workshop and general use. For common use a laser printer, one memory stick [256 MB], a zip-drive [100 MB] and a floppy-drive.

Connect your laptop to the Internet

How to connect to the Internet from your Apple laptop?

1. Select "System Preferences" under the Apple-Menu or in the tray
2. Double click on the symbol "Network" → new content in the window
3. Click on "Configure" → new content in the window
4. Select on Location: "Automatic" and on Show: "Built-in Ethernet"
5. Click on "TCP/IP" and select on Configure: "Using DHCP"

How to connect to the Internet from your PC laptop?

1. Select "My Network Place"
2. Click the right button of the mouse and select "Properties" / Local Area Network Connection
3. Click the right button of the mouse and select "Internet Protocol (TCIP/IP) / Properties / Obtain an IP address automatically

How to connect your laptop to a printer

To install a printer, see the page http://www.csf.ethz.ch/faq/itfaq/connectprinter

Pre-conference events: Sunday evening

Check-in begins on Sunday 14 afternoon. Welcome drink at 18:00, followed by the dinner at 19:00.

Special event: banquet

On Wednesday, a banquet is organized. We will taste a typical Swiss speciality: the raclette (molten cheese and cooked meat). To know the tale of the raclette (Swiss touch of humor), please follow this (active) link:

http://www.hatman.ch/index.php?option=com_content&task=view&id=23&Itemid=38

Here is the menu:

Antipasto misto della casa (Mixed appetizer of the house)

***

Salmone affumicato, verdure grigliate, terrina di verdure (Smoked salmon, grilled vegetables, vegetable terrine)

Insalata Waldorf, insalata russa (Waldorf Salad, Russian salad).

***

Raclette, scelta di carne da grigliare (Raclette, choice of meat by grilling)

Salse a scelta (Sauce choice)

Patate al vapore e sottaceti (Steamed Potatoes and pickles)

***

Semifreddo alle castagne (Semifreddo Chestnut)

To persons who whish to achieve peace and joy by sampling local wine, we will try and propose a wide range of bottles to accompany your dishes. Rheological experiments on cheese are not encouraged during this party.

Monday October 15

09:00–10:00	*Plenary lecture*	Flow instability at the approach of the yield stress	P. Coussot
10:00–10:30	*Refreshments*		
10:30–10:50	*Short talks*	How to find the yield surface in a homogeneous stress field	P. Møller
10:50–11:10		Destabilization of a saturated and weakly consolidated granular assembly	C. Chevalier
11:10–11:30		Steady bubble rise and deformation in Bingham fluids and condition for their entrapment	J. Tsamopoulos
11:30–11:50		Yielding, wall slip, and landslides	D. Bonn
11:50–13:30	**Lunch**		
13:30–14:30	*Plenary lecture*	Colloid and granular pastes as cohesive-frictional materials	H. van Damme
14:30–15:00	*Refreshments*		
15:00–16:00	*Plenary lecture*	A continuum model for the viscoplasticity of dense suspensions and granular media	J. Goddard
16:00–16:20	*Short talks*	Shear rejuvenation, aging, and shear banding in yield stress fluids	A. Alexandrou
16:20–16:40		Insights into the rheology of papermaking fibre suspensions	M. Martinez
16:40–17:00		Energy losses in pipe fittings for viscoplastic fluids	V. Fester
17:00–17:20		Laminer/turbulent transition of viscoplastic fliods at high Oldroyd number	P. Slatter
17:20–17:40		Thermo-convective instability of viscoplastic fluids	C. Nouar
17:40–18:00		Thermo-convective transitional flow of a yield-stress fluid in a pipe	C. Nouar
18:00–18:15	*Welcome*	Speech by CSF manager Claudia Lafranchi	
18:30–20:00	**Dinner**		

Monday talks

Title: Flow instability at the approach of the yield stress

Author: Philippe Coussot (Institut Navier, University of Eastern Paris)

Speaker: P. Coussot (philippe.coussot@lcpc.fr)

The steady-state behavior of various pasty materials is generally described by a continuous model such as the Herschel-Bulkley one, which may be fitted to data obtained from decreasing or increasing shear stress or shear rate ranges. However such data hardly correspond to steady state, in particular for low shear rates. Systematic creep tests over long duration show that for various pasty materials (clay suspensions, foams, concentrated emulsions, cement paste, etc) some kind of instability occurs around the yield stress: the shear rate either reaches a large value or continuously decreases towards zero, which suggests that the flow is unstable below a critical apparent shear rate. A further analysis of rheometrical data with a Couette geometry and taking into account the shear rate heterogeneity in the gap shows that this corresponds to a flow instability below an effective critical shear rate (viscosity bifurcation).

The determination of the velocity profiles in a wide range of velocities within the gap of a Couette geometry (with the help of Magnetic Resonance Imaging Velocimetry) confirms this result for various materials but also shows that for some fluids (Carbopol gel) it is negligible and for some others (a model emulsion) the things are more complex around the yield stress (residual flow at low shear rates?). We end by showing that the critical shear rate effect is intimately linked to the thixotropic character of the fluid. In particular for a clayey emulsion MRI velocimetry makes it possible to directly observe, at a local scale, the development of the viscosity bifurcation effect in time.

Title: How to find the yield surface in a homogeneous stress field

Authors: Peder Møller[1], Stéphane Rodts[2], Thijs Michels[3] and Daniel Bonn[1,4]

Speaker: Peder Møller (peder.moller@gmail.com)

1. École Normale Supérieure, Laboratoire de Physique Statistique, Paris, France
2. Laboratoire des Matériaux et Structures du Génie Civil, Champs-sur-Marne, France
3. Eindhoven University of Technology, Eindhoven, The Netherlands
4. Van der Waals-Zeeman Institute, Amsterdam, The Netherlands

Experimentalists within the field of yield stress fluids often have difficulties finding *the* yield stress and predicting flow criteria from what they do find. At the same time theorists have difficulties explaining how a yield stress fluid can form a shear band even in a homogeneous stress field. We show how a very simple concept – a steady state flow curve with a slope which is positive above some critical shear rate and negative below it – is sufficient to explain these phenomena. Furthermore we present direct experimental evidence for the existence of the region with a negative slope. We also present experimental data to prove that indeed shear banding can occur in a homogeneous stress field and that the position of the yield surface agrees perfectly with the proposed model.

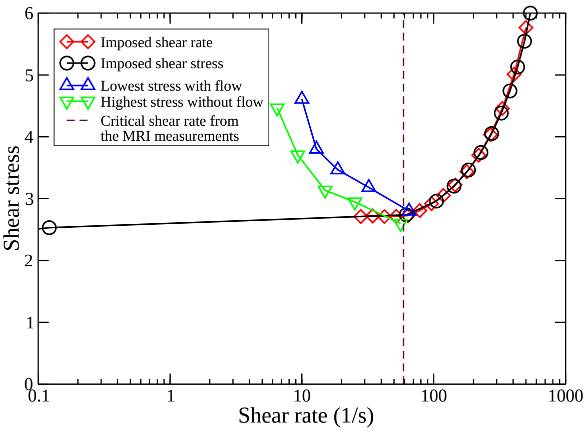


Figure 1: *Rheological properties of the fluid as observed by different types of measurements; imposed shear rate, imposed shear stress, and viscosity bifurcation experiments for several initial states. Above a critical shear rate the measurements at imposed stress and rate agree with each other while below this critical shear rate steady state flows can be obtained only with imposed shear rate experiments and the resulting stress does not depend on the shear rate - there is a stress plateau. This critical shear rate is seen to agree well with the critical shear rate found from the MRI measurements - shown as a vertical line. The steady state flow curve falls between the two lines from the viscosity bifurcation experiments. It evidently has a negative slope in the region below the critical shear rate.*

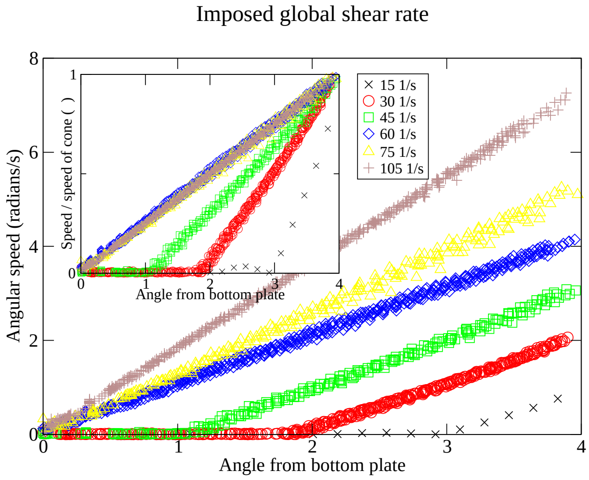


Figure 2: *Velocity profiles in a 4 degree cone-plate geometry for different globally imposed shear rates. At* 60 $1/s$ *and above, no shear banding is observed. The local shear rate (the slope of the velocity profile) is constant throughout the fluid and increases with imposed shear rate. Below* 60 $1/s$ *the shear rate is not constant throughout the fluid, but zero in some part and high in another part - shear banding. While the fraction of the fluid that is sheared increases with imposed shear rate, the local shear rate in the sheared region is constant for all shear rates at* 60 $1/s$ *and below. The insert shows the velocity profiles rescaled by the velocity of the cone. The transition between the sheared and the unsheared regions is very abrupt and the shear rate in the sheared region constant which is incompatible with the Bingham picture but agrees perfectly with the proposed model.*

Title: Destabilization of a saturated and weakly consolidated granular assembly

Authors: C. Chevalier, A. Lindner and E. Clement (PMMH, ESPCI, Paris).

Speaker: Christophe Chevalier (christophe.chevalier@lcpc.fr)

We study the destabilization of a saturated and weakly consolidated granular assembly induced by injection of a pure fluid. This question can be linked to geophysical problems like erosion or dyke stability. We work with a porous media formed by polystyrene beads imbibed by silicone oil and localized in a linear Hele-Shaw cell. When injecting pure oil, one observes two mechanisms: flow of the pure fluid through the fixed granular structure or mobilization of this structure leading to the formation of a granular paste. Mobilization of the granular structure leads to a decompaction of the system and allows after a certain waiting time, mainly depending on the level of injection pressure, the formation of a pure fluid flow channel associated with the motion of the granular paste. More precisely, we describe the macroscopic characteristics of the flow and patterns (such as average velocity, finger width...) observed as a function of the microscopic flow properties (such as grain size, grain fraction, cell thickness...). In addition, we also report experiments involving the injection of air into the same model system. In this case we visualize qualitatively the mobilization of the granular matrix as a function of injection pressure and initial compaction.

Title: Steady bubble rise and deformation in Bingham fluids and conditions for their entrapment

Authors: Chatzidai N., Pavlidis M., Dimakopoulos, Y., and Tsamopoulos, J. (University of Patras, Greece)

Speaker: John Tsamopoulos (tsamo@chemeng.upatras.gr)

We examine the buoyancy-driven rise of a bubble in a Bingham fluid assuming axial symmetry and steady flow. Bubble pressure and rise velocity are determined, respectively, by requiring that its volume and center of mass remain constant. The continuous constitutive model suggested by Papanastasiou is used to describe the viscoplastic behavior of the material. The flow equations are solved numerically using the mixed finite-element/Galerkin method. The nodal points of the computational mesh are determined solving a set of elliptic differential equations to follow the often large deformations of the bubble-surface. The accuracy of solutions is ascertained by mesh refinement and by predicting very accurately previous experimental and theoretical results for Newtonian fluids. We determine the bubble shape and velocity and the shape of the yield surfaces for a wide range of material properties. Besides the yield surface away from the bubble which surrounds it, unyielded material can arise either behind the bubble or around its equatorial plane in contact with the bubble. As the Bingham number, $Bn = \tau_y/\rho g R$, increases, the yield surface at the equatorial plane and away from the bubble merge and the bubble gets entrapped. When the Bond number is small and the bubble cannot deform from spherical, the critical Bingham number can be determined by a combination of plastic boundary layer analysis and computations. The resulting critical Bingham number is ~ 0.14, whereas the critical Bingham number for entrapping a sphere at zero Reynolds number is ~ 0.095 (Beris et al., 1985). As the Bond number increases allowing the bubble to squeeze through the material easier, the critical Bingham number increases as well.

Title: Yielding, wall slip, and landslides

Authors: Daniel Bonn (ENS-Paris & WZI-Amsterdam), Peder Møller (ENS-Paris)

Speaker: Daniel Bonn (bonn@lps.ens.fr)

I will discuss some laboratory experiments that suggest that yield stress fluids do not have three flow regimes (liquid, solid and shear banding/yield stress) but rather four. The fourth one is characterized by a large wall slip, and can account for some rather impressive landslides. I will discuss the example of 'quickclay' from the Rissa landslide near Trondheim in Norway.

Title: Colloidal and granular pastes as cohesive-frictional materials

Author: Henri Van Damme (ESPCI, Paris, France)

Speaker: Henri Van Damme (Henri.VanDamme@espci.fr)

Colloidal and granular pastes as cohesive-frictional materials – Direct inter-particle contact and friction are essential elements of the rheological behavior of coarse granular fluids like geological rocky flows. The purpose of this contribution is to examine to what extent – and, eventually, in which conditions – contact and friction have also to be considered in colloidal and fine granular fluids. Creep and yielding, dissipation and plastic flow, shear-thickening and jamming, and finally fracture will be discussed on the basis of experimental results obtained with model systems like monodisperse colloidal silica particles or with "real" systems like cement slurries. The ambiguous role of hydrodynamic lubrication – source of viscous dissipation but also mean of preventing contact – will be particularly scrutinized. It will be claimed that, in both colloidal silica and coarser cement pastes, direct contact friction between particles is contributing to the yield stress and to the overall energy dissipation after yielding.

Addition of non-adsorbing or adsorbing soluble polymers or surfactants is a convenient way to control hydrodynamic and/or contact lubrication. Using this tool, we will analyze the conditions for the crossover from a regime where dissipation is mainly due to hydrodynamic dissipation within the suspending fluid – mainly in confined interparticle regions – to a regime where dissipation is mainly due to particle-to-particle friction. It is shown that, in the first regime, increasing the viscosity of the interstitial fluid by addition of a non-adsorbing polymer, leads to an increase of the paste viscosity, in agreement with classical models for concentrated suspensions. On the contrary, in the second regime, it leads to a decrease of the paste viscosity due to a lower probability of direct contact between particles. At high shear rate, when this hydrodynamic lubrication becomes less efficient, flow enters into a shear-thickening and, possibly jamming regime. The onset of this regime is shown to involve giant fluctuations of stress, assigned to the formation and breakup of direct frictional contact chains. The surface state of the particles is a determining factor in this transition. When the particles are covered with a layer of surfactant molecules for instance, with contact lubrication properties, the transition is pushed back toward larger shear rates. On the contrary, when friction is increased by roughening the particle surface, the transition occurs at lower shear rates.

Title: A continuum model for the viscoplasticity of dense suspensions and granular media – from Stokesium to Mohr-Coulombium

Author: J. D. Goddard (Department of Mechanical and Aerospace Engineering, University of California, San Diego)

Speaker: J. D. Goddard (jgoddard@ucsd.edu)

Fluid-particle systems with internal forces arising only from viscosity or intergranular friction represent an important special case of "purely dissipative" materials [1] described by a 4th-rank viscosity tensor $\boldsymbol{\eta}$ depending on deformation history. In a recently proposed simplification [2], $\boldsymbol{\eta}$ is given by a tensor polynomial in a symmetric 2nd-rank structure or "fabric" tensor $\mathbf{A}$, whose evolution is determined by the history of deformation. Expressing the latter as a corotational integral, with memory function involving two exponential relaxation modes, one obtains a good fit to existing data on viscosity and normal stress in steady shear reversal experiments on concentrated suspensions. As an extension of [2], the present paper gives predictions for shear and normal stress in sinsuoidal simple shear.

In contrast to existing phenomenological models, the present approach provides a rational distinction between instantaneous Stokesian response and non-linear effects arising from Stokesian-dynamic evolution of microstructure or from non-Stokesian particle contact. The latter serves as an essential link between idealized suspensions ("Stokesium") and granular media ("Mohr-Coulombium") and suggests a straightforward generalization to the viscoplasticity of fluid-saturated and dry granular media [2]. This generalization involves two distinct time constants based on viscosity, confining pressure and grain inertia, which have been identified in previous works [4–6] and which serve to characterize various flow regimes.

A brief discussion is given of a recent extension [6] of the above model to non-homogeneous suspensions, with particle flux induced by gradients in particle concentration, deformation rate, and fabric.

References

(1) J. D. Goddard. *J. Non-Newtonian Fluid Mech.*, 14:141–60, 1984.
(2) J. D. Goddard. *J. Fluid Mech.*, 568:1–17, 2006.
(3) J. D. Goddard. *Acta Mech.*, 63:3–13, 1986.
(4) N. Huang, et al. *Phys. Rev. Lett.*, 94:028301/1–4, 2005.
(5) P. Jop, Y. Forterre, and O. Pouliquen. *J. Fluid Mech.*, 541:167–92, 2005.
(6) J. D. Goddard. *Submitted for publication*, 2007.

Title: Shear rejuvenation, aging and shear banding in yield stress fluids

Authors: Andreas Alexandrou (University of Cyprus)

Speaker: A. Alexandrou (andalexa@ucy.ac.cy)

In yield stress materials, a finite stress value must be exceeded for flow to occur. The knowledge of the response of yield stress fluids to shear stresses is important for process and application optimization. During prolonged processing of general yield stress materials the local shear rate in some regions may become equal or lower than the critical value where aging and shear rejuvenation become important. Under certain conditions also shear localization or shear banding can develop.

In this work we study shear rejuvenation, aging and shear localization in shear thinning yield stress fluids in a typical rotational rheometer and we provide a common framework to describe such phenomena. A theory based on the Herschel-Bulkley flow model appropriate for the breakdown and buildup of structure is proposed, and the effects of model parameters on various variables are examined using a novel computational method well suited for problems with singularities.

Title: Insights into the rheology of papermaking fibre suspensions

Authors: D.M. Martinez (Chemical and Biological Engineering, University of British Columbia, Vancouver Canada).

Speaker: D.M. Martinez (martinez@chml.ubc.ca)

The flow of papermaking fibre suspensions is characterized in three different yet complimentary studies. In the first study we visualize the transient settling of radioactively labeled papermaking fibres using positron emission tomography (PET). Here we identify a gel point, that is a point in which the mobility of the fibres are greatly diminished. At this point the suspension behaves as a network (albeit flimsy) and can support mechanical load. In the second study we examine the motion of these suspensions in a sudden expansion using PET. With slow flows ($Re \approx 7000$) we find that the suspension was not fluidized and the radioactively labeled fibres passed through the expansion as a plug. No mixing was observed between the central jet and the static outer layer and the shape of the unyielded region is clearly identified. At larger velocities ($Re \approx 13{,}000$), we observed that the papermaking suspension was fully fluidized. Our results indicate that in this regime that albeit fluidized, symmetry was broken and concentration inhomgeneities were evident. In the third study, we measure optically the evolution of concentration inhomgenieties in a sudden contraction and relate this to a Markov process. We identify the point of transition to turbulence by examining the changes in suspension properties (i.e. orientation, fibre motion). From these observations we attempt to characterize the rheological behaviour of these suspensions.

Title: Energy losses in pipe fittings for viscoplastic fluids

Authors: V.G. Fester and P.T. Slatter (Cape Peninsula University of Technology, South Africa).

Speaker: V.G. Fester (FesterV@cput.ac.za)

A critical precursor to practical engineering hydraulic design is dynamic similarity. Since many industrial fluids display a viscoplastic rheology, and because these flows occur – by the very viscous nature of the fluid – in the laminar regime, it is important to be able to establish dynamic similarity in this context. This is particularly true for the short runs typical of in-plant hydraulic designs, where the losses in pipe fittings fittings can exceed that in the straight pipe sections. Using experimental data and an appropriate Reynolds number, it is shown that dynamic similarity can indeed be established, and that these fittings losses can be orders of magnitude greater for laminar viscoplastic flows, than those expected in turbulent flow.

Title: The laminar/turbulent transition of viscoplastic fluids at high Oldroyd number

Authors: P.T. Slatter (Cape Peninsula University of Technology, South Africa).

Speaker: P.T. Slatter (SlatterP@cput.ac.za)

There is considerable pressure to operate industrial pipeline systems at higher concentrations, causing the viscous character of the fluid to become increasingly viscoplastic. Prediction of the transition velocity is fundamentally important for design and operation. The objective of this paper is to extend previous work using the Bingham plastic model to the more general Herschel-Bulkley rheological model, and to use the Oldroyd number as the basis of the analysis. Using phenomenological predictive approaches in literature and experimental data, it is shown that the problem is both particularly acute and industrially relevant at high Oldroyd number. The predictive approach developed by the author is shown to predict the data best.

Title: Thermo-convective transitional flow of a yield stress fluid in a pipe: evidence of a stable non linear state

Authors: A. Esmael, C. Nouar (Université de Nancy, LEMTA (UMR 7563 CNRS-INPL-UHP). 2, Avenue de la Forêt de Haye, BP 160, 54504 Vandoeuvre-Les-Nancy, France).

Speaker: C. Nouar (Cherif.nouar@ensem.inpl-nancy.fr)

In two independent articles, Escudier and Presti (1996) and Peixinho et al. (2005) studied experimentally the flow structure of aqueous solutions of 1.5 wt % Laponite and 0.2 wt % Carbopol respectively in a cylindrical pipe. It was observed that the mean velocity profiles are axisymmetric in laminar and turbulent regimes, and present an increasing asymmetry with increasing Reynolds number in transitional regime. The two former groups of authors published jointly paper (see Escudier et al. 2005) to highlight this effect with additional observations for other shear thinning fluids. The present communication provides a three-dimensional description of this asymmetry from axial velocity profiles measurements at three axial positions and different azimuthal positions. The obtained results indicate that the asymmetry is very weak near the entrance section and increases along the duct. It is shown that these results traduce the existence of a stable non-linear state characterized by two contra-rotating longitudinal vortices. Theoretical analysis based on the Self-Sustained-Process proposed par Waleff (1996) is in progress.

Title: Thermo-convective instability of viscoplastic fluids

Author: Christel Métivier (ENSEM, Nancy, France).

Speaker: C. Nouar (cherif.nouar@ensem.inpl-nancy.fr)

The stability of Rayleigh-Bénard Poiseuille flow is investigated for a yield stress fluid. It is assumed that the rheological behavior is described by the Bingham model. The basic flow is characterized by a central plug zone in which the second invariant of the deviatoric stress tensor is less or equal to the Bingham number B, a dimensionless yield stress. The

Bingham model assumes that inside this zone the material moves as a rigid solid and that outside this zone, it behaves as a viscous fluid. The aim of our study is to highlight the effect of the yield stress on the stability conditions. A major difficulty with this type of fluid is the possibility to have two phases: a "gel-like" behavior in which regions the stress is not determined and a fluid-like behavior where yielded. The linear stability analysis of this flow leads to propagating convective patterns, on the both sides of the plug zone, in the form of travelling waves. This analysis shows that the critical conditions, i.e., critical Rayleigh Ra_c and wave numbers, increase with B. Thus, increasing the Bingham number stabilizes the flow. New results concerning the evolution of the amplitude and of the plug zone are obtained with the weakly non linear analysis. This analysis allows us to take into account the non linearities due to, for example, the effective viscosity. It assumes that the perturbation remains very weak in amplitude and close to the linear conditions. It is shown that, at low values of Péclet number, the bifurcation is supercritical, similarly to the Newtonian case. At larger Péclet numbers, there is a sharp change from supercritical to subcritical bifurcation. This sharp change in behavior is a consequence of the large nonlinear viscosity. The weakly non-linear analysis only remains valid very close to Ra_c. In other words, the perturbed problem becomes rapidly fully non linear. Extension of the weakly non-linear method becomes impossible since the yield surface topology would change.

Tuesday October 16

09:00–10:00	*Plenary lecture*	From dry granular flows to submarine avalanches	O. Pouliquen
10:00–10:30	*Refreshments*		
10:30–10:50	*Short talks*	Segregation in frictional granular flows	J. McElwaine
10:50–11:10		Rheophysical investigation of concentrated noncolloidal particle suspensions in a wide-gap Couette cell	S. Wiederseiner
11:10–11:30		Avalanche experiments of isodense granular suspension	C. Bonnoit
11:30–11:50		Application of the Lambert W function	R. Huilgol
11:50–13:30	**Lunch**		
13:30–14:30	*Plenary lecture*	Solidity of liquid foams	F. Graner
14:30–15:00	*Refreshments*		
15:00–16:00	*Plenary lecture*	Modelling of fluidized geomaterials via viscoplasticity: application to fast landslides	M. Pastor
16:00–16:20	*Short talks*	Couette flow of a foam: numerical simulations and experiments	I. Cheddadi
16:20–16:40		Drag flow of viscoplastic fluids past cylinders	E. Mitsoulis
16:40–17:00		Drag forces on spheres moving through yield stress fluids	J. de Bruyn
17:00–17:20		Analysis of wall slip in flows of viscoplastic liquids in rotational rheometers	M. Naccache
17:20–17:40		Modeling of the flow of elasto-viscoplastic liquids	P. Mendes de Souza
17:40–18:00		On the numerical modelling of squeeze flow and ram extrusion	I. Wilson
18:00–18:20		Squeeze flow and other tests of dense particulate pastes	I. Wilson
18:30–20:00	**Dinner**		

Tuesday talks

Title: From dry granular flows to submarine avalanches

Author: Olivier Pouliquen (IUSTI, Marseille)

Speaker: Olivier Pouliquen (Olivier.Pouliquen@univ-provence.fr)

Despite the apparent simplicity, the flow of an assembly of rigid grains that interact solely by frictional interactions still resists our understanding. No constitutive equation is able to describe the rich phenomenology observed with granular material. However, in the dense flow regime where the granular media flows like a liquid, a simple visco-platic description seems to be relevant. I will review the successes of this approach by showing quantitative predictions in different flow configurations, and discuss the limits observed close to the jamming transition. The consequence of this granular visco-plastic rheology for the case of immersed granular flows for which the interstitial fluid plays an important role will be discussed. More precisely, experiments about the triggering of submarine avalanches will be presented.

Title: Segregation in frictional granular flows

Author: Jim McElwaine (DAMTP, University of Cambridge).

Speaker: Jim McElwaine (J.N.McElwaine@damtp.cam.ac.uk)

Segregation occurs in many geophysical flows with plastic behaviour including avalanches and rock-slides, but there is no generally accepted theory and almost no quantitative comparisons. We develop a general theory of segregation based on multi-component diffusion, analyse its consequences and compare the predictions with discrete element method simulations. The effects of the segregation on the frictional rheology are analysed.

Title: Rheophysical investigation on concentrated noncolloidal particle suspensions in a wide-gap Couette cell

Authors: Sébastien Wiederseiner & Christophe Ancey (EPFL).

Speaker: Sébastien Wiederseiner (sebastien.wiederseiner@epfl.ch)

An optical visualization apparatus has been developed to measure the particle velocity and concentration profiles of highly concentrated particle suspensions in a Couette rheometer.

Ancey et al. [1] showed that for concentrated particle suspensions there is a transition from a frictional to a viscous behavior that occurs at a given critical shear rate. So one of the complexities arising with this type of fluid is the yield stress. As discussed by Nguyen & Boger [2], the problem associated with correct shear rate determination from the torque - angular velocity measurements can be very complex with fluids exhibiting a yield stress. Usual methods can not be used anymore and this especially when the annular gap between the cylinders is large as encounter in particle suspensions rheology.

For this kind of wide-gap geometry and for complex fluids, the flow curve must be derived by solving the so-called Couette inverse problem, [3]. An alternative way of obtaining the flow curve is to measure the velocity profile across the gap, then differentiate it to derive the shear rate.

To get experimental benchmark data for the Couette inverse problem, we are carrying out velocity profile measurements. Investigations are conducted on iso-index, iso-density suspensions of PMMA particles within a Newtonian fluid. The velocity profiles are measured using Fluorescent Particle Imaging Velocimetry techniques. Other processes (wall slipping, particle depletion or migration, and shear banding) can also be documented with this technique. We present our experimental setup and some preliminary results.

(1) Ancey, C. and P. Coussot, "Transition from frictional to viscous regime for granular suspensions," *Comptes Rendus de l'Académie des Sciences de Paris* **327**, 515–522 (1999).

(2) Nguyen, Q. and D. Boger, "Characterization of yield stress fluids using the concentric viscometry," *Rheologica Acta* **26**, 508–515 (1987).

(3) Ancey, C., "Solving the couette inverse problem by using a wavelet-vaguelette decomposition," *Journal of Rheology* **49**, 441–460 (2005).

Title: Avalanche experiments of isodense granular suspension

Authors: C. Bonnoit, A. Lindner, B. Andreotti, E. Clément (ESPCI, Paris, France).

Speaker: C. Bonnoit (bonnoit@pmmh.espci.fr)

Particle laden flows such as avalanches, mud flows are ubiquitous in nature as they may display solid or fluid-like behaviour. In spite of their catastrophic human and economical tolls, the perspective of risk modelling is hindered by the lack of conceptual clarity since the rheological law remains poorly understood at the most fundamental level. Recently, significant advances in the understanding of dry granular flows were made, in part due to the systematic use of avalanche plane as a rheometer suited to access a central constitutive parameter: the effective friction coefficient (dependent of the shearing rate). Here we seek to extend such studies in the context of dense granular suspensions flowing down an inclined plane in order to investigate if similar constitutive relations may exist. The suspensions are prepared at high packing fractions and consist of non-Brownian spherical particle with density matched in salty water. For various tank flow rates and tilt angles, we performed systematic studies of the flow height and the surface velocity by using a P.I.V. technique. Therefore, we are in a position to assess the pertinence of previously found constitutive relations available for dry granular materials but in the context of dense granular suspensions.

Title: Application of the Lambert W function to obtain analytic solutions for the Papanastasiou model

Authors: R. R. Huilgol and Z. You (Flinders University, Adelaide), and E. Mitsoulis (NTUA, Athens)

Speaker: R. R. Huilgol (raj@infoeng.flinders.edu.au)

Abstract: The Papanastasiou model has been used widely in order to overcome the difficulties in locating the yield surface of a Bingham fluid. Despite this, there are no analytical solutions for the Papanastasiou model. In order to find such solutions, it is essential to invert the constitutive equation so that one can express the magnitude of the shear rate in terms of the magnitude of the shear stress. The Lambert W function plays a crucial role in this inversion. For viscometric flows, such as channel and Poiseuille flows, one can obtain explicit analytic solutions, whereas for the Couette flow, a fully analytic solution is not possible even for the case of the small gap. Extensions to unsteady flows will be discussed as well.

Title: The solidity of liquid foams

Author: François Graner (LPS, Joseph Fourier University, Grenoble)

Speaker: graner@ujf-grenoble.fr

We will first introduce liquid foams, their applications, some interesting properties, and the physical questions they raise. We will then present their mechanical properties, which are sometimes solid-like (either elastic, or plastic), and sometimes like those of a flowing liquid. To understand such a rich behaviour, we built foam channels. We measure the force foams exert on an obstacle around which they are flowing. Simultaneously, since they are two-dimensional foams, we observe the bubble deformations. We will introduce physical quantities that can be measured to characterize the tensorial deformation of such disordered media; and we will discuss their applications to other materials. Finally, we will suggest how we write a constitutive equation which simultaneously accounts for elastic, plastic and viscous behaviours; and how we test its predictions.

Title: Modelling of fluidized geomaterials via viscoplasticity: application to fast landslides

Authors: Manuel Pastor[a, b], José A. Fernández Merodo[a, b, c], Bouchra Haddad [a], Diego Manzanal [a], Pablo Miraa [b], Isabel Herreros[a, b, c] Laura Tonni[d] and V.Drempetic[a, b]

Speaker: Manuel Pastor (Manuel.Pastor@cedex.es)

a Grupo M2i, Dpto. de Matemática e Informática Aplicadas a la Ing Civil. Universidad Politécnica de Madrid.

b Ingeniería Computacional, Centro de Estudios y Experimentación de Obras Públicas

c Universidad Rey Juan Carlos

d Universitá de Bologna

Fast catastrophic landslides cause many victims and important economic damage around the world every year. It is therefore important to predict their path, velocity and depth in order to provide adequate mitigation and protection measures. The distance travelled by these fluidized avalanches is large in many cases, such as lahars in volcanoes. Three dimensional models are extremely expensive, and depth integrated models provide a reasonable compromise between computational cost and accuracy. One important aspect to model is the constitutive/rheological behaviour of the materials.

The purpose of this work is to present models able to describe -with different degrees of approximation- the behaviour of fluidized soils. We will begin discussing the process of fluidization or liquefaction, where a solid soil is transformed from solid to a fluid like material, and presenting some of the many available constitutive models which allow describing this phenomenon.

One particular type of models which are widely used are the so called "depth integrated" obtained from the general 3D models by integrating along depth. They require obtaining of "depth integrated stresses" and "basal friction forces". Here we will provide insight on how to derive both. We will present the 2D depth integrated forms of Bingham, Bagnold and Chen models, for which we will present simplified methods which allow to obtain in a simple manner the basal friction without having to solve polynomials of 3rd or higher degrees.

We will present numerical applications obtained with the SPH, a meshless technique which presents the advantage of combining very fine, structured meshes describing the topography with the SPH mesh.

Title: Couette flow of a foam: numerical simulation and experiments

Authors: Ibrahim Cheddadi[1],Pierre Saramito[1], Françcois Graner[2], Philippe Marmottant[2], & Christophe Raufaste[2].

[1] Laboratoire Jean Kuntzmann, B.P. 53, 38041 Grenoble

[2] Laboratoire de Spectrométrie Physique, 140 Av. de la physique, BP 87 - 38402 Saint Martin d'Hères

Speaker: I. Cheddadi (ibrahim.cheddadi@imag.fr)

We focus on the numerical resolution of a new model proposed in [1], which may be able to describe visco-elasto-plastic fluids such as liquid foam.

Liquid foam is a complex fluid that allows easy measures thanks to statistical tools [4] based on image analysis (2D case) : it is now possible to measure not only velocity but also components of elastic stress and plastic rearrangements everywhere in the foam. As corresponding quantities exist in the model, full comparison between experiments and numerical simulations is possible.

We choose to study the Couette flow of a foam, as presented in [2]. We propose a time splitting algorithm based on a θ-scheme ; it allows to simplify the highly non-linear initial problem resolution into a sequel of (i) elliptic problems resolutions and of (ii) constitutive equation resolutions. Then, problems (i) and (ii) can be solved by classical methods.

Numerical results are compared to experimental measures [2, 3]. We show that our model can predict complex behaviour, both in transient and stationary regimes.

References:

[1] P. Saramito. A new constitutive equation for elastoviscoplastic fluid flows. J. non-

Newton. Fluid Mech., accepted, 2006. http://hal.archives-ouvertes.fr/hal-00109101.

[2] E. Janiaud and F. Graner. Foam in a two-dimensional Couette shear: a local measurement of bubble deformation. J. Fluid Mech., 532 :243-267, 2005.

[3] G. Debrégeas, H. Tabuteau, and J. M. di Meglio. Deformation and flow of a two-dimensional foam under continuous shear. Phys. Rev. Letter, 87(17), 2001.

[4] F. Graner, B. Dollet, C. Raufaste, P. Marmottant Statistical tools to characterize discrete rearranging patterns, in two or three dimensions: cellular materials, assemblies of particles in preparation, 2007

Title: Drag flow of viscoplastic fluids past cylinders: comparison between experiments and simulations

Authors: Evan Mitsoulis (National Technical University of Athens School of Mining & Metallurgical Engineering, Zografou 157 80, Athens, Greece)

Speaker: Evan Mitsoulis (mitsouli@metal.ntua.gr)

Recent experiments (Jossic and Magnin, 2001) on drag flow past circular cylinders for viscoplastic gels have shown limiting drag values beyond which there is no movement. The symmetric problem was analyzed via numerical simulations with the finite element method. Different aspect ratios have been studied ranging from a disk to a long cylinder. The Herschel-Bulkley constitutive equation is used for fitting rheological data for four gels. For the simulations, this model is used with an appropriate modification proposed by Papanastasiou, which applies everywhere in the flow field in both yielded and practically unyielded regions. The emphasis is on determining the extent and shape of yielded / unyielded regions along with the drag coefficient for a wide range of Bingham numbers. The simulation results are compared with the experimental values for cessation of flow and show that the values are highest for the disk and lowest for the long cylinder.

Title: Drag force on spheres moving through yield-stress fluids

Authors: John R. de Bruyn (University of Western Ontario, London, Ontario, Canada) Hervé Tabuteau (LCVN, Montpellier, France) Philippe Coussot (Institut Navier, Paris, France)

Speaker: John R. de Bruyn (debruyn@uwo.ca)

We have studied the motion of spheres falling through carefully characterized Carbopol and Laponite gels. Laponite shows significant rheological aging while Carbopol does not. In Carbopol we observe three regimes of motion as a function of sphere density, following an initial transient: steady motion at high density, stoppage at low density, and motion with a continuously decreasing speed at intermediate densities. We interpret our results in terms of the yielding of the material, and obtain a value for the yielding criterion in excellent agreement with previous theoretical predictions due to Beris *et al.* Similar flow regimes are observed for Laponite, but the behaviour is also a function of the age of the material. The yielding criterion differs from the predictions in this case, and we show that this is due to the fact that only a very thin layer of material around the moving sphere is fluidized.

Title: Analysis of wall slip in flows of viscoplastic liquids in rotational rheometers

Authors: Flavio H. Marchesini, M. F. Naccache and P. R. de Souza Mendes (Department of Mechanical Engineering, Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, RJ, Brazil).

Speaker: Monica F. Naccache (naccache@mec.puc-rio.br)

Rheological measurements of viscoplastic liquids are still a great challenge. One of the main difficulties is the wall slip occurance. It is observed that wall slip occurs in the range of low and medium shear stresses. In this work, some data using water-based carbopol solutions are obtained experimentally using the rotational ARES rheometer (TA Instruments), with the bob and the vane geometries, and with two different grooved geometries. A numerical solution was also performed to analyze the flow kinematics in these geometries, and to evaluate the assumptions used to obtain the experimental results. The solution of the conservation equations of mass and momentum were obtained via the finite volume technique using the FLUENT software. The Generalized Newtonian Fluid constitutive equation, and the SMD viscosity function (de Souza Mendes and Dutra, 2004) were used to model the Carbopol behavior. The experimental results suggest that wall slip occurs in the smooth-Couette (bob) and vane geometries at lower shear rates, while the grooved geometries suppresses wall slip for most of the cases investigated. The numerical results show that flow kinematics in the Vane geometry is different from the kinematics obtained in the Bob geometry, since the fluid invades the space between the blades. However, in the grooved geometries, the kinematics is almost not affected. Additionally, the numerically-obtained stress fields show that higher stress values are obtained near the solid surfaces, both in the grooved and vane geometries. The comparison between numerical and experimental results shows that numerical smooth-Couette results are in good agreement with the experimental results pertaining to the grooved geometries.

Title: Modeling the flow of elasto-viscoplastic liquids

Authors: Paulo R. de Souza Mendes, Mônica F. Naccache, and Bruno Nassar (Department of Mechanical Engineering, Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, RJ, Brazil).

Speaker: Paulo R. de Souza Mendes (pmendes@mec.puc-rio.br)

We employ a recently-proposed constitutive equation (de Souza Mendes, 2007) to model two different flows of elasto-viscolastic materials. This constitutive equation predicts a viscoelastic behavior below the yield stress and a viscoplastic behavior beyond it. One of the flows analyzed is the start-up of Couette flow, focusing the attention on the range of shear stress such that there exist both a yielded flow region and an unyielded one. The other flow for which solutions are presented is the one through an axis-symmetric abrupt expansion-contraction. For the latter, the governing equations are solved via a finite-element method assuming inertialess flow. The results obtained are compared with the experimental ones available in the literature (de Souza Mendes et al., 2007).

References

de Souza Mendes, P. R., 2007. Dimensionless non-newtonian fluid mechanics. J. Non-Newtonian Fluid Mechanics (submitted).

de Souza Mendes, P. R., Naccache, M. F., Varges, P. R., Marchesini, F. H., 2007. Flow of viscoplastic liquids through axisymmetric expansions contractions. J. Non-Newtonian Fluid Mech. 142, 207-217.

Title (1): On the numerical modelling of squeeze flow and ram extrusion of badly-behaved pastes

Authors: Patel[1], M.J., Wilson[1], D.I., Blackburn[2], S., Mascia[1], S.

(1) Department of Chemical Engineering, University of Cambridge, Cambridge, CB2 3RA, UK

(2) IRC in High Performance Materials, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK

Speaker: Ian Wilson (diw11@cam.ac.uk)

Particulate pastes undergoing extrusion can exhibit differential velocities between the solid and liquid phases, termed liquid phase maldistribution or migration (LPM). The phenomenon is detrimental to product quality and homogeneity. LPM is observed experimentally but understanding and predictive capacity in paste and extruder design is limited. Most models for LPM feature one-dimensional analyses. Here, a two-dimensional model based on soil mechanics approaches (modified Cam-Clay & Drucker Prager) was implemented in the ABAQUS finite element package, where the liquid and the solids skeleton are treated separately.

Significant viscoplasticity is often observed during paste extrusion and this was also considered. Remeshing routines were developed that allow simulations to run at acceptably low error over significant ram displacements.

Title (2): Squeeze flow and other tests of dense particulate pastes

Authors: Wilson[1], D.I., Blackburn[2], S., Mascia[1], S., Patel[1], M.J.

(1) Department of Chemical Engineering, University of Cambridge, Cambridge, CB2 3RA, UK

(2) IRC in High Performance Materials, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK

Speaker: Ian Wilson (diw11@cam.ac.uk)

Dense particulate pastes with solids content approaching the maximum packing fraction are used in many commercial applications, despite the problems encountered with these systems as a result of phenomena such as wall slip, liquid phase migration and structuring. These phenomena also pose challenges in rheological testing and the interpretation of data obtained from such experiments. Recently we have used squeeze flow in combination with capillary rheometry (ram extrusion) to study the extrusion behaviour of a range of particulate pastes, and draw important features from the overlap of the results obtained from the two geometries. This paper will report data obtained from model systems, of ballotini in viscous Newtonian binders, developed in tandem with numerical modelling methods, as well as systems used in metal injection moulding, ceramic catalyst forming and the manufacture of pharmaceutical granules. The phenomenology exhibited is rich and invites discussion and further work.

Wednesday October 17

09:00–10:00	*Plenary lecture*	Gravity viscoplastic flows	N. Balmforth
10:00–10:30	*Refreshments*		
10:30–11:30	*Plenary lecture*	Shallow flows of viscoplastic and granular materials	A. Hogg
11:30–11:50		Dam-break problem and viscoplastic flows: new experimental results	S. Cochard
11:50–12:10		Experimental investigation of viscoplastic free surface flows. Application to debris flows	G. Chambon
12:10–13:30	**Lunch**		
13:30–14:30	*Plenary lecture*	Prolegomena to variational inequalities and numerical schemes	R. Huilgol
14:30–15:00	*Refreshments*		
15:00–16:00	*Plenary lecture*	Plastic strains in granular soils	F. Nicot
16:00–16:20	*Short talks*	The somewhere obscure relation between grains and matrix constituting natural debris flows	E. Bardou
16:20–16:40		Rheology and Rayleigh-Bénard convection of crystal-rich magma	A. Rust
16:40–17:00		Weakly compressible Poiseuille and extrudate-swell flows of Herschel-Bulkley fluids	G. Georgiou
17:00–17:20		Two-phase debris flow modeling	J. Kowalski
17:20–17:40		Impact of a yield-stress fluids on a rigid surface	Y. Forterre
17:40–18:00		Kinematic interfacial instabilities in primary cementing of oil and gas wells	M. Moyers
18:00–18:30			
18:30–21:00	**Banquet**		

Wednesday talks

Title: Gravity viscoplastic flows

Author: Neil J. Balmforth (University of British Columbia, Vancouver)

Speaker: Neil J. Balmforth (njb@math.ubc.ca)

In this lecture I will review aspects of the free-surface flow dynamics of a layer of viscoplastic fluid, focussing on how such a fluid flows over a sloping surface under gravity (the "slump test" and its inclined relative) and how a fluid layer responds to the oscillatory motion of the underlying bottom surface (the "viscoplastic Stokes layer"). Both cases have been suggested to offer insight into the rheology of the material, and act as simple rheometers, and I will review experimental efforts in this direction.

Title: Shallow flows of viscoplastic and granular materials.

Author: Andrew J. Hogg (Centre for Environmental & Geophysical Flows, University of Bristol)

Speaker: Andrew J. Hogg (A.J.Hogg@bristol.ac.uk)

Many natural flows, such snow avalanches, mud slides and debris flows, are characterised by 'shallowness'; their velocity is predominantly parallel to the underlying boundary with negligible acceleration perpendicular to it. Thus an accurate leading-order model of their motion can be based on the shallow-water equations in which the pressure is hydrostatic and the streamwise dynamics exhibit a balance between inertia, drag and the streamwise pressure gradient.

Dam-break flows, whereby material at rest within a lock is abruptly set into motion by the rapid removal of the lockgate, are a particular shallow flow and are of widespread interest, not just because of the generic unsteady flows they generate, but also because of their direct application to environmental and engineering problems. In this contribution, I will present results that show how unsteady dam-break flows are slowed by hydraulic resistance and arrested by a yield stress (visco-plastic materials) or by the action of drag (granular materials).

Title: Experimental investigation of viscoplastic free surface flows. Application to debris flows.

Authors: G. Chambon, A. Ghemmour (Cemagref - ETNA Unit Grenoble, France.).

Speaker: G. Chambon (guillaume.chambon@cemagref.fr)

Debris flows are natural surges constituted by a mixture of grains and blocks in a viscoplastic matrix. We present a new experimental setup dedicated to understanding the dynamics and rheological properties of these free surface flows. It consists of a 3-m-long and 0.5-m-wide inclined channel whose bottom is constituted by an upward-moving conveyor belt with controlled velocity. This setup allows us to obtain gravitary surges that are stationary in the laboratory frame. Debris flow matrix is modelled by a transparent viscoplastic gel (Carbopol) in which millimetric grains can be added.

As a first step, series of experiments have been conducted using the viscoplastic gel alone. The flow was monitored with digital cameras, and the shape of the free surface was extracted from the pictures. The obtained stationary surges present steep, blunt-shaped fronts followed by a zone of uniform flow height. We report on the evolution of surge characteristics (uniform height, front shape) as a function of belt velocity and slope angle. These results demonstrate in particular that our setup can be viewed as a large-scale rheometer well suited to determine the mechanical properties of debris flow materials. Moreover, these results also provide well-documented benchmarks to test the long-wave models used for viscoplastic free surface flows, and suggest possible improvements to these models.

Finally, preliminary results concerning the behavior of grain/viscoplastic-fluid mixtures will also be presented. The objective of this study is to get better insight into the grain migration and segregation mechanisms occurring in natural debris flows, and to understand the role of these processes on the global surge dynamics.

Title: Dam-break problem and viscoplastic flows: new experimental results

Authors: Steve Cochard and Christophe Ancey (EPFL, Lausanne).

Speaker: S. Cochard (steve.cochard@epfl.ch)

The dam-break problem (i.e., the sudden release of a given volume of fluid down a slope) has attracted a great deal of attention from mechanicians and physicists over the last few years, with particular interest devoted to the free-surface profile and the spreading rate. Experimentally, impediments to accurate measurements of the free-surface evolution are numerous because of the significant variations in its curvature and velocity.

Essentially, our idea was to test the shallow-flow equations under extreme conditions in a well-controlled environment—the laboratory—where both the initial and boundary conditions are prescribed. Here, 'extreme conditions' means that we focus our attention on time-dependent flows (surges with a front) mobilizing Newtonian or non-Newtonian fluids, experiencing different stages from release to run-out: acceleration (balance between inertia and pressure gradient), a nearly fully developed regime (flow at equilibrium), and deposition (predominance of dissipation processes).

The evolution of the free-surface is presented for three test cases:

- A Newtonian fluid down a channel for four different slope angles.
- Viscoplastic materials down a channel for five different slope angles, for 2 different masses and for 4 different yield stresses.
- Viscoplastic materials down an incline plane for five different slope angles and for 4

different yield stresses.

Title: Prolegomena to variational inequalities and numerical schemes for compressible viscoplastic fluids

Author: R. R. Huilgol (Flinders University, Adelaide, Australia)

Speaker: R. R. Huilgol (raj@infoeng.flinders.edu.au)

After reviewing various results for incompressible Bingham fluids including the derivation of the variational inequality and an operator-splitting method for the solution of flow problems, a variational inequality is derived for compressible viscoplastic fluids in which the viscosity and yield stress depend on the pressure, temperature and shear rate, and inertial effects are present. An extension of the operator-splitting scheme to the flows of compressible viscoplastic fluids, when inertia and thermal effects are manifest, is proposed.

Title: Plastic strains in granular soils: micromechanical investigation of failure and plastic flow rule

Authors: François Nicot (Cemagref, Grenoble) and Félix Darve (Laboratoire Sols Solides Structures, UJF-INPG-CNRS, Grenoble)

Speaker: François Nicot (francois.nicot@cemagref.fr)

This lecture deals with two basic features of granular materials. First, a certain type of failure, described as a loss of sustainability, is investigated. For nonassociated materials such as granular assemblies a broad domain exists, strictly within the plastic limit, where different failure modes can coexist. The notion of loss of sustainability was recently shown to be a proper mode of bifurcation. Given a mechanical rate-independent system in equilibrium under prescribed control parameters, the mechanical state is reputed unsustainable if and only if the system can reach spontaneously another mechanical state. It was established in a very general manner that such bifurcation modes, characterized by a development of kinetic energy, are detected by the vanishing of the second-order work. Afterward, by specializing the investigation to granular materials, both macroscopic (on the specimen scale) and microscopic (on contact scale) second-order works are shown to be related through a fundamental multiscale relation. This relation, at the basis of our microstructural investigation, indicates that a material cause (related to the plastic behavior of some contacts) together with a geometrical cause (related to the deletion of contacts) are responsible for the vanishing of the macroscopic second-order work.

Then, the existence of a regular or a singular flow rule for the plastic strains is queried from a multiscale approach. By considering our micro-directional model, it is shown that a regular flow rule exists only in two-dimensional conditions, and disappears as soon as more general three-dimensional loading conditions are considered. The microstructural origin of this basic feature is discussed, and the strong influence of the loading history on the nature of the plastic flow rule is clearly pointed out.

References

– Darve, F., and Laouafa, F. (2000): Instabilities in granular materials and application to landslides. Mechanics of Cohesive-frictional Materials, Vol. 5, n° 8, pp. 627-652.

- Darve, F., and Laouafa, F. (2002): Constitutive equations and instabilities of granular materials. In Modelling and mechanics of granular and porous materials, Capriz et al. eds., Birkhauser publ., pp. 3-43.
- Darve, F., Servant, G., Laouafa, F., and Khoa H.D.V. (2004): Failure in geomaterials, continuous and discrete analyses. Comp. Methods Appl. Mech. Engrg., Vol. 193, pp. 3057-3085.
- Darve, F., and Vardoulakis, I. (2005): Instabilities and degradations in geomaterials. Darve and Vardoulakis Eds., Springer publ.
- Darve, F., and Nicot, F. (2005): On incremental non linearity in granular media: phenomenological and multi-scale views (Part I). Int. J. Num. Anal. Methods in Geomechanics. Vol. 29, pp. 1387-1409.
- Darve, F., and Nicot, F. (2005): On flow rule in granular media: phenomenological and multi-scale views (Part II). Int. J. Num. Anal. Methods in Geomechanics. Vol. 29, pp. 1411-1432.
- Nicot, F., and Darve, F. (2005): A multiscale approach to granular materials. Mechanics of Materials, Vol. 37 (9), pp. 980-1006.
- Nicot, F., and Darve, F. (2006): Micro-mechanical investigation of material instability in granular assemblies. Int. J. of Solids and Structures, Vol. 43, pp. 3569-3595.
- Nicot, F., and Darve, F. (2006): On the elastic and plastic strain decomposition in granular materials. Granular Matter, Vol. 8(3-4), pp. 221-237.
- Sibille, L., Nicot, F., Donze, F., and Darve, F. (2006): Material instability in granular assemblies from fundamentally different models. Int. J. Num. Anal. Methods in Geomechanics, in press.
- Nicot, F., Darve, F., and Khoa, H.D.V. (2006): Bifurcation and second-order work in geomaterials. Int. J. Num. Anal. Methods in Geomechanics, in press.
- Nicot, F., Sibille, L., Donzé, F., and Darve, F. (2006): From microscopic to macroscopic second-order works in granular assemblies. Mechanics of Materials, in press.
- Nicot, F., and Darve, F. (2007): Basic features of plastic strains : from micro-mechanics to incrementally nonlinear models. Int. Journal of Plasticity, in press.
- Nicot, F., and Darve, F. (2007): A micro-mechanical investigation of bifurcation in granular materials. Int. J. of Solids and Structures, in press.
- Darve, F., Sibille, L., Daouadji, A., and Nicot, F. (2007): Bifurcations in granular media, macro- and micro-mechanics. Compte-Rendus de l'Académie des Sciences, in press.
- Nicot, F., and Darve, F. (2006) : Micro-mechanical bases of some salient constitutive features of granular materials. Int. J. of Solids and Structures, in press.

Title: The somewhere obscure relation between grains and matrix constituting natural debris-flow

Author: Éric Bardou (UNIL, Lausanne).

Speaker: Éric Bardou (eric.bardou@unil.ch)

Natural debris-flows are made up by collection of grains that span several orders of magnitude (7-8) in diameter and water. Woody debris may have a strong influence in the flow properties in the Nature. Here, we choose the bias to study only the mixture of grain and water. Matrix has no unanimously accepted definition. In this context – and before to go further – matrix could be seen as the finer part of the grains that virtually fill the space between the bigger grains.

The energy dissipation during the flow is a function of diverse processes occurring inside the flowing mass (hydrodynamic effect, collisions, friction, etc.). At the same time, following their type (closely linked with their size), the grains could develop different interaction with their environment (mechanical effect and colloidal effect mainly). In our view, there is probably some threshold in the global flow properties that follow the balanced distribution of the particle type (those which enhance an energy dissipation type or another). Based on field observations and laboratory experiments it appears that the influence of the finer particles (less that some percent in mass) may not be negligible. Attempts to explain these influences give some hints for discerning matrix from grains. Then, the matrix could be defined as the particles collection that is responsible for the development of the more intense colloidal effects. Depending upon the particle type (especially the clays) the threshold may change from one material to another.

From these observations it appears that the model based only on the mechanic (hard-spheres model) may advantageously be complemented by introduction of physicochemical modules (kind of soft-spheres model). Furthermore, the qualitative observations reported here could already be used in natural hazard mitigation (sampling of material, hydrological influence, debris flow / bed load transition, etc.).

Title: Rheology and Rayleigh-Bénard convection of crystal-rich magma

Authors: A.C. Rust (University of Bristol, U.K.), N.J. Balmforth (University of British Columbia, Canada).

Speaker: Alison Rust (Alison.Rust@bristol.ac.uk)

Eruptions of magmas containing 30–50% crystals are common, however, the rheology of these viscoplastic fluids is not well constrained. We explore the sensitivity of the dynamics of convection in magma chambers to rheological models for crystal-rich magmas. We present theoretical and experimental stability results on Rayleigh-Bénard convection of fluids with a yield strength. For a Bingham fluid that is treated as rigid at stresses below the yield strength, an order one stress perturbation is required to initiate motion for any temperature difference (i.e., linearly stable at all Rayleigh numbers). However, magmas may not be perfectly rigid solids at small stresses and we find that stability is sensitive to the rheology below the yield stress. If the fluid is viscoelastic or very viscous at low stresses then there are critical Rayleigh numbers for instability, which in the viscoelastic case is an oscillatory instability.

In the laboratory we examine the convection of a fluid with a Herschel-Bulkley rheology. By varying rheology and temperature gradients we evaluate how convective instability is modified by yield stress. We also examine the effects of localized perturbations on the onset and subsequent pattern of convection. We find that yield strength drastically inhibits the onset of convection and if convection does occur, flow is much more localized than for a Newtonian fluid under the same conditions. Our results highlight the importance of understanding the details of the nature of yield strength for predicting the onset and pattern of convection. Furthermore they suggest that the effect of yield strength on convection may depend on whether the magma is initially stagnant (e.g., the heating of a locked mush) or whether the magma develops a yield strength due to crystallization as it convects.

Title: Weakly compressible Poiseuille and extrudate-swell flows of Herschel-Bulkley fluids

Authors: E. Taliadorou, G. Georgiou (Department of Mathematics and Statistics, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus), Andreas Alexandrou (University of Cyprus)

Speaker: Georgios Georgiou (georgios@ucy.ac.cy)

Under the assumption of weak compressibility, the pressure gradient in compressible Poiseuille flow of a Herschel-Bulkley fluid is a function of the axial coordinate and satisfies a non-linear equation that involves the material parameters and the density of the fluid. The density is calculated by means of an equation of state. In the present work, both the linear and the exponential equations of state are considered. For a given pressure, the nonlinear equation can be solved using the Newton method and by means of numerical integration the pressure distribution can be calculated across the flow direction. The velocity profiles across the channel can then be constructed. It is shown that the position of the yield point approaches the wall as one moves upstream from the channel or capillary exit. As a result, for a given channel-length no flow can occur if the imposed pressure at the inlet is below a critical value. Results for the compressible planar and axisymmetric extrudate-swell flows of Herschel-Bulkley fluids will also be presented and discussed.

Title: Two-phase debris flow modeling

Authors: Julia Kowalski (SLF, Davos) and Jim McElwaine (University of Cambridge, UK).

Speaker: J. Kowalski(kowalski@slf.ch)

Debris flows constitute a major hazard in mountainous areas. They consist of mobilized sediments spanning a wide range of grain sizes and the flows are fully or partly saturated with water. Attempts to physically model debris flows follow two different approaches. The first treats the entire debris flow as one bulk non-Newtonian material, the other explores the internal dynamics by describing it as a multicomponent mixture, where each phase is considered separately. Specifying a bulk rheology for the entire flowing body is a well established and successful method to model mudflows. However it is difficult to describe flows with a granular front and a muddy tail. Here it is substantial to account for the two different components. Because of the small aspect ratio of height to length of the flow, most models are formulated in a depth-integrated version, vertical acceleration within the flowing body is neglected. Two of such approaches are suggested by Iverson and Pitman. In the Iverson model the volume fraction of the components are fixed. As a consequence, the terms describing the basal friction always have the same composition. In our two-phase approach, we explicitly account for vertical particle movement. This is done by considering the mass per unit area, depth-integrated concentration and the vertical centre of mass as our system variables, rather than the height of the flow. Then the internal settling is modeled by a decrease of the vertical centre of mass and the basal friction varies with the vertical particle distribution. This model generalizes the ideas of Iverson's debris flow model. A short summary of the derivation of the model equations is presented and a 1D numerical test computation is discussed with respect to the underlying physics.

Title: Impact of a yield-stress fluid on rigid surfaces

Authors: Li-Hua Luu and Yoël Forterre (IUSTI, CNRS Université de Provence, Marseille, France).

Speaker: Yoël Forterre (yoel.forterre@polytech.univ-mrs.fr)

We investigate experimentally the impact of a drop made of yield-stress fluid on rigid surfaces. Using different fluids (Carbopol, Bentonite) and impacted surfaces (wetting and non-wetting), we found different regimes from full elastic recoil and bouncing to irreversible viscoplastic coating. Simple scaling arguments, together with a minimal model of inertial elastoviscoplastic spreading, are able to capture the whole phenomenology. Implication of these results for impact crater formation in yield-stress fluids will be briefly discussed.

Title: Kinematic interfacial instabilities in primary cementing of oil and gas wells

Authors: M. A. Moyers-Gonzalez (Université de Montréal) and I. A. Frigaard (University of British Coulumbia).

Speaker: M. A. Moyers-Gonzalez (moyers@dms.UMontreal.ca)

In this talk we investigate the possibility of kinematic interfacial instabilities occurring during the industrial process of primary cementing of oil and gas wells. Primary cementing displacement flows occur in long narrow eccentric annuli during the construction of oil and gas wells. A common problem is that the displacing fluid fingers up the upper wide side of the annulus, leaving behind a "mud channel" of displaced fluid on the lower narrow side of the annulus. Tehrani *et al.* report that the interface between displacing fluid and mud channel can in certain circumstances become unstable. Here we give an explanation for these instabilities via analysis of the stability of two-layer eccentric annular Hele-Shaw flows, using a transient version of the usual Hele-Shaw approach, in which fluid acceleration terms are retained.

Thursday October 18

09:00–10:00	*Plenary lecture*	Adaptive meshing in viscoplasticity	P. Saramito
10:00–10:30	*Refreshments*		
10:30–11:30	*Plenary lecture*	The energetics of snow avalanches	P. Bartelt
11:30–11:50	*Short talks*	Numerical simulation of the motion of a glacier	M. Picasso
11:50–12:10		Numerical simulation of 3D Bingham fluids	E. Muravleva
12:10–13:30	**Lunch**		
13:30–14:00		Wrap-up meeting	

Thursday talks

Title: Adaptive meshing in viscoplasticity

Author: Pierre Saramito (IMAG, Grenoble, France)

Speaker: Pierre Saramito (Pierre.Saramito@imag.fr)

This lecture deals with the numerical computation of yield stress fluids. A specific automatic mesh refining approach is developed, combined with the augmented Lagrangian algorithm. The proposed approach permits the accurate determination of yield stress surfaces. The demonstration of the efficiency of this approach, compared to older "regularizations" methods is demonstrated on three computations of practical interest. First, the fully developed Poiseuille flow of a yield stress fluid in a square section is presented [1]. The dead regions in outer corners and the plug region in the center are exhibited. Numerical computations cover the complete range of the dimensionless number describing the yield stress effect, from a Newtonian flow to a fully stopped flow. The limit load analysis and the associated limit yield surface are obtained by an extrapolation procedure. Next, the numerical modeling of the steady flow of a yield stress fluid around a cylinder is presented [2] Three categories of yielded regions are exhibited. The asymptotic behavior when the cylinder gets close to the wall is investigated. Finally, an extensions of the method to slip yield boundary condition at the wall is developed [3]. In conclusion, some theoretical convergence properties of the adaptive finite element method are recalled [4].

(1) P. Saramito and N. Roquet. An adaptive finite element method for viscoplastic fluid flows in pipes. *Comput. Meth. Applied Mech. Engng*, 190(40-41):5391–5412, 2001.

(2) N. Roquet and P. Saramito. An adaptive finite element method for Bingham fluid flows around a cylinder. *Comput. Appl. Meth. Mech. Engrg.*, 192(31-32):3317–3341, 2003.

(3) N. Roquet and P. Saramito. Stick-slip transition capturing by using an adaptive finite element method. *Mathematical Modelling and Numerical Analysis*, 38(2):249–260, 2004.

(4) N. Roquet, R. Michel, and P. Saramito. Errors estimate for a viscoplastic fluid by using Pk finite elements and adaptive meshes. *C. R. Acad. Sci. Paris, Série I*, 331(7):563–568, 2000.

Title: The energetics of snow avalanches.

Author: Perry Bartelt (SLF, Davos)

Speaker: Perry Bartelt (bartelt@slf.ch)

A fundamental problem in snow science is to find constitutive relations describing the motion of snow avalanches. Such relations are typically used in depth-averaged numerical models to predict avalanche inundation areas. In this presentation, we apply energy concepts to study frictional mechanisms in avalanches. We begin by analysing a series of chute experiments with granular materials in which the basal shear S and normal forces N, slip velocities u_0 and flow heights h are simultaneously monitored over time. Because we directly measure the friction coefficient $\mu = S/N$, we can observe how the gravitational work rate, the energy source, is transformed by the bulk frictional processes to internal energy (heat). The experiments reveal that when the gravitational work rate decreases, the friction coefficient increases, but with a definite time lag. This experimental result suggests that part of the gravitational work is used to generate random kinetic energy, which mechanically regulates the friction, before it too, is dissipated to heat. The time lag, or frictional hysteresis, found in the experiments is related to the difference between the production and decay of random kinetic energy. Steady flow states can exist only when the production and decay of random kinetic energy are in balance. This leads to unchanging friction coefficients (and constant velocities) observed in the experiments. More interesting are the flow states outside of steady state, which exist at the avalanche head and tail, that can be exploited to find the production and decay constants of the flowing material. Because we perform large scale chute experiments with snow, we can relate the results of the small scale granular experiments to larger scale snow flows. We show how these results can be used to explain a variety of snow avalanche behaviour, including the starvation of avalanches on steep slopes, real avalanche deposits or measured avalanche velocity profiles. At the end of the presentation, we discuss how the study of avalanche energetics has improved the numerical modelling of snow flows.

Title: Numerical simulation of the motion of a glacier

Authors: Marco Picasso, H. Blatter (Institute for Atmospheric and Climate Science ETHZ), G. Jouvet and J. Rappaz (Institut d'Analyse et Calcul Scientifique EPFL).

Speaker: Marco Picasso (marco.picasso@epfl.ch)

The motion of a three dimensional glacier is considered. Our goal is to find a set of climatic data for which the shape of the glacier fits the moraines that have been observed. This could provide information about the climate during the moraines formation.

Given the shape of a glacier, ice is modelled as an incompressible non-Newtonian fluid. The geometry is obtained solving a transport equation for the Volume of Fluid function (VOF). Such techniques have already been used for solving other free boundary problems such as mould filling or viscoelastic jets and filaments. Climatic effects (accumulation of ice on the top of the glacier and ablation on the tongue) are taken into account by adding a source term in the transport equation.

A first order splitting scheme allows diffusion and convection phenomena to be decoupled. Two different meshes are used. A coarse unstructured mesh with standard stabilized finite elements assures to solve a non linear Stokes problem. Then, the VOF function is computed on a fine structured grid. Accumulation and ablation of ice is performed by adding and removing some VOF according to the source term.

Given a stationary climatic input, a steady state shape of the glacier is observed after a certain time. Numerical results will be presented for the Muragl glacier in Switzerland.

Title: Numerical simulation of 3D flows of Bingham fluid

Author: Ekaterina Muravleva (Lomonosov Moscow State University, Moscow, Russia).

Speaker: Ekaterina Muravleva (catmurav@gmail.com)

This talk deals with the numerical simulation of three-dimensional non-isothermal steady Bingham fluid flow. Mathematical difficulties related to the classical Bingham model are overcome thanks to the use of a Lagrange multiplier and an augmented Lagrangian/Uzawa method. The governing equations are discretized using a finite difference method. Questions of approximation and stability are discussed. We formulate special consistency constraints for discrete operators, which is necessary for correctness of iteration method. We also examine more sophisticated model of yield stress fluid describing magma motion in volcanic conduits. Our investigation is made under several assumptions: magma is incompressible Bingham fluid, stress yield limit depends on crystal content, crystal growth rate is constant. Models with non-homogenious (temperature-dependent) yield limits are considered.

Participants

Title	**Name**	*First name*	*Academic institution*	*Country*	*Contact*
Prof.	**ALEXANDROU**	Andreas	University of Cyprus	Cyprus	andalexa@ucy.ac.cy
Prof.	**ANCEY**	Christophe	École Polytechnique Fédérale de Lausanne	Switzerland	christophe.ancey@epfl.ch
Mr	**ANDREINI**	Nicolas	École Polytechnique Fédérale de Lausanne	Switzerland	nicolas.andreini@epfl.ch
Prof.	**BALMFORTH**	Neil	University of British Columbia	Canada	njb@math.ub.ca
Dr	**BARDOU**	Eric	UNIL	Switzerland	eric.bardou@unil.ch
Dr	**BARTELT**	Perry	Schnee- und Lawinen Forschung	Switzerland	bartelt@slf.ch
Dr	**BONN**	Daniel	École Normale Supérieure	France	bonn@lps.ens.fr
Ms	**BONNOIT**	Claire	ESPCI (PMMH)	France	bonnoit@pmmh.espci.fr
Dr	**CHAMBON**	Guillaume	Cemagref	France	guillaume.chambon@cemagref.fr
Mr	**CHEDDADI**	Ibrahim	INPG (IMAG)	France	ibrahim.cheddadi@imag.fr
Dr	**CHEVALIER**	Christophe	LCPC & PMMH	France	christophe.chevalier@lcpc.fr
Mr	**COCHARD**	Steve	École Polytechnique Fédérale de Lausanne	Switzerland	steve.cochard@epfl.ch
Dr	**COUSSOT**	Philippe	LSMGC	France	Philippe.Coussot@lcpc.fr
Dr	**de BRUYN**	John	University of Western Ontario	Canada	debruyn@uwo.ca
Dr	**DE SOUZA MENDES**	Paulo	Pontificia Universidade Catolica	Brazil	pmendes@rdc.puc-rio.br
Dr	**DUBASH**	Neville	University of British Columbia	Canada	ndubash@math.ubc.ca
Dr	**FAUG**	Thierry	Cemagref	France	thierry.faug@cemagref.fr
Dr	**FESTER**	Veruscha	Cape Peninsula University of Technology	South Africa	FesterV@cput.ac.za
Dr	**FORTERRE**	Yoel	Université de Provence (IUSTI)	France	yoel.forterre@polytech.univ-mrs.fr
Prof.	**FRIGAARD**	Ian	University of British Columbia	Canada	frigaard@math.ubc.ca
Mr	**GAMPER**	Lukas	ETHZ	Switzerland	gamperl@ethz.ch
Prof.	**GEORGIOU**	Georgios	University of Cyprus	Cyprus	georgios@ucy.ac.cy
Prof.	**GODDARD**	Joe	University of California San Diego	USA	jgoddard@ucsd.edu
Dr	**GRANER**	François	Joseph Fourier University	France	graner@ujf-grenoble.fr¿
Prof.	**HOGG**	Andrew	University of Bristol	UK	A.J.Hogg@bristol.ac.uk
Prof.	**HUILGOL**	Raj	Flinders University	Australia	raj@infoeng.flinders.edu.au
Ms	**KOWALSKI**	Julia	Schnee- und Lawinen Forschung	Switzerland	kowalski@slf.ch

Title	**Name**	*First name*	*Academic institution*	*Country*	*Contact*
Dr	**MARTINEZ**	Mark	University of British Columbia	Canada	martinez@chml.ubc.ca
Dr	**MC ELWAINE**	Jim	University of Cambridge (DAMTP)	UK	J.N.McElwaine@damtp.cam.ac.uk
Prof.	**MITSOULIS**	Evan	School of Mining (NTUA)	Greece	mitsouli@metal.ntua.gr
Mr	**MOLLER**	Peder	École Normale Supérieure	France	peder.moller@gmail.com
Dr	**MOYERS**	Miguel	Université de Montréal	Canada	m.a.moyers-gonzalez@durham.ac.uk
Ms	**MURAVLEVA**	Ekaterina	University of Moscow	Russia	catmurav@gmail.com
Dr	**NACCACHE**	Monica	Pontificia Universidade Catolica	Brazil	naccache@mec.puc-rio.br
Dr	**NICOT**	François	Cemagref	France	francois.nicot@grenoble.cemagref.fr
Dr	**NOUAR**	Cherif	ENSEM (LEMTA)	France	Cherif.nouar@ensem.inpl-nancy.fr
Prof.	**PASTOR**	Manuel	CEDEX	Spain	Manuel.Pastor@cedex.es
Dr	**PICASSO**	Marco	École Polytechnique Fédérale de Lausanne	Switzerland	marco.picasso@epfl.ch
Dr	**POULIQUEN**	Olivier	IUSTI	France	olivier.pouliquen@polytech.univ-mrs.fr
Dr	**RUST**	Alison	University of Bristol	UK	Alison.Rust@bristol.ac.uk
Dr	**SARAMITO**	Pierre	INPG (IMAG)	France	Pierre.Saramito@imag.fr
Dr	**SASSI**	Roberto	Università Delgli studi di Milano	Italy	sassi@dti.unimi.it
Dr	**SLATTER**	Paul	Cape Peninsula University of Technology	South Africa	SlatterP@cput.ac.za
Dr	**SLIM**	Anja	University of British Columbia	Canada	anja@math.ubc.ca
Prof.	**TSAMOPOULOS**	John	University of Patras	Greece	tsamo@chemeng.upatras.gr
Prof.	**VAN DAMME**	Henri	ESPCI	France	Henri.VanDamme@espci.fr
Mr	**WIEDERSEINER**	Sébastien	École Polytechnique Fédérale de Lausanne	Switzerland	sebastien.wiederseiner@epfl.ch
Dr	**WILSON**	David	University of Cambridge	UK	diw11@cam.ac.uk

	Monday 15	Tuesday 16	Wednesday 17	Thursday 18
8h				
9h	Coussot	Pouliquen	Balmforth	Saramito
10h	Moller Chevalier	McElwaine Wiederseiner	Hogg	Bartelt
11h	Tsamopoulos Bonn	Bonnoit Huilgol	Cochard Chambon	Picasso Muravleva
12h		**LUNCH**		
13h	Van Damme	Graner	Huilgol	
14h				
15h	Goddard	Pastor	Nicot	
16h	Alexandrou Martinez Fester Slatter	Cheddadi Mitsoulis de Bruyn Naccache	Bardou Rust Georgiou Kowalski	
17h	Métivier/Nouar Nouar	Mendes Wilson Wilson	Forterre Moyers	
18h		**DINNER**	(banquet)	
19h				