



Science Meeting – Scientific Report

Proposal Title:

Deformation mechanisms and microstructures in Earth materials: From ice to perovskite

Application Reference N°: 5824

1) **Summary**

The research network on the Micro-Dynamics of ICE, Micro-DICE, organized a scientific workshop on deformation mechanisms and microstructures in Earth materials with special emphasis on ice, as part of the EGU General Assembly 2015 scientific programme. The workshop has been held as session (CR4.1/TS2.11) in the cryosphere science programme with co-organization by the tectonics & structural geology programme group (<http://meetingorganizer.copernicus.org/EGU2015/session/17136>).

The dynamic nature of Earth systems (e.g. cryosphere and lithosphere) results in deformation of different materials in the solid state. Polycrystalline ice in glaciers, polar ice bodies and sea ice deform to adjust dynamically to their environment, and poly-mineralic rocks deform during crustal or mantle tectonics. The range of deformation processes and mechanisms can best be identified on the microscale but will control the behavior of the whole system. Understanding these can provide physically based knowledge on mechanical properties of the materials, which is the pre-requisite for constitutive relationships and predictions under changing conditions (e.g. global warming).

Recent advances in analysis, modeling and interpretation of microstructures in many Earth materials and shared expertise from different disciplines give insight into the complex interplay of (sub-)grain microstructure, anisotropy, fluid or melt phases and impurities. Linking microstructures to geophysical signals such as radar imaging and seismic profiling promises important up-scaling possibilities which are mandatory with respect to Earth system modeling.

In view of natural versus laboratory time scales modeling, observational, and experimental methods have to be used. We received contributions from modeling as well as natural/experimental/analytical studies, which contribute to glaciology based on the identification of deformation processes and related mechanisms.

The EGU General Assembly 2015 brought together geoscientists from all over the world

to one meeting covering all disciplines of the Earth, planetary and space sciences. It thus provided a forum where scientists, can present their work and discuss ideas with experts in all fields of geosciences. EGU therefore represented an ideal venue to host a Micro-DICE session to provide interaction with a broad international community of geoscientists. This 2015 session followed on from and builds on the success of sessions held since 2011.

2) Description of the scientific content of and discussions at the event (up to four pages)

The role of defects in the mechanical response of Earth and Planetary materials (from micro to macro) was presented by Christine McCarthy, by introducing her laboratory experiments to directly measure the plastic and anelastic behaviors of various Earth and planetary materials, including polycrystalline ice.

Continuing with the intermediate scale, however on natural ice, Daniela Jansen reported on small scale folding observed in the NEEM ice core. She presented a process for development of folds on the mesoscale in natural ice. The effects of much larger scaled folds formed by deformation of Eemian and Glacial ice in the deepest part of the NEEM ice core have been presented by Kaitlin Keegan, suggesting that the impurity content is a main driver for rheology differences. Impurity content, grain size data and crystal orientation measurements (EBSD and polarization microscopy method) in original ice core samples have been shown, and outlook to ongoing deformation tests has been given. Advanced statistical treatment of crystallographic data from polarization microscopy including image analysis techniques has been used by Jan Eichler to derive geometry and crystallographic configuration of grain boundaries, also by using NEEM ice core samples. Crystallographic measurements with EBSD were presented by Ernst-Jan Kuiper in order to identify deformation and recrystallization mechanisms in the NEEM ice core.

Moving to process studies on artificial ice Baptiste Journaux presented preliminary measurements of the evolution of lattice-preferred orientations in deformed water ice during annealing using neutron diffraction in order to visualize dynamic recrystallization in situ in 3D. On behalf of Thomas Chauve, Maurine Montagnat talked about strain field evolution during creep deformation in ice with respect to the impact on dynamic recrystallization mechanisms.

Combining experiments, nature observations and numerical simulations Sandra Piazzolo introduced how to utilize microstructural characteristics to derive insights into deformation and recrystallization behaviour not only of polycrystalline ice but e.g. of magnesium alloys and natural anorthosite material. Further focusing on numerical modelling Maria-Gema Llorens reported on computational analysis of coupled viscoplastic deformation and dynamic recrystallization in polycrystalline ice aggregates. Florian Steinbach added another component on this kind of modelling approach, by simulating the composite ice and air and presented numerical modelling results of polyphase deformation and recrystallization in polar firn and ice.

This composite property of firn, consisting of ice and air, plays an important role in the densification and metamorphism processes during the formation of glacial ice. Investigations on these processes under extreme conditions from a cold location in Antarctica (Allan Hills) have been suggested as an analogue for firnification in glacial times by Ruzica Dacic. Ice formed at completely different conditions, namely from an

Alpine location (Colle Gnifetti) is used by Johanna Kerch to demonstrate the cm-scale variations of crystal orientation fabrics and their linkage to paleo-climate proxies. As they are impurities, these palaeo-climate proxies can have influence on the flow behaviour and fabric of polycrystalline ice as presented by Kevin Hammonds. Wolfgang Müller showed new results on combined microstructure and chemistry measurements, by developing a method for spatially-resolved chemical analysis of frozen ice cores by cryo-cell-UV-laser-ablation-ICPMS.

Moving from glacial ice to sea ice Peter Sammonds presented micromechanics of gouge formation in shear zones, which provide a main mechanisms in sea ice deformation and Arctic Ocean dynamics. Sammonds showed that a model developed to understand the micromechanics of rock fault gouge can be applied to the sea ice problem.

3) Assessment of the results and impact of the event on the future directions of the field (up to two pages)

The meeting was a programme session at the EGU General Assembly at the Austria Center Vienna (ACV) on 13 April 2015. The session was part of the cryosphere science programme as well as the tectonics & structural geology programme. It thus was embedded in a wide framework of topics related to ice as well as lithospheric Earth materials.

The aim of the session was to exchange new data and ideas for a better understanding of the deformation and evolution of snow and ice, from polar ice caps, mountain glaciers, sea ice to planetary ice and those interested in linking microstructures to geophysical profiles and sharing knowledge in cognoscent disciplines such as structural geology, planetary science, atmospheric physics and oceanography. The broad audience from climatologists, to oceanographers, glaciologists, geophysicists, petrologists and geologists showed that this goal was met, especially also as individual follow-on meetings after the session (first day of the conference) have been arranged. However the viewing time of the PICO presentations was too short to discuss all data. The MicroDICE reception after the session was well frequented and used to continue discussions and to raise new collaborations.

Two MicroDICE PICO-price winners (Florian Steinbach and Ernst-Jan Kuiper) were elected by the attending steering committee members as well as the presenters.

The final number of submitted contributions was 15. The session has been held in the PICO presentation format (www.egu2015.eu/pico.html), which is an innovative form of science communication combining advantages of oral and poster presentation styles. Each presentation is introduced orally in 2 minutes to the audience to give a quick content information, while a viewing time afterwards can be used to discuss the content in detail along with an electronic, interactive poster on touchable screens provided by the EGU organizers. Especially this "viewing time" is an important and efficient possibility for networking activities among international researchers. It also encourages scientific discussions beyond the actual poster topics, which will be intensified over the whole duration (1 week) of the EGU General Assembly meeting. Our experience with the PICO format is that in principle it gives high freedom to the presenters concerning how and what can be presented, however technical problems occurred and slowed us down slightly. Those difficulties will probably be solved if this presentation format develops to a more mature state in the next years. Furthermore, the viewing time (< 1 hour) was rather short for 15 presentations. These shortcomings have been communicated to the

organizers repeatedly, and participants have been encouraged to forward own suggestions via EGU survey (www.egu2015.eu/feedback).

The PICO session is however a good alternative compared to poster-only session at EGU, if only a rather smaller amount of abstracts (exact threshold amount depending on program group) is submitted. To avoid small submission numbers, it would be advisable to avoid double convening of individuals in several sessions, as the advertisement of the workshops can than be done more efficiently. Topics of the presentations show that the promotion of the workshop within the ice community worked well, while the envisaged connection to rock forming materials was difficult this time.

The Micro-DICE session was convened by Ilka Weikusat (AWI, Bremerhaven & Eberhard Karls University Tübingen, Germany), Holger Stünitz (University of Tromsø, Norway) and Peter Sammonds (University College London, United Kingdom).

4) Annexes 4a) and 4b): Programme of the meeting and full list of speakers and participants

see next page

Annex 4a: Programme of the meeting

MicroDICE session

PICO CR4.1/TS2.11

Deformation mechanisms and microstructures in Earth materials: From ice to perovskite

Convener: Ilka Weikusat

Co-Conveners: Peter Sammonds and Holger Stunitz

Date: Monday, 13 Apr 2015

Location: PICO Spot 3

2-Minutes-Madness

- 10:30– [EGU2015-14195](#)
10:40 From micro to macro: the role of defects in the mechanical response of Earth and Planetary materials
Christine McCarthy
- 10:40– [EGU2015-15530](#)
10:42 Small scale folding observed in the NEEM ice core
Daniela Jansen, Maria-Gema Llorens, Julien Westhoff, Florian Steinbach, Paul D. Bons, Sepp Kipfstuhl, Albert Griera, and Ilka Weikusat
- 10:42– [EGU2015-14666](#)
10:44 Deformation of Eemian and Glacial ice at NEEM, Greenland
Kaitlin Keegan, Dorthe Dahl-Jensen, Maurine Montagnat, Ilka Weikusat, and Sepp Kipfstuhl
- 10:44– [EGU2015-3771](#)
10:46 Geometry and crystallographic configuration of grain boundaries
Jan Eichler, Ilka Weikusat, Sepp Kipfstuhl, and Tobias Binder
- 10:46– [EGU2015-2507](#)
10:48 Identifying deformation mechanisms in the NEEM ice core using EBSD measurements
Ernst-Jan Kuiper, Ilka Weikusat, Martyn R. Drury, Gill M. Pennock, and Matthijs D. A. de Winter
- 10:48– [EGU2015-3706](#)
10:50 Preliminary 3D In-situ measurements of the texture evolution of strained H₂O ice during annealing using neutron Laue diffractometry
Baptiste Journaux, Maurine Montagnat, Thomas Chauve, Bachir Ouladdiaf, and John Allibon
- 10:50– [EGU2015-4871](#)
10:52 Strain field evolution during creep on ice. Impact of dynamic recrystallization mechanisms.
Thomas Chauve, **Maurine Montagnat**, Fabrice Barou, Karoly Hidas, Andréa Tommasi, and Pierre Vacher
- 10:52– [EGU2015-7358](#)
10:54 Utilizing microstructural characteristics to derive insights into deformation and annealing behaviour: Numerical simulations, experiments and nature
Sandra Piazzolo, Maurine Montagnat, Abhishek Prakash, Verity Borthwick, Lynn Evans, Albert Griera, Paul D. Bons, Henrik Svahnberg, and David J. Prior
- 10:54– [EGU2015-7466](#)
10:56 Computational analysis of dynamic recrystallization of ice aggregates during viscoplastic deformation
Maria-Gema Llorens, Albert Griera, Ilka Weikusat, Paul Bons, Ricardo

- Lebensohn, Lynn Evans, and Sandra Piazzolo
 10:56– [EGU2015-1025](#)
 10:58 Numerical modelling of polyphase deformation and recrystallisation in polar
 firn and ice
Florian Steinbach, Ilka Weikusat, Paul Bons, Albert Griera, Maria-Gema
 Llorens, and Jens Roessiger
- 10:58– [EGU2015-7907](#)
 11:00 Extreme metamorphism in a firn core from the Allan Hills, Antarctica, as an
 analogue for glacial conditions
Ruzica Dadic, Martin Schneebeli, Nancy Bertler, Margit Schwikowski, and
 Margret Matzl
- 11:00– [EGU2015-9654](#)
 11:02 Micromechanics of sea ice gouge in shear zones
Peter Sammonds, Sally Scourfield, and Ben Lishman
- 11:02– [EGU2015-711](#)
 11:04 cm-scale variations of crystal orientation fabric in cold Alpine ice core from
 Colle Gnifetti
Johanna Kerch, Ilka Weikusat, Olaf Eisen, Dietmar Wagenbach, and
 Tobias Erhardt
- 11:04– [EGU2015-5375](#)
 11:06 The Effects of Soluble Impurities on the Flow and Fabric of Polycrystalline
 Ice
Kevin Hammonds and Ian Baker
- 11:06– [EGU2015-9104](#)
 11:08 Spatially-resolved chemical analysis of frozen ice cores by cryo-cell-UV-
 laser-ablation-ICPMS
Wolfgang Müller, Damiano Della Lunga, Sune O. Rasmussen, and Anders
 Svensson
- 11:08– **PICO Viewings of interactive presentations at touch screens**
 12:00

PICO 3.1 MCarthy
PICO 3.2 Jansen
PICO 3.3 Keegan
PICO 3.4 Eichler
PICO 3.5 Kuiper
PICO 3.6 Journaux
PICO 3.7 Montagnat
PICO 3.8 Piazzolo
PICO 3.9 Llorens
PICO 3.10 Steinbach
PICO 3.11 Dadic
PICO 3.12 Sammonds
PICO 3.13 Kerch
PICO 3.14 Hammonds
PICO 3.15 Müller

Annex 4b: Full list of speakers and participants
(convenors, presenters, co-authors and audience – (if noted))

Abhishek Prakash	Macquarie University	AU
Albert Griera	Univ.versitat autònoma	ES
Anders Svensson	Niels Bohr Institute	DK
Andréa Tommasi	Univ. Montpellier	FR
Anja Diez	University of California	US
Bachir Ouladdiaf	Institut Laue Langevin	FR
Baptiste Journaux	LGGE	FR
Ben Lishman	UCL	UK
Christian Weikusat	Alfred Wegener Institute	DE
Christine McCarthy	Columbia	US
Coen Hofstede	Alfred Wegener Institute	DE
Damiano Della Lunga	Royal Holloway Univ.	UK
Daniela Jansen	Alfred Wegener Institute	DE
David J. Prior	Univ. of Otago	NZ
Dietmar Wagenbach	Heidelberg Univ.	DE
Dorthe Dahl-Jensen	Niels Bohr Institute	DK
Fabrice Barou	Univ. Montpellier	FR
Florian Steinbach	Univ. Tübingen	DE
Gael Durand	LGGE	FR
Gerrit Lohmann	Alfred Wegener Institute	DE
Gill M. Pennock	Univ. Utrecht	NL
Helene Hoffmann	Heidelberg Univ.	DE
Henrik Svahnberg	Stockholm University	SE
Ian Baker	Dartmouth College	US
Ilka Weikusat	Alfred Wegener Institute	DE
Jens Roessiger	Univ. Tübingen	DE
Johanna Kerch	Heidelberg Univ.	DE
John Allibon	Institut Laue Langevin	FR
Julien Westhoff	Univ. München	DE
Kaitlin Keegan	Niels Bohr Institute	DK
Karoly Hidas	Univ. Montpellier	FR
Kevin Hammonds	Dartmouth College	US
Lynn Evans	Macquarie University	AU
Margit Schwikowski	Paul Scherrer Institute	CH
Margret Matzl	WSL, SLF	CH
Maria-Gema Llorens	Univ. Tübingen	DE
Martin Schneebeli	WSL, SLF	CH
Martyn R. Drury	Univ. Utrecht	NL
Matthijs D. A. de Winter	Univ. Utrecht	NL
Maurine Montagnat	LGGE	FR
Nancy Bertler	Univ. of Wellington	NZ
Nicole Spaulding	University of Maine	US

Olaf Eisen	Alfred Wegener Institute	DE
Olivier Gagliardini	LGGE	FR
Pascal Bohleber	Heidelberg Univ.	DE
Paul D. Bons	Univ. Tübingen	DE
Peter Sammonds	UCL	UK
Pierre Vacher	Univ. de Savoie	FR
Reinhard Drews	Université Libre de Bruxelles	BE
Ricardo Lebensohn	Los Alamos Nat. Lab.	US
Rüdiger Kilian	Univ. Basel	CH
Ruzica Dacic	Univ. of Wellington	NZ
Sally Scourfield	UCL	UK
Sandra Piazzolo	Macquarie University	AU
Sebastian Beyer	Alfred Wegener Institute	DE
Sepp Kipfstuhl	Alfred Wegener Institute	DE
Sina Marti	Univ. Basel	CH
Stefan Dietrich	BfG Koblenz	DE
Sune O. Rasmussen	Niels Bohr Institute	DK
Thomas Chauve	LGGE	FR
Thomas Läpple	Alfred Wegener Institute	DE
Tobias Binder	Alfred Wegener Institute	DE
Tobias Erhardt	Univ. of Bern	CH
Torge Martin	GEOMAR	DE
Verity Borthwick	MGT Resources Ltd	AU
Werner Kuhs	Univ. Göttingen	DE
Wolfgang Müller	Royal Holloway Univ.	UK