Report on Creep and fracture of Earth and planetary materials: from ice to olivine

Convenors: M.R. Drury, M. Montagnat and M. Schneebeli

**Summary**

A successful scientific session on creep and fracture of Earth and planetary materials with special emphasis on ice, was held as part of the EGU 2012 cryosphere science programme (session CR5.1). The session consisted of six oral presentations and eight poster presentations. The topics covered ranged from brittle processes in sea ice, to ductile deformation of upper mantle minerals, including field based, experimental, analytical and theoretical studies. The session attracted a good mix of contributions on fracture and creep of ice and other geological materials including, halite, eclogites, glass, olivine, quartz and shale. To build on the success of the meeting a similar session is planned at the EGU 2014.

## Scientific content and discussions

Background of session: Deformation in the cryosphere and lithosphere of Earth and other planets occurs by creep and fracture of highly anisotropic polycrystalline materials such as ice, quartz, calcite, feldspar, pyroxene and olivine. In these materials deformation mechanisms and rheology are complex and challenging to include in modeling studies of cryosphere and lithosphere dynamics. The interdisciplinary session brought together researchers from different fields, working on a similar topic: understanding cryosphere and lithosphere rheology based on the material properties. The session included contributions from glaciology (land and sea ice), geology, and materials science.

In the oral session, a mix of topics and materials was selected to cover a wide range of processes. In the first invited talk, Professor Peter Sammonds (UC London) showed how environmental parameters controlled shelf ice fracture and how a fracture mechanisms approach could be used to predict the stability of ice shelves. C. Mallet et al. (Ecole Normale Superior, Paris) studied the creep of glass samples produced by slow crack propagation. They found that an exponential law described the rate of crack propagation as a function of temperature, environment and applied stress. In the second invited talk Professor Holger Stunitz et al. (Univerity of Tromso and University Basel) described the theoretical analysis of phase distributions produced by different ductile deformation mechanisms. The method was applied to eclogites deformed at high pressures in subducted crust. Dorthe Dahl Jansen

(University of Copenhagen) presented results from deep echo sounding over the Greenland ice sheet. The basal 10% of the ice thickness revealed very distrurbed layers with spectacular fold structures. Related experimental studies showed very different rheological properties in this basal layer compared to the shallower ice. Discussions focused on the reasons for the different properties.

The final two talks were experimental studies on crustal and mantle minerals. Dimanov et al. (Ecole Polytechnique, Palaiseau) deformed NaCl polycrystals at room temperature and 400°C. They showed that dislocation slip and grain boundary sliding accommodated deformation. The grain boundary sliding was detected by a digital image correlation technique applied to gold particle markers on the surface. In the third invited talk Professor Patrick Cordier et al.(University Lille) showed the results of detailed electron microscopy studies of olivine single crystals deformed at low temperatures appropriate to the lithospheric mantle. Spectacular TEM tomography of dislocation structures showed a wider range of slip planes than expected and insights into the controlling deformation mechanisms.

The poster session held on Friday afternoon was very well attended and busy, with many active discussions. Binder et al. (University Heidelberg) presented a combined transmitted and relection light microscopy analysis of ice core microstructures. There was strong interest from geologists using similar techniques on minerals. Breton et al. (Dartmouth College) showed new experimental and EBSD data on the effect of pressure on ice creep. They confirmed that increasing pressures enhanced the creep rate significantly. Posters on creep processes and microstructures in minerals discussed the basis of using Dauphine twins as a paleostress indicator in quartz (Sintubin et al. Leuven), and the relation between creep compliance and elastic modulus in organic rich shales (Sone and Zoback, GFZ Posdam & Stanford University). Posters on field studies of ice flow discussed a field experiment on ice deformation at the Tete Rouge glacier in France. Gagliardini et al. ( LGGE-CNRS, Grenoble) showed it was important to account for ice damage to reproduce the observed surface displacements. Faillettaz and Funk ( ETH Zurich) analyzed Alpine glacier instabilities and found that different types of instabilities depended on the themal state of the ice-bed interface. Glaciers with cold interfaces showed precursors before instability, while warmer interfaces had no easily detected precursory signs of instability. Jansen et al. (AWI Bremerhaven) reviewed the microstructures found in polar ice and the relationship to recrystallization processes and deformation mechanisms.

## Assesment of the impact of the meeting.

This was first time a session on the topic of creep and fracture in Earth and Planetary materials has been held at EGU in the Cryosphere science program. The session was successful in attracting contributions and provided a good interdisciplinary forum for geologists, glaciologists, and material scientists working on the same processes, to meet and exchange ideas. The oral session attracted a reasonable audience of more than 50 people. On the basis of the interest we plan to arrange a similar session at EGU 2014.

## Annex

Oral session Programme and list of participants

**1) Invited**: *Environmental controls on micro fracture processes in shelf ice*
Peter Sammonds,
University College Londn, Earth Sciences, London, United Kingdom (p.sammonds@ucl.ac.uk)

2) *Slow crack propagation in glass and creep prediction*
Celine Mallet, Jerome Fortin, and Yves Gueguen
Ecole Normale Supérieure, Laboratoire de Géologie, Paris, France (mallet@geologie.ens.fr)

4) *Deformation and folds of the basal ice under the Greenland ice sheet*
Dorthe Dahl-Jensen
University of Copenhagen, Niels Bohr Institute, Copenhagen, Denmark (ddj@gfy.ku.dk)

**3*) Invited***: *The geometry of phase mixing: inferring viscous deformation processes from quantitative spatial distributions*
Holger Stunitz (1), Renee Heilbronner (2), and James McKenzie (2)
(1) University of Tromsø, Dept. of Geology, Tromsø, Norway (holger.stunitz@uit.no), (2) Dept. of Geology, Basel University, Basel, Switzerland

**5)** ) *Ductile deformation mechanisms of synthetic halite: a full field measurement approach*
Alexandre Dimanov (1), Mathieu Bourcier (1), Eva Héripré (1), Michel Bornert (2), and Jean Raphanel (1). (1) Ecole Polytechnique, Laboratoire de Mecanique des Solides (UMR 7649), Palaiseau Cedex, France (dimanov@lms.polytechnique.fr), (2) Ecole des Ponts ParisTech, Laboratoire Navier (UMR 8205), 6-8, Avenue Blaise Pascal, Champs-sur-Marne, 77455 Marne-la-Vallee Cedex, France (michel.bornert@enpc.fr)

**6) Invited**: *Deformation mechanisms of olivine single crystals compressed at 300 MPa and 800-1100_C*
Patrick Cordier (1), Sylvie Demouchy (2), Alexandre Mussi (1), and Andrea Tommasi (2)
(1) University of Lille I, UMET - UMR 8207, Villeneuve d Ascq, France (patrick.cordier@univ-lille1.fr), (2) Université de Montpellier 2 & CNRS, UMR 5342 Geosciences Montpellier, 34095 Montpellier. France

Poster presentations

*Looking at Dauphiné twins in vein quartz as a potential paleostress indicator*

Manuel Sintubin (1,2) and Hans-Rudolf Wenk (1)
(1) Katholieke Universiteit Leuven, Department of Earth and Environmental Sciences, Leuven, Belgium (manuel.sintubin@ees.kuleuven.be), (2) University of California, Berkeley, Department of Earth and Planetary Science, Berkeley, CA, U.S.A. (wenk@berkeley.edu)

*Comparisons of Fabric Strength and Development in Polycrystalline Ice at Atmospheric and Basal Hydrostatic Pressures*
Daniel Breton (1), Ian Baker (1), and David Cole (2)
(1) Thayer School of Engineering, Dartmouth Collge, Hanover, New Hampshire, United States (daniel.j.breton@dartmouth.edu), (2) Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, United States

*Properties of grain boundary networks in the NEEM ice core*
Tobias Binder (2), Ilka Weikusat (1), Johannes Freitag (1), Anders Svensson (3), Dietmar Wagenbach (4), Christoph Garbe (2), and Sepp Kipfstuhl (1)
(1) Alfred Wegener Institute, Glaciology, Bremerhaven, Germany , (2) Interdisciplinary Center for Scientific Computing, Universität Heidelberg, Germany, (3) Niels Bohr Institute, Ice and Climate Research, University of Copenhagen, Denmark, (4) Institut für Umweltphysik, Universität Heidelberg, Germany

*Combined transmission and reflection optical microscopy of ice core sections*
Tobias Binder (2), Ilka Weikusat (1), Thomas Kerst (2), Jan Eichler (1), Anders Svensson (3), Pascal Bohleber (4), Christoph Garbe (2), and Sepp Kipfstuhl (1) (1) Alfred Wegener Institute, Glaciology, Bremerhaven, Germany , (2) Interdisciplinary Center for Scientific Computing, Universität Heidelberg, Germany, (3) Niels Bohr Institute, Ice and Climate Research, University of Copenhagen, Denmark, (4) Institut für Umweltphysik, Universität Heidelberg, Germany

*Alpine glacier instabilities Processes and early warning perspectives*
Jerome Faillettaz (1) and Martin Funk (2) (1) ETHZ, STEP, Zurich, Switzerland (jerome.faillettaz@usys.ethz.ch), (2) ETHZ, VAW, Zurich, Switzerland (funk@vaw.baug.ethz.ch)

*A 3-years full-scale mechanical ice deformation test from the artificial drainages of the Tête Rousse cavity*
Olivier Gagliardini (1,2), Jean Krug (1), Fabien Gillet-Chaulet (1), Gaël Durand (1), Adrien Gilbert (1), Emmanuel Thibert (3), Christian Vincent (1), and Jérôme Weiss (1)
(1) LGGE CNRS / UJF - Grenoble 1, St. Martin d Hères, France (olivier.gagliardini@ujf-grenoble.fr, +33 (0)4 76824201), (2) IUF, Paris, France, (3) IRSTEA, Grenoble, France

*Using composite flow laws to extrapolate lab data on ice to nature*
Hans de Bresser (1), Sabrina Diebold (1), and William Durham (2)
(1) Department of Earth Sciences, Faculty of Geosciences, Utrecht University, The Netherlands, (2) Department of Earth,Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, USA

*Dominant processes for microstructure evolution in polar ice*
Daniela Jansen (1), Sergio Faria (2), Ilka Weikusat (1), and Nobuhiko Azuma (3)
(1) Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany (daniela.jansen@awi.de), (2) BC3 -Basque Centre for Climate Change, Bilbao, Spain (sergio.faria@bc3research.org), (3) Dept. of Mechanical Engineering, Nagaoka University of Technology, Nagaoka, Japan (azuma@mech.nagaokaut.ac.jp)

*Relation between creep compliance and elastic modulus in organic-rich shales observed through laboratory experiments.*
Hiroki Sone (1) and Mark Zoback (2)
(1) GFZ Potsdam, Sektion 3.2 Geomechanics and Rheology, Germany (sone@gfz-potsdam.de), (2) Department of Geophysics, Stanford University, USA (zoback@stanford.edu)