

Solid Earth Geophysics

Newsletter issue 28

June 2002

New Geophysical Fluid Dynamics Laboratory at the ANU

By Dr Ross Kerr and Prof. Ross Griffiths

Research School of Earth Sciences, The Australian National University

ross.kerr@anu.edu.au ross.griffiths@anu.edu.au

(or see: <http://rses.anu.edu.au/gfd/>)

In March last year, the Federal Minister for the Environment Senator Robert Hill officially opened a new geophysical fluid dynamics laboratory at the Australian National University. The purpose-built premises includes a 300 m² main laboratory (fig. 1), a 30 m² temperature-controlled laboratory whose temperature can be maintained in the range 2 – 30 °C, a darkroom, and a support area for the construction of equipment. The laboratory brings together staff with fluid dynamical expertise in the modelling of a range of ocean circulation processes and geological flows. This breadth reflects the wide-ranging importance of fluid dynamics (through the transport of heat, mass and momentum) in geological, geophysical, oceanographic and environmental phenomena.



Fig. 1: One of 9 bays in the main geophysical fluid dynamics laboratory.

Recent fluid dynamics research in the new lab and of interest to the Solid Earth Geophysics community includes an investigation of the dynamics of the growth of lava domes, by PhD student David Osmond and Prof. Ross Griffiths. They have investigated the shape of very slowly growing lava domes extruded onto slopes when the highly silicic lava has a yield strength. Laboratory experiments were performed using slurries made from a mixture of polyethylene glycol (PEG)

wax and kaolin clay extruded on to a sloping plane (fig. 2), and the results compared with their analytical and numerical solutions. By using the ratio of the cross-slope width to the down-slope length of the flow, they have found a means of estimating the yield strength of highly silicic lava flows on simple slopes.

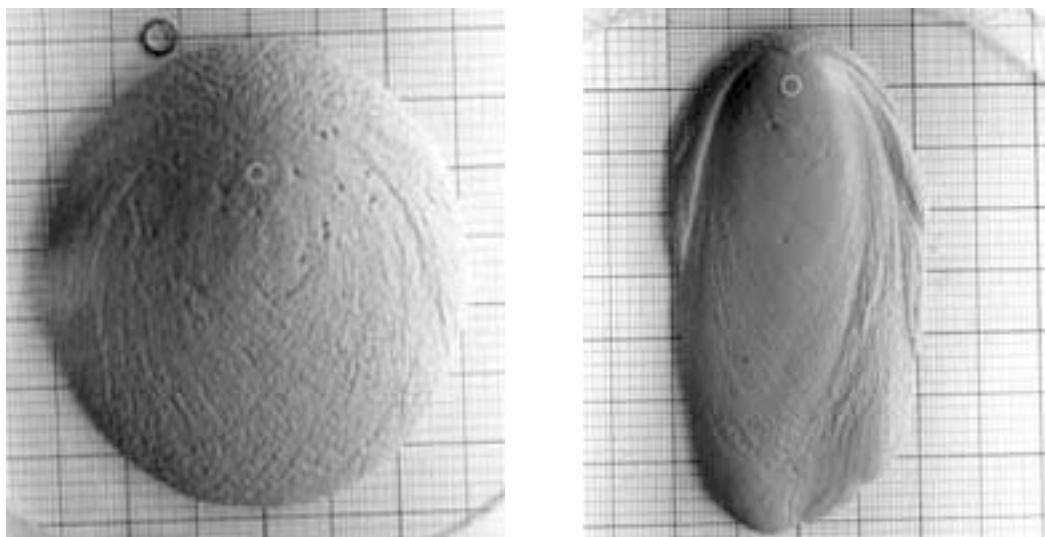


Fig. 2: Overhead photographs of slurry domes flowing down a slope (towards the bottom of the page). The white circles indicate the source locations.

Another study, by Dr Ross Kerr, addressed a recent geological controversy over whether laminar lava flows are able to thermally erode the ground over which they flow. To answer this question, experiments were performed in which hot PEG wax flowed down a sloping channel over a layer of cold solidified PEG wax. The experiments demonstrated the growth and meltback of an initial chill layer (fig. 3), at rates in good agreement with theoretical predictions based on forced convective heat transfer during laminar channel flow at large Péclet numbers. The results have already been used to explain field observations of thermal erosion by basaltic lava flows at Hawaii, Mt. St. Helens and the East Pacific Rise, and by natrocarbonatite lava flows at Oldoinyo Lengai in Tanzania.

Prof. Ross Griffiths, Dr Ross Kerr and Prof. Katherine Cashman (University of Oregon, USA) recently began an investigation of solidification on the surface of long channelised lava flows. In their experiments, PEG wax flows down an inclined, open rectangular channel immersed in cold water. They have found two regimes, depending on the flow velocity and on the temperatures of the wax and water relative to the freezing temperature of the wax (fig. 4). For sufficiently high flow speeds and temperatures, a solid surface crust develops in the centre of the channel some distance from the source. The crust remains separated from the walls by crust-free shear regions as it is carried down the channel. Under these conditions solidification also occurs very close to the source within the sidewall boundary layers, where the solid phase is continually sheared and broken into small pieces. At lower flow speeds and temperatures the solid creates a stationary roof and flow continues through an insulated channel beneath. It is already clear that a detailed understanding of these processes will be crucial for the modelling of lava flows that resurface much of the Earth's crust.

Next year, the temperature-controlled laboratory will be used by Prof. Christopher Kincaid (University of Rhode Island, USA) and Prof. Ross Griffiths, in a project aimed at understanding the three-dimensional dynamics and thermal evolution of the plate and the mantle wedge at subduction zones. They will carry out experiments that will explore different subduction modes (both longitudinal and rollback subduction) as well as the relative motion of the back arc plate.



Fig. 3: Views up the channel towards the source, showing the formation and meltback of a chill layer in a thermal erosion experiment. The first photograph (left) was taken after 2 minutes, and shows the white chill layer that has formed on top of the original cold ground (dyed blue). The second photograph (right) was taken after 36 minutes, and shows that the chill layer has been completely eroded along the centre of the channel but still remains along its sides.

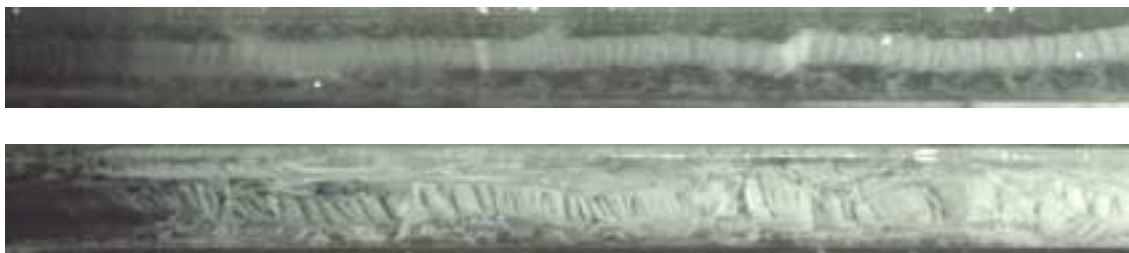


Fig. 4: Overhead photographs of the two regimes of flow with surface solidification along a 44 mm wide channel. The flow is down slope from left to right. The upper photograph shows the formation of a mobile central crust with sidewall shear layers. The lower photograph shows complete surface solidification leading to a stationary roof with underlying flow. The photographs show distances from the source of 0.5 m to 1.1 m and 0.2 m to 0.8 m, respectively.

Particle-in-cell finite elements and geodynamic modeling

By Dr. Rich Albert

Division of Geology and Geophysics, University of Sydney

albert@es.usyd.edu.au

Just about all geodynamicists and geophysicists have heard of Finite Element Analysis (FEA), and the benefits that we've gained by its use are staggering. Originally developed for use in the aerospace industry in the 1960s, this method has become one of the powerhouse techniques to explore the mechanics of solids and fluids in numerous applications. It is a pleasure to note that geoscientists have applied it creatively and successfully to situations that are outside of the realm of the most common engineering applications. But in spite of its successes, there are still limitations to the standard finite element technique that have necessitated the development of other approaches to problems in mechanics. These limitations often apply to geodynamic problems, so by attempting to tackle the complexities of geologic systems, we need to advance the "cutting edge", and take advantage of the latest developments in numerical analysis.

In a nutshell, the standard FE technique of discretization or 'meshing' to solve a solid mechanics problem (such as a bending oceanic lithosphere) suffers from a limitation on the allowable distortion of the mesh. In this Lagrangian formulation of mechanics, the mesh deforms with the body as it is loaded, and at some point the calculations will get less and less accurate if the elements' aspect ratios and/or internal angles are altered toward troublesome values, until a point is reached where continuation is impossible. In contrast, the Eulerian formulation of the continuum is often used for the mechanics of fluids (such as convection in planetary mantles or atmospheric motions), where the mesh is fixed and the fluid flows through it, and information about the flow is calculated at the fixed nodal points of the mesh. The focal point in this formulation shifts from following individual parcels of fluid (as per the Lagrangian approach) to ascertaining the properties (velocity, pressure, etc.) of the fluid at specific locations. This approach removes the problem of mesh distortion and allows analysis of extremely large deformation at the expense of some computational complexity, but by using it we sacrifice the ability to track individual portions of fluid as they advect, and similarly there is no capacity to track the deformation of interfaces within the body of interest without significant modifications to the method.

The limitations mentioned above have been addressed in various ways, such as allowing some distortion of the mesh, but not completely following it (Arbitrary Lagrangian-Eulerian methods – ALE), and remeshing the body as it deforms (the Dynamic Lagrangian Remeshing– DLR). Another avenue is to not mesh the body at all, but simply model it via a collection of separate points, instead of "point-connected" elements (Smooth Particle Hydrodynamics – SPH, Reproducing Kernel Particle Methods – RKPM). Geoscientists (Braun, Beaumont, Fullsack, etc.) have successfully utilized some of these alternate methods in recent years.

Another method is the Particle-in-cell method (PIC), which takes the strength of the Eulerian technique (allowing large deformation of the body without having the mesh deform – i.e., keeping it fixed), and the Lagrangian formulation (tracking the paths and deformation history of individual parcels of the material). From this description, one can visualize the PIC method as a collection of particles that constitute the body, flowing through the elements of the mesh that are fixed in space (Figure 1). The

information (such as the nodal velocities) that is solved on the fixed mesh is mapped to the particles to ascertain their (and the body's) response, such as calculating the strain and/or its rate (depending on the rheological model(s) involved) and hence the stress for each particle, although the details are not within the scope of the present article, as one might expect. By using the mesh's cells purely as a computational convenience, and modeling the stress and deformation of the body via the particles, the body can now undergo extensive deformation and yet the individual particles, material types, interfaces, etc., can be easily tracked. This is the beauty and the strength of the method. It is also clear why this method is so well-suited for problems in geodynamics, because often the geological system of interest involves tremendous deformation yet there is the necessity of tracking what happened to individual materials. Examples include the convection of Earth's mantle over billions of years (where did that subducting slab go, anyway?), or the compression and buckling of a stratified rock mass (what happened to that quartzite layer? How has it deformed relative to the layers that were above and below it?).

A well-established Particle-in-cell Finite Element code, "Ellipsis", written by Louis Moresi of CSIRO (and now Monash University's School of Mathematical Sciences), has been used extensively by researchers at CSIRO (Mühlhaus, Dufour, Wijns), and currently handles 2D viscoelastic/brittle rheologies. As part of a nationwide effort, our work at the University of Sydney has involved extending the code from 2D to 3D and we are continuing with various alterations and benchmarking. One of our 3D models involves the extension of an upper crust/lower crust/upper mantle system, to inspect the stresses and deformation that develop under several phases of multidirectional loading. A sample plot of plastic strains from a two-layer simulation is shown in Figure 2. Although the application of the 3D code is still in its early stages, there is much promise in its potential for unraveling a bit more of the complexity that characterizes geodynamic problems. We have also incorporated the code in a "Modeling Earth Processes" class at the University of Sydney, where thirty students will apply the code to supplement lectures and see the beauty of geophysics at work. Attendees at last year's Chapman Conference in Exploration Geodynamics in Western Australia, saw numerous applications of Ellipsis to problems on multiple length and time scales (see *Report* below) and animations of PIC simulations can be found at: http://www.es.usyd.edu.au/Geophysics/Marine_geophysics/Resprojects/index.html

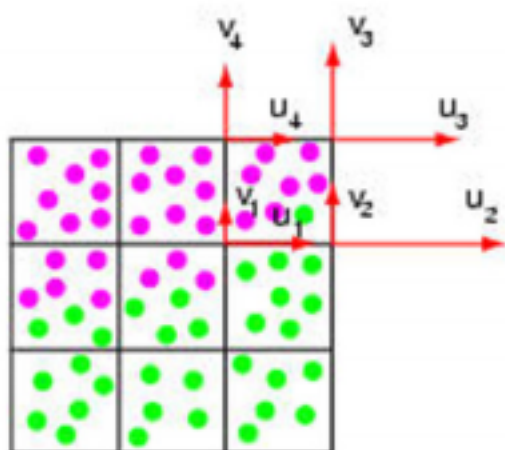


Fig. 1. A schematic representation of PIC methodology with 9 elements and 2 different materials (particles of different colors). Shown are sample local nodal velocities for one of the elements (from the Eulerian part of the calculations), which are to be interpolated to the particles within that element. This is just one of many steps in the solution procedure for PIC FEA.

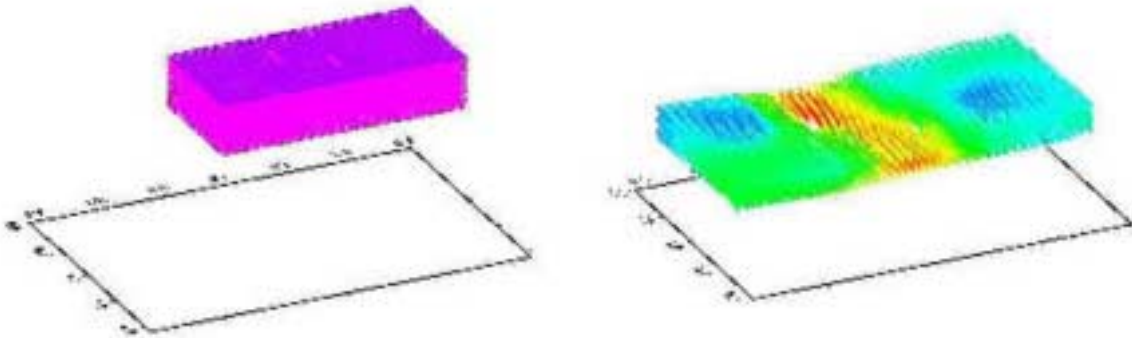


Fig. 2. Two plots of particles and their inelastic strains for one of the 3D simulations with multidirectional extension. Only the top layer (which had upper crustal properties) is shown, at the initial (left) and final (right) times, and the plasticity was localized at the start by creating two weak zones that were slightly offset. The locations of the weak zones are seen in the plot on the left, but in order to make these zones more easily observed, the material occupying them has been removed.

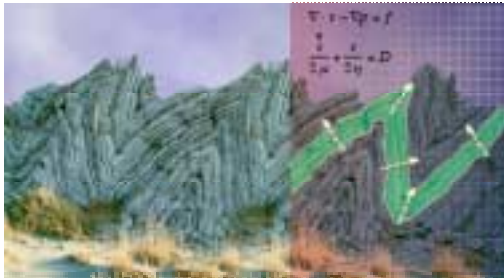
FURTHER READING

Less-technical: L. Moresi, M. Gurnis, and S. J. Zhong. Plate tectonics and convection in the earth's mantle: toward a numerical simulation. *Comput. Sci. Eng.*, 2:22–33, 2000

Technical: L. Moresi, F. Dufour, and H.-B. Mühlhaus. Mantle convection models with viscoelastic/brittle lithosphere: Numerical methodology and plate tectonic modeling. *Pure Appl. Geophysics*, In Press, 2002

Report

Chapman Conference-Exploration Geodynamics



The SGSEG was an important sponsor of the AGU Chapman Conference on Exploration Geodynamics which was held in Dunsborough, WA during August 2001. The meeting brought together Australian scientists from Universities, CSIRO and Industry with their counterparts from overseas. The main theme of the conference was the way in which

quantitative numerical modeling in geodynamics can contribute to the fundamental understanding of geology and, in particular, drive the next generation of exploration geoscience.

An important step along the way to that goal is the development of a broad understanding within the geological community of the capabilities of quantitative modeling and the limitations. Equally important is the need to develop a wide understanding within the modeling community of the needs of geologists and the important problems which could be addressed by modeling.

Over 5 days the participants focused on a range of topics from the global scale, through the basin scale, to the deposit scale, and, in the process, explored the state of the art in geological simulation. During a day-long field trip, modellers unaccustomed to any physical activity more demanding than reaching for a cup of coffee were taken around the granites of the Leeuwin Complex. The final sessions of the meeting were wide ranging discussions designed to bring together different groups of people to begin new collaborations.

The abstracts from the meeting, and many of the presentations are currently archived on the web at

Conference Announcements

ASEG2003 Conference, Feb. 2003 Adelaide

Session "From Solid Earth Geophysics to Exploration" Conveners: Louis Moresi and Dietmar Mueller

Contact: www.aseg.org.au/conference/Adelaide

ASEG 16th Geophysical Conference and Exhibition

Growth Through Innovation

16-19 February 2003

Adelaide Convention Centre

Abstracts (no more than 300 words) are due by June 30, 2002.

This session provides an opportunity for Solid Earth Geophysicists and Geodynamicists to present what they see as exploration implications of their work to industry. We would like to bring together experts in crustal and mantle seismology, potential fields, and geological and geodynamic modeling to assess where the blue sky research of today might lead to applications tomorrow. Two of the most important issues we have to face is (1) the development of a common understanding of the capabilities of modeling among data-oriented geophysicists and geologists and (2) the development of a common understanding of what types of data and data analysis methods are available that can feed back into modeling.

Topics of interest for this session may include:

- New methods for joint analysis of active source seismic reflection and refraction data: how a better understanding of crustal structure can aid exploration
- New approaches in the analysis of magnetotelluric data and how they may be applied to shallow/sub-salt exploration problems
- Textural analysis and artificial intelligence applications for image analysis (potential fields, downhole images such as FMS)
- What has the mantle been doing to the crust: Implications of seismic tomography and geodynamic modeling for exploration
- Tectonic reactivation through time: New methods for integrating large-scale geodynamic modeling, basin modeling, structural data analysis/inversion, and well-seismic data integration
- Advances in simulation of geological processes on the computer. How do we model fluid dynamics and solid mechanics jointly, with the complexity of pervasive reactive fluid flow in the crust which dissolves, precipitates and alters the rocks as they deform?

The 10th International Symposium on deep seismic profiling of the continents and their margins

January 6-10, 2003, Taupo, New Zealand

First Circular is out.

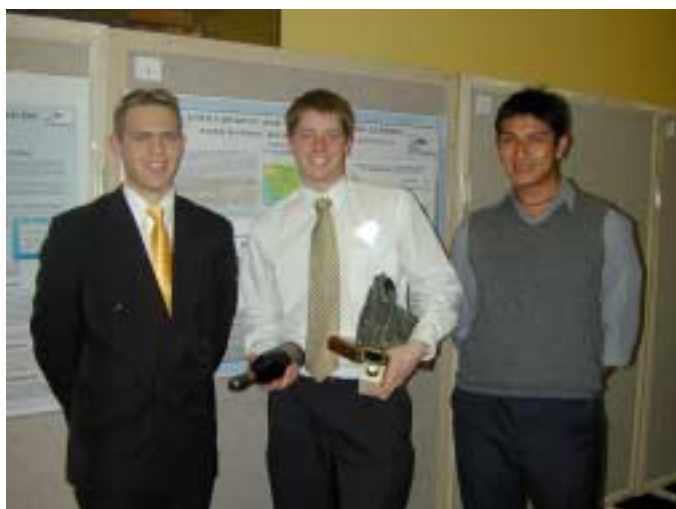
E-mail: seismix2003@GNS.CRI.NZ

Web page: www.gns.cri.nz/news/conferences

From the Treasurer

SGSEG financial balance in June 2002 is \$16539.42. (\$12822.31 in a 6-month term deposit account, and \$3717.11 in a cheque account). In the past year we had an income of \$1546.15 from outstanding capitation and reimbursement from GSA and \$461.74 interest from the term deposit. In the past financial year we have sponsored three conferences: the Chapman Conference (September 2001, Perth) with \$3300, the 10th International Symposium on Deep Seismic profile (to be held next year in New Zealand (\$2500), and Victorian Universities Earth Science Conference (VUESC) to be held in September in Melbourne (\$300). These sponsorships are used as student travel grants or prizes.

The SGSEG last year's contribution of \$300 to the *15th Victorian Universities Earth Sciences Conference (VUESC- La Trobe)* was divided into two \$150 cash prizes and awarded to the *Best Oral Presentation* and *Best Poster Presentation* in the category of "Geophysical and Analytical Methods". The *Best Oral Presentation* was awarded to Hashim Carey, and the *Best Poster Presentation* was awarded to Brian Barrett, both Honours student from the University of Adelaide.



Winners of the Best Oral Presentation and Best Poster Presentation at 15th VUESC: Hashim Carey on the right and Brian Barrett on the left. In the middle is Michael Wall, another student from the University of Adelaide won the Best Overall Poster prize.

From the Editor

The Newsletter will be sent yearly, with the next edition to be released in June 2003. If you would like us to include a feature article, an announcement of general scientific interest, or a question to the SGSEG community don't wait. By sending your material now, it will be uploaded to our website straight away. Act now!

Contact Roberto Weinberg (rweinber@geol.uwa.edu.au).



<i>Chair:</i>	Dietmar Müller, The University of Sydney
<i>Co-Chair:</i>	Louis Moresi, Monash University
<i>Hon. Treasurer:</i>	Carmen Gaina, The University of Sydney
<i>Hon. Secretary:</i>	Richard Albert, The University of Sydney
<i>Newsletter editor:</i>	Roberto Weinberg, University of Western Australia
