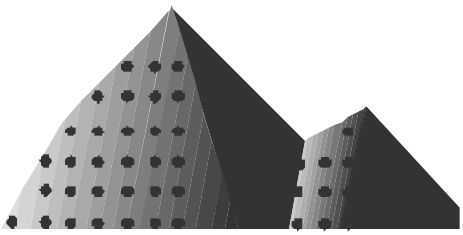


Physical Properties of Earth Materials *Newsletter*

November, 1997

A Note from the Chair

Andreas Kronenberg

Texas A&M University

Judging from the number of outstanding meetings, significant new results in studies of physical and chemical properties of Earth materials, and the many new and developing collaborations within PPEM and Mineral and Rock Physics, and with the broader geophysical community, times are great. Judging from AGU ASLA alerts, the numbers of PhD students in our field, academic and research career opportunities, and perceived needs to reinvent ourselves and the institutions that have favored scientific progress, times are terrible. How this year has been, on an individual basis, surely depends on whether you've been able to focus on the science or the premise for doing science.

When we first organized our informal group of individuals studying rock deformation and PPEM, it was with the purpose of improving the climate for our research and collaboration, raising the visibility and application of our research to important geophysical problems, and perhaps smoothing over political bumps and impediments to the progress of our science. With our annual dinners at the Fall AGU Meeting, organized Special Sessions, initiation of Gordon Conferences in rock mechanics, and this Newsletter, we have succeeded, I believe, in fostering a professional and personal closeness that is beneficial and satisfying. However, our long-term success will be measured by the career opportunities of our younger members and whether we retain or lose some of our brightest stars to other disciplines. No doubt, for those individuals involved, it's a darn good thing that our approach in the Earth sciences so closely resembles that of research in Materials science. What is needed to keep our science healthy? How much can PPEM accomplish towards that end? We can all breathe a sigh of relief that we've lived through and survived the Cold War. Yet, the changing assessments of scientific and technological needs during this period of global warming involve forces and funding issues that are bigger than we can alter to any significant measure. What we can do is to offer each other support and encouragement, and of course share our excitement for our research.

On the weekend preceding this year's Fall AGU Meeting, the PPEM Steering Committee will meet and I encourage you to contact any and all members about issues that you'd like to have raised and discussed. This year's committee consists of Mike Blanpied, USGS, Menlo Park; Brad Hacker, UC Santa Barbara; Greg Hirth, WHOI; Dave

(continued page 2, column 1)

Annual PPEM Dinner Meeting Fall A.G.U.

Where: Sol Y Luna restaurant, 475 Sacramento (near corner of Sansome), in the Financial District approximately 6 blocks north of the Moscone Center. This restaurant specializes in Spanish and Latin American fare, and is famous for introducing tapas (a sort of Spanish dim sum but more substantial), which are still the best dishes on the menu. Check out their Digital Lantern web page at http://www.digitallantern.com/san_francisco/r/0/r65.html (and click on the map at the upper right to see the location). The restaurant will close for us for the evening.

(Continued page 7, column 3)

Inside

Note from Chair

♦ *(continued from page 1)*

Holcomb, Sandia National Lab; me; Chris Marone, MIT; Randy Martin, New England Research; Rich Schultz, U. Nevada, Reno; Peter Schutjens, Shell International; and Janos Urai, U. Aachen. Our e-mail addresses are, respectively, [mblanpied@usgs.gov], [hacker@magic.geol.ucsb.edu], [ghirth@whoi.edu], [djholco@sandia.gov], [a.kronenberg@tamu.edu], [cjm@westerly.mit.edu], martin@ner.com], [schultz@mines.unr.edu], [P.M.T.Schutjens@Siep.Shell.com], and [j.urai@ged.rwth-aachen.de]. For starters, please send any and all of us your nominations for new committee members. Each year, three members of the Steering Committee rotate off and we need to identify three new recruits. This will be the third and final year for Greg Hirth, Randy Martin, and Janos Urai; they have done a terrific job and we will need some outstanding nominees to replace their efforts! The steering committee will select amongst nominations at the upcoming meeting and we will announce the results at the PPEM dinner.

It has been an exciting year with contributions of PPEM members made at meetings in the United States, Europe, and Canada. Due to the contributions of co-conveners, Harry Green and Brian Evans, and the assistance of Terry Tullis and many outstanding presentations, this year's Gordon Conference on Dynamic Metamorphism was a great success. Many thanks to Harry, Brian and Terry, and to the Gordon Conference Staff! Between the

(Continued page 4, column 2)

Conference Reports

Deformation mechanisms in nature and experiment

Holger Stunitz

University Basel

From March, 17th to 19th, 1997, an international conference on "Deformation mechanisms in nature and experiment" was held in Basel, Switzerland. The conveners were Renee Heilbronner, Stefan Schmid and Holger Stunitz. The idea of this conference was to revive some of the spirit and the enthusiasm of earlier conferences with a similar general theme. In 1977, the first conference on microstructures, deformation mechanisms, and fabrics was held in Leiden, Netherlands, followed by several other meetings of this type in Barcelona, Goettingen, Utrecht, Leeds, etc. Structural geologists and experimentalists were drawn together by a common interest in identifying and analysing deformation processes in rocks, whether they were deformed naturally or experimentally. Somehow, this common theme had faded over the past years, and, unfortunately to many of us, the group of experimentalists and that of process-orientated structural geologists have drifted apart more and more. One attempt to counteract this trend was to call people to an international meeting and try to reinstall a regular series of conferences, which may be a forum or platform to exchange ideas and results between process-orientated structural geologists and experimentalists. We believe that the meeting in Basel has achieved some of these goals. About 140 participants from all over the world came to Basel for the three-day-programme. The main topics included: chemical effects on deformation and solution transfer, deformation mechanisms in polyphase rocks, deformation of rock analogues and modelling, grain boundaries and fractures, and recrystallization in nature and experiments. A post-conference field trip to the Ivrea Zone lead by Mark Handy, Ernie Rutter and Stefan Schmid gave an opportunity to continue many discussions in the field. A post-conference workshop on orientation imaging and EBSD-orientation- analysis was well attended and showed that there is a rapidly growing interest in these new tools and techniques in orientation analysis. The next meeting will be held in 1999 in Germany and will be organized by Georg Dresen and Mark Handy.

Relationship between various properties in sedimentary and crystalline rocks

Report on a symposium at EGS 97 Vienna:

Ernst Huenges[1], *Ilmo Kukkonen*[2], *and Janos Urai*[3]

[1]GFZ Potsdam, [2]Geological survey of Finland, [3]RWTH Aachen

Composition, texture, pore structure, pore fill and ambient physical conditions influence the physical properties of rocks in a complex manner. The technique to

estimate one physical property with the aid of measurements of others (at different scales) is commonly used in geophysical modelling. Applications are predictions of wellbore stability, hydrocarbon exploration and production, as well as in geophysical modelling of the lithosphere.

The session aimed at discussing the state of the art in methods to estimate in-situ properties using correlations between laboratory measurements, data from boreholes and field observations. Contributions were invited on petrophysical investigations of mudrocks and shales as well as on metamorphic, plutonic, and volcanic rocks, and on methods of predicting these properties over different length scales.

Altogether 18 oral and poster presentations were given in the session in Vienna, and 8 of them are in press in a special issue of Physics and Chemistry of the Earth.

The proceedings cover articles which discuss relationships between several petrophysical properties with the aim to improve thermal modelling (see Kukkonen and Peltoniemi 1997). A special technique - applied in the East but not well known in the West - to estimate permeability using the general singular approximation based on the correlation between elastic and transport properties is presented by Bayuk and Chesnokov (1997). Modelling thermal conductivity using measurements on drill cuttings from sedimentary rocks is investigated by Troschke and Burkhardt (1997). Transport properties in rock salt are the subject of the papers of Spangenberg et al. (1997) and Popp and Kern (1997), while elastic and thermal properties were studied by Seipold et al. (1997). Müller (1997) focuses on the future outlook of the simulation of in situ conditions.

The contributions give an overview of current work in this field of petrophysical research, and improve our understanding of the physical properties of rock bodies which are not at present accessible for direct observation.

Gordon Conference on "Dynamic Metamorphism"

August 10-15, 1997

Andreas Kronenberg[1]
and
Wouter van der Zee[2]

[1]Texas A&M University
[2]RWTH Aachen

This year's Rock Deformation Gordon Conference entitled "Dynamic Metamorphism" was held at Colby-Sawyer College near Mount Sunnappee and Lake Sunnappee in New Hampshire, August 10 to 15. This exciting conference engaged its participants in the long standing problem that deformation and reactions often occur concurrently and understanding them involves much more than superposing what we know about isochemical deformation processes and phase equilibria. We can all thank Harry Green and Brian Evans for organizing this successful conference and Terry Tullis for helping with its coordination. Invited talks were informative and provocative. Discussion was lively. Afternoons were enjoyed by investigating the local geology and testing the physical and chemical properties of New Hampshire by hiking, swimming, birding, and of course, pontificating on the basis of high resolution outcrop observations. Perhaps the only problem was that microphones couldn't keep up with participants as spontaneous questions, commentary and discussion emerged.

Attendance exceeded 90 participants and the number of late-breaking results in the two evening poster sessions swelled to the room's capacity. The success of this conference should ensure a steady forum for informal discussion of special topics in our field. The next Gordon Conference on Physical Properties of Earth Materials is expected to be arranged for the summer of 1999 in the general area of the physical and chemical properties of surfaces and mineral-fluid interfaces. While this seems like a long way off, it is not too early to contact Brian Evans and/or Ernie Rutter, who will co-convene this next Gordon Conference, and share your good ideas.

For those who have not attended, here is the list of contributions:

ROCK DEFORMATION
Colby-Sawyer 2
August 10-15, 1997

Chair: Harry W. Green II, hgreen@ucrac1.ucr.edu
Vice-Chair: Brian Evans, brievans@mit.edu

Pressure solution and competing phenomena I -- field observations

1) "Pressure Solution" vs. Cataclastic & Cementation Processes During Diagenesis: Paul Nadeau.
2) "Pressure Solution" and Related Processes in Low-Grade Metamorphic Rocks: Stephen Cox.

Pressure solution and competing phenomena II -- theory and experiment

1) Constraints on Mechanisms and Rates from Single-Crystal Experiments: Christopher Spiers. Constraints on Mechanisms and Rates from Polycrystalline Experiments: Christopher Spiers.
2) Thermodynamic Theory of Pressure Solution: Wolfgang Heidug and Yves Leroy
3) Densification Polymorphic Transformations under Stress and Their Relevance to the Thermodynamics of Pressure Solution: Harry Green.

Interaction of deformation with hydration and dehydration reactions

1) Mechanistic Overview: Kate Brodie
2) Modeling of Dehydration Reactions under Stress: Dave Olgaard.
3) Fluids and Dynamic Metamorphism at Higher Grades: Ron Vernon.

Dynamic partial melting I - Continental crust

1) Experimental Dynamic Melting of Granitic Compositions: Gayle Gleason.
2) Field Evidence for the Interaction of Deformation and Partial Melting: Michael Brown

Dynamic partial melting II - mantle

1) Experimental Dynamic Melting of Peridotite: Greg Hirth.
2) A granular flow theory for deformation of partially-molten materials: Mervyn Paterson
3) Field Evidence for Interaction of Deformation & Partial Melting of Mantle: Peter Kelemen.
4) Geophysical Evidence for Partial Melting in the Upper Mantle: Don Forsyth.

Interaction of solid-solid phase transformations and deformation

1) Transformation-Induced Faulting and Deep Earthquakes: Pamela Burnley.
2) A micromechanical model for transformation-induced faulting: Ming Liu.
3) Effects of kinetics on deformation during mineral reactions: David Rubie.

Rock memory -- how do rocks record the P-T-t-e-s conditions of their history?

1) The Power and Limitations of Chemistry: Jane Selverstone.
2) The Power and Limitations of Microstructures: Mark Jessell.

Note from Chair

♦ *(continued from page 2)*

New York Rocks Symposium and the 2nd North American Rock Mechanics Symposium, many outstanding sessions were organized addressing such topics as micromechanics and constitutive modeling of rock failure, strain localization, and dynamics of granular systems. Deformation mechanisms that operate in natural and in experimental time frames were compared at the Basel Conference, focusing on microstructures of naturally deformed rocks and experimentally deformed samples. A variety of physical properties, mechanisms and textural controls on rock properties examined at the EGS Meeting in Vienna, including correlations between physical properties. In addition, sessions addressed elastic wave velocities, their anisotropy and frequency dependence, electro-magnetic and electro-kinetic properties, and the dependencies of these properties on textures, microstructures, porosity, and heterogeneity. Finally, subsurface fluid flow was examined as it is affected by faults at the recent GSA Penrose Conference.

Thanks to our co-editors, Janos Urai and Dave Holcomb, and the contributors to this Newsletter, a number of this year's conferences are summarized here, along with topical articles. In many cases, the authors are those same individuals we can thank for organizing these exciting meetings and sessions.

I'd like to draw your attention to upcoming Special Sessions at this Fall AGU Meeting and symposia that are currently being planned. The Special Session on "Water in the Mantle" (T10) organized by Joe Smyth and Dave Kohlstedt will address both the incorporation of water in the mantle and the consequences of this incorporation for mechanical and physical-chemical properties; so, it should be of great interest to both members of PPEM and the high pressure mineral physics community. Two Special Sessions have been organized in honor of Charles Prewitt; John Parise and Bob Hazen have organized a session of particular interest to PPEM members on the "Physics and Chemistry of Minerals and Mantle Materials" (V02) and Gordon Brown and Georges Calas have organized a session on "Applications of Synchrotron Radiation in the Earth and Environmental Sciences" (V12). In addition, Shun Karato and Guy Masters have organized a Special Session

Note from Chair

♦ *(continued from page 4)*

on "Mineral Physics and Seismic Tomography" (S06). With the Importance of outreach and collaboration by PPEM and Mineral and Rock Physics membership with the broader geophysical community, the spread of these special sessions across sections (T, V, and S) is a very good sign.

Plans are underway for the next Gordon Conference in the general area of surfaces and interfaces, their character and roles in defining on rock properties. It is not too early to talk with Brian Evans and Ernie Rutter, who will co-convene this conference and share your good ideas for sessions and discussions. Also coming up is an international conference on "Textures and Physical Properties of Rocks", to be held in Goettingen (further meeting and application information can be found at http://www.gwdg.de/~bleiss1/tppr .html). Information regarding additional upcoming meetings can be forwarded to our membership by contacting me or Mike Blanpied, who has kindly agreed to maintain and improve our e-mail, surface mail, and phone correspondence lists.

This Fall AGU Meeting is expected to be outstanding; in addition to the arranged Special Sessions, we can all thank Pamela Burnley (Mineral and Rock Physics Representative) and Greg Hirth (Tectonophysics Member) for representing us on the AGU Program Committee and organizing oral and poster sessions of interest to PPEM membership. Following the sessions, there are several occasions to celebrate. If you miss your colleagues at the all-Union Icebreaker on Sunday night, you'll surely have a better chance to find them, share ideas and catch up on the latest at the Mineral and Rock Physics Wine and Cheese on Monday night. Moreover, the Student Award will be announced at that occasion. As you may know, this award is open to all students engaged in research involving mineral and rock physics, with Jan Tullis presiding over the Selection Committee. Come and celebrate the achievements of our newest members. Also, I encourage you to think about deserving young nominees for next year's award and about your own financial support of this award with a tax-deductible contribution to AGU's fund for the Mineral and Rock Physics Outstanding Student Award. You can add this contribution to your check when you renew your AGU membership, or at any time during the year.

Take special note of Tuesday night's PPEM Dinner and make sure you send in your application to Bill Durham by November 24 with your check made out to PPEM (see the announcement in this Newsletter). Brian Bonner and Bill Durham, a legendary team, have paced the streets of San Francisco and come up with an outstanding restaurant to sample Spanish cuisine, Sol y Luna. This is only a few blocks north of the Moscone Center; a cash bar will be available at 6:30 and dinner will start at 7:30 pm. Your check covers everything beginning at 7:30, including five courses, wine with dinner, tip and tax and, as usual, we've reduced the cost for students. Also take special note of Wednesday evening's AGU Awards Ceremony. Join in, stomp your feet loudly for Al Duba, and make sure the oxygen fugacity is buffered as he joins the Fellows of AGU, and thereby proves that Fellows wear Plaid. If you can't make the Awards Ceremony, please join in and congratulate Al during the meeting sometime on this happy and well-deserved honor!

I have many to thank, including Mike Blanpied for taking on treasurer responsibilities and Rich Schultz for serving as secretary to the PPEM Steering Committee. Many thanks go to Bill Durham and Brian Bonner for arranging this year's dinner, Janos Urai and Dave Holcomb and contributors of articles for turning out this Newsletter, and to the organizers of our AGU Special Sessions, Gordon Conference, and many other meetings sessions. I am very grateful to Mervyn Paterson for contributing proceeds from the sale of remaining stock of his book on "The Brittle Field" to the PPEM fund; the only regret is that it went out of print! I also thank AGU for generously supporting the mailing and xerox costs for this Newsletter.

There are two embarrassments, though, and you can blame me for these; the first is the state of our members correspondence lists and the second is our homepage ("What Homepage?" you may ask). With regard to our correspondence lists, we have made improvements but still have a lot of corrections and updates to make. And the good news is: we have a plan to improve them further, and will be contacting you in the near future for corrections. With regard to establishing a PPEM website, we have had grand plans, but will need to prioritize this now.

Lab Reports

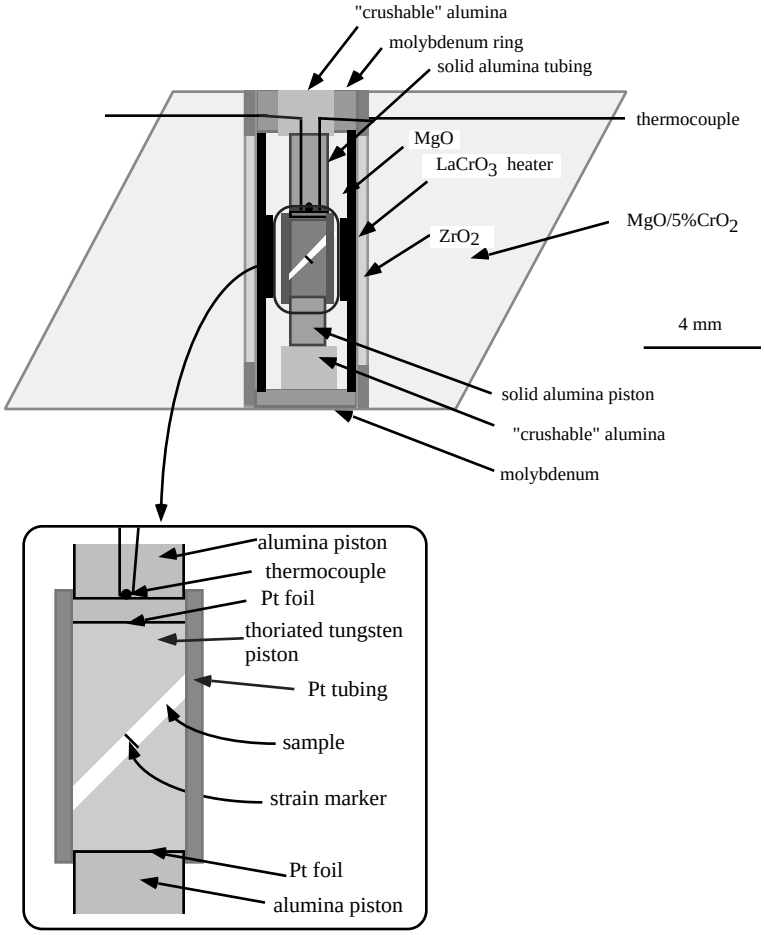
Deformation Experiments Under Ultra-High Pressures

Shun Karato[1] and David Rubie[2]

[1]University of Minnesota [2]Bayerisches Geoinstitut

Developing a new experimental technique is a key component of any creative research. During the 1960's, David Griggs at UCLA developed a new high-pressure deformation apparatus by modifying the piston-cylinder type high-pressure apparatus, which had been developed mainly by Boyd and England. This new apparatus enabled the deformation behavior of many minerals and rocks to be investigated up to ~3 GPa and ~1500 K. Along with this development he established the highly-active and leading rock deformation laboratory at UCLA. Parallel to this development, both Mervyn Paterson and Hugh Heard designed gas-medium, high-pressure (high-temperature) deformation apparatus that can provide high-precision mechanical data, although the maximum achievable pressure (0.5 GPa) is significantly less than that of the Griggs apparatus. Since these developments, there has been little improvement in deformation apparatus except for the development of a liquid-cell assembly for the Griggs apparatus, by Harry Green, with which the resolution of stress measurement is significantly improved.

Although these apparatus provide important experimental data concerning rheology under shallow upper mantle or crustal conditions, many of the key issues in global dynamics these days are concerned with dynamics of the deep mantle. Because of the pressure limitations of existing apparatus, answers to many critical questions cannot be obtained. For example, to understand the interaction of mantle convection currents with the transition zone (at ~ 400-700 km deep), one needs to know not only the densities and phase diagrams of the relevant minerals but also their rheological properties. However, nothing is known about the rheological properties of deep mantle minerals such as ringwoodite (the spinel phase of $(Mg,Fe)_2SiO_4$) or $(Mg,Fe)SiO_3$ perovskite (which is likely to be the most abundant mineral in the Earth). Also, models for deep-focus earthquakes that have been proposed by Harry Green, Steve Kirby and others are based on data obtained at low pressures on analogue materials. Thus, extending our capabilities to perform deformation experiments at significantly



New sample assembly for deformation experiments using a multianvil apparatus. The assembly is based on a MgO octahedron of 14 mm edge length. The sample is a thin (200 μm) disk oriented at 45° to the compression axis and is deformed in simple shear

higher pressures is critical for obtaining a better understanding of the dynamics of the Earth's deep interior.

Several attempts have been made to obtain rheological data at pressures exceeding that of the Grigg's apparatus using two different approaches. (1) Several groups (e.g., Kinsland and Bassett; Meade and Jeanloz) have used the diamond anvil cell (DAC) to investigate plastic properties at high pressures. By measuring the stress distribution in the sample, one can infer its yield strength up to pressures exceeding 40 GPa. However, because uniform heating is difficult, all of the existing data have been obtained at room temperature. This severely limits the applicability of the results to the Earth's deep interior where temperature is a high fraction of the melting temperature. (2) Several attempts have been made to use the multianvil apparatus for deformation experiments. The first attempt was made in Kumazawa's laboratory at Nagoya University in the early 1980's by making the sample assembly mechanically anisotropic in order to convert hydrostatic compression to non-hydrostatic stress. This was achieved by locating the sample between hard pistons and thus deforming it in triaxial compression. This technique was used up to ~5 GPa to investigate lattice-preferred orientation in Mn_2GeO_4 modified spinel. The same method was adopted by Gilles Bussod at the Bayerisches Geoinstitut in the early 1990's and by Harry Green at Riverside.
A careful analysis by Bill Durham, who visited the Bayerisches Geoinstitut in 1994-1995, revealed, however, that much of deformation in these early attempts to use the multianvil apparatus occurred during early pressurization and not at high *P* and *T*. In addition, because the stroke of the piston movement in this design is limited, the amount of strain that can be achieved is small (typically less than a few %). Furthermore, estimates of stress were based on piezometers (such as recrystallized grain size) and were very uncertain. Our work (published in J. Geophys. Res., 102: 20,111-20,122, 1997) has extended these previous efforts in several ways. Perhaps the most important difference between the new design and the previous ones is the use of simple shear geometry (see Figure). This design has four major advantages over the earlier triaxial compression design. (1) Much larger strains are possible. (2) The deformation geometry is presumably similar to that in the convecting mantle, so that the results of microstructural observations (such as lattice preferred orientation) can be directly applied to the Earth's interior. (3) The deformation during initial pressurization is minimized partly due to sliding at the sample-piston interfaces. (4) The deformation occurs as a relaxation process and through a theoretical analysis it is possible to estimate creep strengths.

The design currently works up to ~16 GPa and ~2000 K (to shear strains of ~100%), conditions equivalent to those at ~500 km deep in the mantle. This design has been applied to study the deformation of the alpha, beta and gamma phases of $(Mg,Fe)_2SiO_4$ and, for example, the activation volume for olivine has been determined to be 14 (±1) x 10^{-6} m^3 mol^{-1}. The rheological behavior of high-pressure minerals and the microstructural development in such materials during deformation can now be studied directly under the conditions where they are stable.

PPEM Dinner

♦ *(continued from page 1)*

When: Tuesday evening, December 9, 1997
Cash bar starting at 6:30 pm
Dinner starting at 7:30 pm

Menu: Tapas, tapas, tapas

Cost: $45 people/$25 students; includes dinner, wine, tip, and tax.

Reservations must be made before 24 November 1997, payment shortly thereafter. See reservation form on page 10.

Payment: Please make checks payable to "PPEM"
Non-U.S. participants unable to pay by check may reserve now, and pay Bill Durham at the AGU meeting
(Reservation form see page 10)

Applied Rock Mechanics: Some topics in the oil industry

Peter Schutjens
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Shell Research & Technical Service Laboratory, Rijswijk, the Netherlands

Here at Shell - as well as in other oil companies - the main focus is on the relation between fluid production (be it oil, gas or water) and the deformation and failure of reservoir rocks. The work in applied rock mechanics in an oil-industry environment has its disadvantages and advantages compared to fundamental research in rock deformation : We often have to rely on indirect observations (logs, seismic, well-testing) and cannot "see" the rock that we are dealing with. We often

cannot apply the powerful separation-of-variables concept that is of so much use in laboratory experiments: Wells and reservoirs are for production, not for finding out how rocks work! And. there always is the hurry to produce more and faster. But there is also an advantage: Our production operations change the stress state in the upper few kilometers of the Earth, and there is the possiblility to look at reservoirs and wells as a natural laboratory.

Let me give you a taste for some research topics in rock mechanics that are being studied in some oil industry laboratories, guided by looking at some 250 abstracts that were recently submitted to the EUROCK-98 Conference in Trondheim, Norway (*For information send an e-mail to rune.holt@iku.sintef.no)*

1. Interaction of borehole fluids and the sidewall rock

During the drilling of a well, a borehole is filled with a heavy liquid to prevent the reservoir pore fluids from flowing into the well and creating a blow-out. The borehole fluid is generally a water-based or oil-based solution with mud components and additives to control its density and viscosity. The borehole fluid has a pressure and chemistry different from the formation pore fluid, and that is why recent investigations focus on the time-dependent and temperature-dependent interaction between the borehole fluid and the formation as the key factor controlling the stability of the borehole. In particular, shaly intervals seem to be prone to collapse, with the risk of sticking of the drillpipe. This can be very expensive : In the Central North Sea, drilling a hole to 5 km depth in a reservoir at 100 MPa pore pressure and at 180°C costs some 30 Milion US$.

A number of chemical and physical concepts are linked to borehole stability analysis. Most chemical aspects deal with cation exchange processes, and include pressure diffusion, chemical osmosis, pore pressure variation, particle hydration, and the associated swelling of layers. Physical aspects of borehole instability focus on the borehole deformation mechanism : How does a shale deform when it is penetrated by a fluid of different chemistry than its original pore fill ? How is the borehole deformation affected by the total stress anisotropy, and the inclination of the borehole with reference to the stress field ? And can a temperature difference between borehole fluid and formation change the pore pressure to the extent that deformation occurs ?

2. The stress path in and around a compacting reservoir

It is often assumed that reservoirs of large lateral extent compact uniaxially, that is, only in the vertical direction with no horizontal strain. This assumption implies the supposition that the total stress in and around the reservoir "reacts" to the compacting reservoir so as to maintain uniaxial strain. However, there is no specific reason to assume that reservoirs will not deform horizontally during depletion. As far as I know, no attempts have been made to measure this.

Field data obtained by time-lapse measurement of the minimum total horizontal stress in depleting reservoirs show that the minimum total horizontal stress decreases with decreasing pore pressure. The occurence of low-magnitude earthquakes near producing reservoirs provides another source of evidence that compaction changes the total stress state in the reservoir. Observations in mines show that extraction-induced stress changes lead to slip along faults and bedding planes. From the laboratory, it is well known that there is a strong influence of stress path on compaction. The stress path governs the relative importance of elastic *versus* inelastic mechanisms, and the type of inelastic mechanism. Stress path thus controls whether a sample (and a reservoir !) will become weaker or stronger with depletion, and at what stress state failure may occur.

So there is a need to understand how production-induced reservoir compaction changes the total stress inside and outside the reservoir. Reservoir compaction in its turn will depend on how the total stress state will evolve with ongoing depletion. This coupling between reservoir deformation and stress state calls for 3-D in-situ stress measurements as a function of depletion, and for numerical models based on mechanism-based constitutive relations for reservoir compaction (see topic 3). These numerical models should incorporate the (often complex) reservoir structure, and should also take the deformation behaviour of the rock surrounding the reservoir into account.

3. Non-linear and time-dependent compaction

The theory of linear poro-elasticity is often invoked when dealing with production-induced reservoir compaction, borehole deformation and reservoir stress analysis. But there are strong reasons to doubt its validity in

poorly consolidated reservoir rocks, or in rocks where chemical processes occur (see topic 1) or when stress changes are large compared to the pre-production state of stress (see topic 2). There is experimental evidence that, under realistic depletion-induced stress paths, reservoir rocks show non-linear stress-strain behaviour and inelastic time-dependent compaction/deformation. : Laboratory tests on well-consolidated sandstones from the Groningen reservoir showed 5% to 60% inelastic compaction at planned depletion, with the contribution of inelastic compaction increasing about linearly with porosity. Compaction creep behaviour associated with compaction weakening in a deep gas/condensate field in the North Sea amounted to 50 millistrain, and changed the completion, perforation and production strategy. Despite the growing wealth of laboratory and (yes !) field data, there is as yet no micro-mechanical theory to describe (and thus predict) non-linearity and time-dependence in reservoir rocks.

Do these topics appeal to you ? You will not hear a lot about them at the coming AGU. Then why not join the EUROCK 1998 conference, and meet the guys at the coal-front ? You may also consider getting in touch with your colleague in the oil industry. He will be happy to brief you on the status of his work, and you may even identify an area of cooperation. Our management, recognises that cooperation with researchers outside Shell can be beneficial. They encourage us to travel and publish. The keywords now are globalisation, virtual teams and openness. Since the early nineties, for example, our 4-man Shell Compaction Team has benefited from extramural research cooperations with some 7 groups. One group has worked on an exotic topic like finding methods to mitigate production-induced subsidence by vertical expansion of near-surface layers (other than by raising the pore pressure !). For 1998 and the years beyond, there may be a growing need for expert rock mechanics analysis of production-induced technical problems. The above topics were just a first shot : There is more to come as we have to drill deeper, over longer distances, and in formations which are very different from porous quartz-rich sandstone.

AGU MRP Student Award Fund

A. Kronenberg[1] and S.-I. Karato[2]

[1]Texas A&M

[2]U. Minnesota

One of the most important things we can do for our field is to recognize our outstanding young student members. It is time to renew your AGU membership, and we would like to ask you to consider making a tax-deductible contribution to the Outstanding Student Award in Mineral and Rock Physics. You can make this contribution at any time in the year that you like. However, the easiest time to do this is now, by including a contribution to the Mineral and Rock Physics Outstanding Student Fund with your membership renewal. If you are considering becoming a Supporting Member of AGU, you can designate that $40 of your annual $80 contribution will go directly to the MRP Student Award.

At the moment, only a few hundred dollars are left for the student award, and much of this presumably came from our colleagues in high pressure mineral physics. Your students in PPEM are now eligible for this award, as part of MRP, and it would be wonderful to be able to make this award available to students in coming years, as it has in the past. We know that there are lots of good charitable causes, but a small contribution from all of us taxable characters would help greatly! Many Thanks in Advance

EGS ' 98 call for papers

Janos Urai

RWTH Aachen

The next meeting of the European Geophysical Union will be held in Nice (a resort town on the French Riviera) on 20 to 24 April 1998. This meeting will host a long series of symposia on PPEM, and you are all encouraged to contribute. Deadline for submission of abstracts is December 15 1997. More info is available at eh conference web site (http://www.copernicus.org/EGS/egsga/72f.htm), or from myself. Here is a list of the symposia on Physical Properties of Geomaterials (SE)

SE39 Physical properties of geomaterials

01. Open session on physical properties of geomaterials (posters only), Convener: J.L. Urai (Aachen), Co-Convener: E. Huenges (Potsdam)
02. Imaging, analysing and modelling pore structure in geomaterials, Convener: C. David (Strasbourg), Co-

Conveners: D.L. Olgaard (Houston), A. Rodriguez Rey (Oviedo)

03. The effect of rock micro-structure and fluids on rock physical properties, Convener: P.W.J. Glover (Aberdeen), Co-Convener: I. Main (Edinburgh)
04. Pore pressure as a geomechanical and geophysical parameter, Convener: H.-J. Kümpel (Bonn), Co-Convener: J.-R. Grasso (Grenoble)
05. Physical properties of partially molten rocks, Convener: L.N. Dell'Angelo (Zürich), Co-Convener: C. Rosenberg (Giessen)
06. Physical properties of mudrocks, Convener: S.T. Horseman (Nottingham), Co-Convener: J.L. Urai (Aachen)

SE40 Petrophysical control of anthropogenic and natural Earth's processes, Convener: E. Huenges (Potsdam), Co-Convener: J. Safanda (Praha)

Editors for the '97 Newsletter
Janos Urai & Dave Holcomb

Editor's Note

This newsletter should provide an informal, but informative, platform for communication and cooperation among those studying physical properties of rocks by experimental techniques. In that spirit, we seek scientific contributions, discussions of events, conferences, and books, and opinions regarding the business of science. Your ideas and opinions are solicited for new issues. To maintain informality and to encourage spontaneity, the articles are offered here with the understanding that they are the author's opinions and are not to be cited. You should contact the authors for formal documentation.

1997 PPEM Dinner reservation form.

Reservations must be made before 24 November 1997. Send this form or reasonable facsimile by e-mail to: durham1@llnl.gov or make a hardcopy and send by posted mail to the address below.

Please reserve:

_____places at $45.00 each

_____student places at $25.00 each
(Students who are receiving direct grant support for the PPEM dinner are kindly requested to pay full fare.)

_____I am mailing a check made out to "PPEM"

to: W. B. Durham, L-201
UCLLNL
P.O. Box 808
Livermore, CA 94550
USA

_____I will pay Bill Durham at the AGU meeting BEFORE the dinner

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