A Note from the Chair

Andreas Kronenberg
Texas A&M University

Up to now, the PPEM community has shown remarkably good judgement and chosen some really outstanding Chairs to the steering committee. Yet, after the legacies left by Steve Kirby, Dave Kohlstedt, and Brian Evans, I find myself leaning against the armrest of The Chair, wondering what ever happened to this group's senses. During my tenure as Chair, though, I will resist the urge to quote or paraphrase Woody Allen and I will resist the urge to change the name of our group, even though it is only convenient to write when expressed by its first letters. Now for the Good News: Shun-ichiro Karato has accepted the Chair of the broader Mineral and Rock Physics Committee, to which we belong, so I do not think that we will falter too badly for lack of leadership. I certainly look forward to working with Shun and building upon our ties with the greater Mineral and Rock Physics community.

We will benefit from an outstanding steering committee this year which consists of Mike Blanpied, U.S.G.S., Menlo Park; Fred Chester, St. Louis Univ.; Harry Green, U.C., Riverside; Greg Hirth, W.H.O.I.; Dave Holcombe, Sandia National Lab; Dave Lockner, U.S.G.S., Menlo Park; Randy Martin, New England Research; Rick Schultz, Univ. Nevada, Reno; and Janos Urai, now at the University in Aachen, Germany. Each year, though, three members of the steering committee rotate off and we need to identify three new recruits. This is the third and final year for Fred Chester, Harry Green, and Dave Lockner. Any interested AGU member can nominate an individual to serve on the committee, and you are invited to suggest names to any current committee member. The new committee members will be chosen at the steering committee meeting held on the Saturday before this coming Fall AGU Meeting.

Several interesting conferences were held this year to which PPEM members contributed, which examined the development of shear zones, effects of fluids, and deformation mechanisms in nature and in the lab, and a larger number of new conferences are currently being planned and organized. Many of this year's conferences are summarized in this newsletter along with topical articles, and I would like to draw your attention to the announcements of several promising, upcoming meetings and research initiatives. In particular, the upcoming Gordon Conference on deformation and mineral reaction to be held this summer should be of interest to a very large number of us. Harry Green and Brian Evans have done an (Continued page 2, column 1)
Note from Chair

outstanding job organizing this conference, placing emphasis on the fundamental processes of dynamic metamorphism and examining these processes in a wide range of geologic conditions from stylolite formation during diagenesis to partial melting in the crust and mantle, to dehydration- and phase-transformation-induced faulting in the deep mantle. Moreover, the format of this conference should lead to lots of discussion and new thought. As this is only the second Gordon Conference to concentrate on rock mechanics, its success is very important if we are to establish an ongoing series. I certainly hope that you can attend and participate in lively discussion.

We have a number of good reasons to celebrate at this coming AGU meeting. I invite all of you to join me in congratulating Jan Tullis on her recognition as an AGU Fellow. Jan’s enthusiastic spirit and accomplishments are well known to us and it is wonderful to see her honored by the AGU for her outstanding and perceptive work on the deformation of crustal rocks. It will also be good to see Bob Liebermann become a Fellow of AGU, who as chair of Mineral and Rock Physics has made so many of us feel welcome. The MRP Wine and Cheese will be held on Sunday night where this next year’s outstanding student award will be announced. Hartmut Spetzler and the awards committee know this year’s results at this time. However, as you know, Nick Beeler received this award last year for his wonderful studies of velocity-dependent friction along with Nobumasa Funamori for his work on the thermal expansion and equation of state of Mg-perovskite at lower mantle conditions. And while no meeting can be scheduled to be perfect for the entire AGU membership, we owe a lot to Jim Tyburczy and Greg Hirth for representing Mineral and Rock Physics and Tectonophysics, respectively, on the Program Committee and for putting such an outstanding schedule together.

Finally, it is always a pleasure to call your attention to the PPEM Dinner which will be held on Monday night at the Caffe Delle Stelle, yet another find by Mike Blanpied. Several proposals were put forward for an activity at this year’s dinner from an Aria sung by Lisa Dell Angelo entitled “Bella Isabella in Carrara” to an interpretive stick-slip dance for bad dancers, but we have decided to keep it simple and allow as much time as possible for informal conversation with your friends and fellow researchers at individual tables.

Now, on a more serious note, as I see it, the goals and purposes of the PPEM committee have changed with time (Continued page 3, column 1)

Report from AGU
Committee on Mineral and Rock Physics

Shun-ichiro Karato
University of Minnesota

From the Chair of the Mineral and Rock Physics Committee

Following Bob Liebermann at the State University of New York at Stony Brook, I am serving as chair of the Mineral and Rock Physics Committee of AGU for the term 1996-1998. The main objective of this committee, as I understand it, is to facilitate the activities of this subdivision of AGU. Traditionally there have been some differences between our two groups of scientists: “mineral physicists” more or less worry about microscopic aspects of structure and properties of minerals and "rock physicists" worry about somewhat more macroscopic processes or properties such as fracture and creep strength of rocks, and fluid permeability. This distinction makes sense to some extent because the former is concerned with problems at the single crystal level while the latter with problems at the polycrystal level. Another distinction, as I see it, is that mineral physicists mainly investigate properties of minerals under extreme conditions of the earth’s deep interior, and hot topics in this area are usually the properties of minerals at high pressures, whereas rock physicists usually study properties of rocks at relatively shallow earth conditions. Although it is important and often necessary to separate problems in terms of these technical (sub-)subdisciplines, interesting new progress may often occur when concepts or (Continued page 19, column 1)

Mineral and Rock Physics Reception at Fall AGU 1996

Sunday, December 15
5:30 to 7:30 PM
Moscone Center
Room 236

The Mineral and Rock Physics Reception this year will feature local wines, fruit and cheese. The reception will be held from 17:30-19:30 on 15 December 1996 in Room 236 of the Moscone Center under the sponsorship of AGU Committee on Mineral and Rock Physics.
and they will surely continue to evolve. All of us recognize the benefits we have gained from the development of closer ties within our community. The PPEM committee was originally organized to break down the divisions that separated us according to specialty, technique, and branch of the family tree of rock squeezers. To a large extent, we have succeeded. The PPEM dinners have been wonderful in bringing us together, leading to exchange of ideas on an informal basis and to a collegial atmosphere that benefits us and our science. Discussion has led to ideas for special AGU sessions that explore those areas of inquiry that lie between our traditional research specialties and that examine new applications of physical properties studies to geophysics. Outside of AGU, we have organized a wide range of meetings and sessions, and initiated a new series of Gordon Conferences. Finally, the newsletter has served us well to report on activities and meetings both within and outside of the AGU and to link our membership throughout Pangea, no matter what side of a rift you landed on.

In addition to strengthening our ties within the field of rock mechanics, we have begun to develop a relationship with the mineral physics community and with other earth scientists taking experimental and theoretical approaches to studying the physical and chemical properties of rocks and minerals. While some of our membership has always regarded themselves as mineral physicists (as well as members of the rock mechanics community), others have not shared the same research interests with high pressure mineral physicists focused on deep Earth problems. Recognizing that we are not all working on the same problems, I would like to see us develop even closer ties to members of the Mineral and Rock Physics community and fulfill the goals implicit in our broadly named group, bringing in members of AGU who investigate physical properties that include but are not restricted to mechanical properties. The Mineral and Rock Physics community has extended an open invitation to us, which can be recognized in many ways, including representation on the MRP Committee, entrusting its leadership to individuals who are simultaneously members of PPEM, and through the recognition of our students with research awards. In order to accept this invitation, though, what is needed is our active participation, through contributions to initiatives of MRP as well as those of PPEM, and through the organization of special sessions and meetings that explore topics of common interest to both communities. You are invited to nominate outstanding students for consideration for the MRP Student Award, whether you are their advisor or not, and I hope that many of you consider making a contribution to the MRP student fund at the time you pay your AGU dues, or at any other time this year.

Finally, a very important activity of PPEM is to examine new applications of our science to plate dynamics, structural geology and fault mechanics, and the physics of the deep Earth's interior. As we become more certain of our internal ties within PPEM, we may wish to place greater emphasis on outreach to the broader geophysics community as well as to the materials science and engineering communities.

(Continued page 4, column 1)
would like to encourage greater numbers of collaborative, cross-disciplinary special sessions and meetings that develop applications of physical properties studies of Earth materials, and contributions of our membership to new and innovative scientific endeavors that draw on mechanistic physical and chemical insight. Our membership can, for example, contribute a great deal to studies of deep-seated fault rocks recovered by drilling, as has recently been accomplished on the Nojima fault near Kobe, Japan, and along the ridges and transforms of the ocean floor, and as is currently proposed for the San Andreas fault of California. Finally, we share many interests with crystal physicists, materials scientists, and engineers outside of AGU, and I would like to encourage contributions to these fields and cross-disciplinary collaborations.

The continuing success of PPEM will depend on our ability to respond to needs, our ability to adjust to a changing funding climate, and to recognize opportunities. This will require a continuing dialogue. As you perceive the need for change in direction and goals of PPEM, please let me know what you think we ought to be doing (that we're not doing now) and where we should be going. Feel free to e-mail me at a.kronenberg@tamu.edu at any time, or you may wish to contact a member of the steering committee. The steering committee is also working on developing a home page for the purpose of improving communication, as well as updating our e-mail directory, to be interfaced with those of the Mineral and Rock Physics Committee and the Tectonophysics Section of AGU.

The Founding of a Rock Standards Library: The Acquisition of the Lorano Bianco Carrara Marble

Dave Olgaard
ETH-Zentrum

Certain rocks are considered standards to the PPEM community because they are used again and again in experiments to investigate physical properties of the Earth’s lithosphere. Specimens of the better known examples such as Westerly granite, Solnhofen limestone and Carrara marble can be found holding down a table or blocking a door in almost every rock mechanics laboratory. However, there is Westerly granite and then there is Westerly granite. Since original stocks of many classic rocks have often been used up, suitably similar samples are often difficult to obtain because as new faces and galleries are cut in the quarries the rock often changes. The subtle spatial variations in mineralogy or microstructure that make sculptures and headstones unique, can make repeating previous experimental results almost impossible. Therefore, there is a need to create a library of classic rock standards, that are available to everyone for comparison testing to corroborate previous work and for standardizing different machines in different labs.

Carrara marble is one such classic Earth material, obtainable from almost any rock supplier anywhere in the world. Carrara marble covers temples in Bangkok, skyscrapers in Chicago, l’arc d’Europe in Paris and every bathroom floor in Italy. However, after a visit to the quarries of Carrara it is evident that not all Carrara marbles were created equal. Although random Carrara marbles are remarkably uniform in bulk chemistry, there are subtle differences in grain size, grain boundary morphologies, impurity content, crystallographic and grain-shape preferred orientations etc. that give different colors and characteristics. You can find bianco, venato, bardiglio, crema, calacatta, fantastico and statuario, all distinctly different to look at but all called Carrara because they come from one of over a hundred quarries near the Ligurian coast of Italy above the village of Carrara. These quarries were started in Roman times and have been worked continuously since the 11th century. Even Michaelangelo went to Carrara for the finest statuario marbles. Today this region is the largest supplier of marble in the world (40% of the US market!). Carrara is also the home of the famous Tuscan delicacy “Lardo” - made by solidifying and curing pure animal fat in marble crypts for several months. Yum!?

Acquiring a block of marble: We recently purchased a large block of classic Carrara and are offering to supply interested labs with a piece. Massimo Coli (Univ. of Florence) arranged a trip in mid-July with Antonio Crisculo (geologist for IMEG, a large marble supplier) to some of the quarries, where we were able to choose the block. The most important criteria for our block were: homogeneous across the block, freshly cut, not friable, no fractures or large veins, minimally foliation and a typical Carrara grain size (~200 μm). We decided that bianco (white) marble from the Lorano area near the crest of the

(Continued page 16, column 1)
Rock Mechanics Research Facilities at Shell International Exploration and Production, Research and Technical Services, Rijswijk, the Netherlands

Peter Schutjens, Flip de Bree, Bart Pestman Shell, Rijswijk

Supporting the wide range of needs of the Shell E&P Operating Units, there are three rock mechanics related experimental facilities at Shell in Rijswijk. Projects range from short term service work to provide high quality rock property data for operations, to longer term research aimed at developing new techniques to be implemented at the few years time scale.

Inflow Performance Laboratory
Work is aimed at problems related to sand production, wellbore stability and hydraulic fracturing. The lab has three major experimental setups. The first is a room temperature, fully automated (MTS Teststar) triaxial testing facility for 25 mm diameter cylindrical samples, at pressure up to 70 MPa with a servo controlled pore fluid system. Experimental work is aimed at determining elastic properties and failure criteria of sandstones and mudrocks under fully drained conditions, with the possibility to measure pore volume change during deformation.

The second apparatus is the sand production tester (Roxell), a triaxial pressure vessel for samples up to 170 mm long and 70 mm diameter with an axial hole. It is aimed at the study of the onset and progress of sand production from a wellbore which gradually collapses during production of hydrocarbons. This apparatus can independently apply axial and radial total stress with simultaneous rapid radial flow of reservoir fluid. To allow study of the progressive failure of the wellbore with time, experiments can be carried out in a Computer Tomograph with real time observation of the wellbore.

The third apparatus is the Borehole Collapse Cell, designed to study the interaction of mudrocks and drilling fluids under simulated downhole conditions. It is aimed at capturing the complex processes which occur at the time scale of days in wells drilled through very low permeability mudrocks, eventually leading to wellbore collapse and drilling problems. The apparatus consists of a triaxial pressure vessel for samples up to 170 mm long and 70 mm diameter, with an axial hole. Pressures up to 70 MPa and temperatures up to 180 deg. C are available. This apparatus can independently apply axial and radial total stress, and has an internal rubber sleeve to allow hydrostatic consolidation of the samples. In a typical experiment a mudrock sample is loaded in the vessel, saturated with in-situ pore fluid and loaded in an undrained fashion, followed by consolidation to the desired in-situ conditions. After consolidation the internal sleeve supporting the wellbore is replaced by a drilling fluid, and the stress-strain behavior is monitored together with the radial fluid flow. In combination with finite element modeling.

Lab Report

New PPEM Bibliography Under Construction

Brian Evans
M.I.T.

Have you ever wished for a specialized bibliographic reference that covered the literature on physical properties of rocks, rock deformation, and mineral physics? Maybe you have tired of waiting for information from a general bibliographic search tool to be transferred over the web. Or you had to search through 451 references to work by people named Schmid to find the particular reference that Stefan Schmid wrote in 1977. Maybe you wanted a list of references to import into your bibliography management software. Now there is an answer in sight.

Georg Dresen, at the GeoForschungsZentrum, Potsdam, Germany, and Brian Evans at Mass. Inst. Tech., Cambridge, MA are trying to organize the formation of a special bibliographic tool that will contain a list of recent research papers pertaining to rock mechanics, physical properties of rocks, and mineral physics. The intent of the project is to provide a specialized reference list that could be downloaded from a web site to an individual. The list could then be imported into any one of several bibliography maintenance programs on a scientist's local computer. The list would be useful in doing literature searches, maintaining a current reference list, and in constructing end notes for research papers.

The project will depend on the voluntary submission of bibliographies from individual (Continued page 16, column 3)
The Effects of Fluids on Rock Physical Properties: Evidence from Laboratory and Field Experiments

Dave Olgaard
ETH-Zentrum

The European Geophysical Society's 1996 General Assembly was held last May in The Hague, The Netherlands. Of particular interest to PPEM members was the interdisciplinary session on the effects of fluids on physical properties of Earth materials convened by D.L. Olgaard, T. Popp, C.J. Peach, and P. Meredith.

The twenty-six oral and poster contributions were a mixture of laboratory experiments, numerical modeling and field measurements by geophysicists from across Europe and around the globe. The topics were loosely divided into four groups: 1) mechanical effects of fluids from microscopic to macroscopic scales: pressure solution and water-enhanced creep, fluid pumping, pore pressure-induced faulting, diagenesis and faulting, regional tilting from lake levels, and production-induced reservoir compaction, 2) changes in physical properties of saturated rocks under triaxial loading: damage analysis using acoustic emissions, electrical conductivity, and permeability, 3) fluids and hydrostatic pressures: seismic attenuation, seismic velocities, streaming potentials, thermal diffusivity and conductivity, and electrical resistivity, and 4) chemical effects: dehydration reactions, dielectric constants and radon isotope measurements.

The posters were left up all week allowing ample time for viewing. Although the oral session was on the last day of the meeting, it was very well attended and the discussions were lively and informative. If you are interested in details, most of the contributions will be published as reviewed short papers in a thematic issue of Physics and Chemistry of the Earth, due out in early 1997. Fluid effects on rock physical properties will again be featured at the 1998 EGS General Assembly to be held in Nice, on the French Riviera. We look forward to seeing you there.

Conference on High-Strain Zones

S.J. Mackwell 1 and M.E. Zimmerman 2
1 Pennsylvania State Univ. 2 Univ. Minnesota

In September, a conference on "Structure and Properties of High Strain Zones in Rocks" was held in Verbania, Italy. It was organized by Ernie Rutter and Kate Brodie from the University of Manchester and Attilio Boriani and Luigi Burlini from the Universita di Milano. The conference went from September 3-7 and included scientific presentations, posters, and an afternoon field excursion for all participants, as well as longer field trips to specific field locations in the area.

The conference was held in the Hotel Castagnola in Verbania-Pallanza on the beautiful Lago Maggiore in northern Italy. From many of the hotel rooms you could look out over the lake at the small scenic islands of Isola Madre, Isola Superiore, and Isola Bella. The last of these islands is dominated by a magnificent 17th century palace and gardens, where Napoleon rested for a while during his European tour.

The scientific program included oral sessions on (a) Geometry and development of high-strain zones, occurrences at large and small scales, field relationships, strain measurement and distribution, shape fabrics, classification and nomenclature, (b) Dating of shear zones, (c) Microstructures, deformation mechanisms and chemical changes, (d) Experimental studies relating to high-strain deformation, (e) Geophysical and petrophysical aspects of high-strain zones, (f) Association of shear zones with melts and relations with metamorphism, and (g) Regional studies of high-strain zones. Throughout the meeting, the talks were of high caliber, and the discussion sessions lively, as were the less formal conversations around the posters (and later in the local bars and restaurants). It was an excellent opportunity for scientists focussing on different aspects of shear zones to discover new viewpoints and discuss common problems.

On the last formal day of the conference, all participants were taken on a half-day field excursion to get a closer look at the section through the Ivrea-Verbano zone transition to the Serie dei Laghi in the lower Valle d'Ossola. The afternoon was sunny and warm, making it ideal for such a trip. In the following two days, one-day field trips were led to the Ivrea Zone in Valle d'Ossola, and in Val Sesia, to the Serie dei Laghi, CMB line, Ivrea zone in Val Cannobina, to the Pogallo line in Val Pogallo, to the Voltri Massif, and to the Alpine section in the Val d'Ossalo. Parti (Continued page 18, column 1)
The German Deep Drillhole (KTB) Experience: Results and Implications

Special Section of the Journal of Geophysical Research, to appear in early 1997

Eds: Prof. Volker Haak (GFZ, Potsdam), Dr. Alan G Jones (GSC, Ottawa)

The main objective of the German Continental Deep Drilling Program (KTB) was defined as fundamental geoscientific research on the nature of geophysical structures and phenomena, the stress field and thermal structure of the Earth's crust, rock fluids, energy- and mass transport processes, as well as the architecture and evolution of a given crustal section. KTB has been one of the greatest Earth science projects of the last decade worldwide. An international cooperation between all Earth scientists in a true interdisciplinary manner results after 7 years of drilling in a new view of the continental crust. After completion of drilling activities 1994 the research program is now coming to an end. Thus it is time to present a paramount view of the results by the group of scientists who worked during the last 10 years on the KTB problems. The about 20 benchmark papers are grouping around the five main research themes of the project:

♦ Nature of geophysical structures and phenomena, seismic reflectors, electrical, magnetic and gravimetric anomalies.
♦ The stress-field of the Earth's crust and the brittle-ductile transition, orientation and magnitude of mechanical stresses.
♦ The thermal structure of the crust as a function of depth, temperature distribution, heat-production and heat-flow.
♦ Fluids and transport processes, fluid sources, fluid composition and pathways.
♦ Structure and evolution of the Variscan crust in Mid-Europe, architecture, mechanisms of deformation and dynamics of a reactivated crust.

The results presented in this Special Issue will show the impact of direct in-situ probing of the Earth's crust through drilling and extensive borehole measurements as well as detailed laboratory investigations to the interpretation of geophysical surface measurements and the development of geodynamic models. Additional information is given for recent developments in drilling technology, high-temperature borehole logging tools and data-management.

Alan G Jones, GSC, Ottawa


Eds: M. Matsu'ura, I.G. Main, C. Marone, S.R. McNutt, J.B. Rundle, and M. Takeo

This volume follows from a special session with the same title at the 1995 IUGG meeting in Boulder Colorado. The theme of the volume is to develop quantitative descriptions of the basic processes governing earthquake nucleation, including fault constitutive relations under realistic environmental conditions. Approximately 20 papers covering laboratory, theoretical, and field-based approaches to earthquake generation are included. Papers emphasize the interdisciplinary nature of the subject and the complexity of the problems involved. Subject material includes studies of the mechanics of foreshocks and aftershocks, fault creep, frictional strengthening and fault healing, fault interaction, friction micromechanics and constitutive laws, and the mechanics of earthquake aforeslip. Further information may be obtained from M. Matsu'ura, Chief Guest Editor (matsuura@geoph.s.u-tokyo.ac.jp).

Chris Marone, MIT, Cambridge, MA.

Fault-Related Rocks - - A Photographic Atlas

Eds. A. Snoke, J. Tullis and V. Todd

In June of 1996, Art, Vicki and I completed a task we had begun over 10 years earlier, namely editing a photographic atlas illustrating meso- to micro-scale structures from brittle faults through ductile shear zones. The initial concept was developed during informal discussions at the GSA Penrose Conference on Petrogenesis and Significance of Mylonitic Rocks in 1981. Many participants felt that a new consensus about mylonites and ductile shear zones had been achieved at the conference, due largely to the open discussions that occurred among field and experimental geoscientists from many countries. We felt that a collection of photographs of features characteristic of faults and shear (Continued page 19, column 3)
Meeting Announcements

Deformation Mechanisms in Nature and Experiment
March 17-19, 1997
Basel, Switzerland

The aim of the conference is to refresh the discussion and exchange between scientists engaged in experimental rock deformation and structural and microstructural field studies. We would like to focus on deformation processes, both in experiments and naturally deformed rocks.

For more information and registration forms, consult our web-site: www.earth.unibas.ch or write to: "Deformation mechanism conference", Geologisch-Paläontologisches Institut, Bernoullistr. 32, 4056 Basel, Switzerland

NYRocks '97
June 29-July 2, 1997
Columbia University, NY

The 36th U.S. Rock Mechanics Symposium, NYRocks '97, is organized by the Henry Krumb School of Mines, Columbia University in the City of New York, and the American Rock Mechanics Association under the sponsorship of the U.S. National Committee for Rock Mechanics. The theme of the Symposium is "Linking Science to Rock Engineering". The technical program includes keynote lectures in the areas of excavation and ground control, site characterization, fracture and fracture phenomenon, and coupled processes and fluid flow.

Chris Scholz is organizing a special session on "Fault and Earthquake Mechanics" that focuses on the applications of studies of rock friction and fracture to problems of earthquake and fault mechanics. Joanne Fredrich and Teng-fong Wong are convening a session on "Micromechanics and Constitutive Modeling". This session will explore recent advances in understanding and modeling deformation of pressure-sensitive, dilatant geologic materials under conditions favoring either brittle fracture or ductile compactive failure. John Gale, Fred Paillet and Colleen Barton are organizing a day-long session on "Geomechanics and Fluid Flow" with several sub-sessions on permeability anisotropy; lab and field studies; fracture networks and fracture statistics.

Abstract deadline for some special sessions has been extended to Nov. 1, 1996. For information contact Kunsoo Kim, Columbia University, mail code 4711, 500 W. 120th St. NY, NY, 10027 kk21@columbia.edu

The 1997 Gordon Conference on Rock Deformation
August 10-15, 1997
Colby-Sawyer College,
New London, New Hampshire

Dynamic Metamorphism: The Interaction of Deformation and Mineral Reactions

Chair: Harry W. Green, II;
Vice-chair: Brian Evans

Structural geologists and metamorphic and igneous petrologists have long known that chemical reactions and mechanical deformation strongly influence each other. Sometimes the interactions are straight forward. For example, a metamorphic reaction may change the mineral assemblage, causing a concomitant change in the mechanical properties. In other cases the interaction may occur indirectly through a change in an environmental variable, as when a prograde reaction releases a volatile fluid and lowers the effective pressure on the rock mass. In still other cases, the interaction may be direct, but not straightforward. Such direct interactions involve processes in which the mechanical and chemical driving forces combine to determine the process rates. For this subset of cases, the coupling may be quite subtle and involve only portions of the mechanical or chemical driving forces. Important examples of direct coupling include static fatigue cracking in the presence of a corrosive fluid, pressure solution processes in the mid to upper levels of the crust, weakening of minerals by changes in the chemical fugacity of water and other chemical components, and the effect of partial melts on rock strength.

Our understanding of the exact physics and chemistry of these interactions has suffered because the topics fall at the join of several disciplinary fields: petrology, structural geology, mechanics of materials, solid state chemistry, physical chemistry and material science. Often workers studying these interactions are divided even further by classifications according to the methods: laboratory, field geology, and theoretical. The goal of this conference is to promote a multidisciplinary assessment of our understanding of the coupling between chemical and mechanical forces in minerals and rocks. Progress in technical apparatus, theoretical understanding, and field observations have created an opportunity for (Continued page 17, column 1)
Scientific Drilling into the Hyogo-ken Nanbu Earthquake Rupture, Nojima Fault, Awaji Island, Japan

Hisao Ito
Geological Survey of Japan

The Hyogo-ken Nanbu (Kobe) earthquake of January 17, 1995, was the most damaging to hit Japan since the 1923 great Kanto earthquake that destroyed large parts of Tokyo and Yokohama. The earthquake epicenter was located about 20 km southwest of Kobe and just northeast of Awaji Island, and occurred along the fault network of the Rokko Mountains near Kobe and to the southwest along the Nojima fault on Awaji Island. The 10 km long surface break on the Nojima fault displayed offsets up to approximately 2 m. The earthquake was the direct cause of 5,502 deaths and 41,527 injuries. It destroyed a total of 394,440 private homes and caused the evacuation of about 340,000 people. The economic loss may be the greatest ever from a natural disaster, and amounts to approximately 200 billion U.S. dollars. Although Japan has long had a very active earthquake hazards reduction program, the destruction by the Hyogo-ken Nanbu earthquake has further stimulated government and scientific action.

One area of research resulting from the earthquake is scientific drilling into and around the active faults in the Kobe region, including the Nojima fault on the northeastern portion of Awaji Island. There are three major research groups actively drilling and conducting experiments in boreholes around Kobe and the Nojima fault. This article provides a brief summary of the drilling programs and activities to date. A list of references is provided at the end of the article for those wanting more information.

The three research groups are 1) the Geological Survey of Japan (GSJ), led by Dr. Hisao Ito, and funded by the Agency of Industrial Science and Technology and the Ministry of International Trade and Industry, 2) the National Research Institute for Earth Science and Disaster Prevention (NIED), led by Dr. Ryuji Ikeda, and funded by the Science and Technology Agency, and 3) the University Group (UG), led by Prof. Masataka Ando, and funded by the Ministry of Education. The groups are working somewhat independently, and are conducting similar types of geological and geophysical investigations, in situ experiments, and downhole monitoring activities.

The GSJ and NIED have completed several boreholes located close to the epicenter, near the ends of the earthquake rupture, and on the Nojima fault near the epicenter and where the maximum surface displacements were observed. These latter boreholes, the GSJ Hirabayashi and NIED Hirabayashi are located 75 m and 320 m, respectively, from the surface trace of the Nojima fault and cross the fault zone at depth. The GSJ hole is 747 m deep and the NIED is 1800 m deep. The six other boreholes range between 300 m and 1300 m depth. The three UG boreholes are also located on the Nojima fault, but at a location where both the main Nojima fault and a subsidiary fault is observed. The depth range of these holes is 500 m to 1800 m. Drilling the 1800 m hole should be completed in November, 1996.

Continuous core has been collected from almost all of the boreholes. GSJ has had close to 100% core recovery in all their boreholes. At Hirabayashi, continuous core was taken between the depth 150 m-746 m, with 98% recovery across the fault zone. The core shows a deformed zone between 557 and 713 m, with clay gouge between 623.4 and 625.4 m. This depth interval corresponds to a fault zone thickness of approximately 30 m. Preliminary core observations indicate polyphase deformation but it is not yet known which, if any, of the deformation features were generated in the most recent earthquake. The NIED and UG also have collected or are collecting core from across the Nojima fault, but core recovery rate has not yet been reported. The GSJ and UG are planning extensive study of the core materials. For the Hirabayashi core, the GSJ has photographed the core using a core scanning system, made stress measurements on samples (AE/DR, DSCA), and are measuring physical properties including seismic velocity, density, permeability, and fracture strength. In addition, petrographic studies, analysis of fractures and core deformation, fluid inclusion analysis, and dating core materials are in progress. The NIED and UG are conducting similar studies of their core materials.

All groups have completed or will make a number of downhole measurements, particularly in the holes across the Nojima fault. In the Hirabayashi borehole the GSJ has carried out conventional caliper, electrical resistivity, density, neutron, gamma ray, micro-resistivity, and temperature logging. The hole was imaged using both BHTV and FMI tools. In addition, the velocity structure was investigated using a Schlumberger Dipole Shear Sonic...
Imager and a 3-component geophone VSP. In general, direct observation of features in the core show good correlation with in-situ properties measured in boreholes with remote geophysical techniques. Similar downhole measurements, though possibly not as extensive, are being completed in the NIED and UG boreholes. Downhole experiments in several of the boreholes include hydraulic fracturing stress measurements, and pore pressure and permeability measurements. No high fluid pressures have been reported for the wells crossing the fault zone.

The large number of boreholes will allow the groups to establish a network of monitoring stations. Water level will be monitored in most of the GSJ and UG boreholes. In addition, downhole 3-component strain meters and downhole seismometers are to be installed. Magnetometers, acceleration seismometers, and resistivity monitor with downhole electrode will be placed in a couple of the holes.

Researchers from Japanese and US universities and the USGS are currently collaborating with the GSJ and NIED but there are plenty of further opportunities for international cooperation or collaborative science. It is unlikely that the drilling into the Nojima fault will mark the end of scientific drilling in Japan. In fact, scientists in Japan have plans for super-deep drilling in the future (JUDGE - Japanese Ultradeep Drilling and Geoscientific Experiments). For additional information, contact Dr. Hisao Ito, Geological Survey of Japan, 1-1-3, Higashi, Tsukuba, Ibaraki 305 Japan, e-mail: g0193@gsj.go.jp

GSJ Reports


NIED Reports


UG Reports


A lot has happened since we last wrote about the San Andreas Fault Zone Drilling Project (FZDP) for the PPEM newsletter (see October 1994 issue). As the first step toward our ultimate goal of drilling a 10-km-deep hole into the San Andreas fault zone, in June of this year we submitted a proposal for a 2.5-km-deep Pilot Fault Zone Drilling Project to the National Science Foundation’s Continental Dynamics Program, with additional support sought from the U.S. Geological Survey and the Department of Energy. As described below, in this proposal we requested funding not only for drilling and coring but also for scientific studies associated with the Pilot Project. In particular, we recommended that a source of dedicated funding be made available by NSF, the USGS and DOE for scientists wishing to participate in this multi-disciplinary project, with funds to be distributed on a competitive (i.e., proposal-driven) basis.

This year we also submitted supplementary proposals for the Pilot Project to the International Continental Drilling Program (ICDP) and the U.S.-Japan Earthquake Disaster Mitigation Partnership. The ICDP proposal requested support in the form of project engineering and supervision; on-site analysis of core, cuttings and fluids; and data management. The U.S.-Japan Proposal sought joint funding of the Parkfield Pilot Project and arose out of an initiative by the White House Office of Science and Technology Policy and Japan’s Science and Technology Agency to create a bilateral program in earthquake hazard reduction.

As some of you may be unfamiliar with the FZDP, we begin this update with a brief project overview. We then discuss in more detail the scientific goals, site selection and experimental plan for the Pilot Drilling Project.

**Overview of the San Andreas Fault Zone Drilling Project**

For the past several years we have been leading an international initiative for integrated surface-based geological and geophysical investigations and deep scientific drilling along the San Andreas fault system (see Hickman, Zoback, Younger and Ellsworth, *EOS, Trans. AGU*, pp. 137, 140 and 142, 1994). This project is motivated by the need to understand the physical and chemical processes operating within the fault zone and to answer fundamental questions about earthquake generation along major plate-boundary faults. The ultimate goal of the FZDP is to drill a vertical hole next to the San Andreas fault and core inclined branches off this hole to penetrate the fault at depths of about 3, 6, and 10 km. Through a comprehensive program of coring, fluid sampling, down-hole measurements, laboratory experimentation and long-term borehole monitoring, we would obtain critical information on the structure, composition, mechanical behavior and physical state of the San Andreas fault system at depths down to the nucleation zones of great earthquakes.

The first stage of site selection for the 10-km-deep hole is now well underway, with about 20 reconnaissance field investigations – incorporating geologic mapping, active and passive seismology, potential field methods (aeromagnetics, gravity and magnetotellurics), aqueous geochemistry and borehole geophysics – being conducted along four segments of the San Andreas fault potentially suitable for deep drilling. These studies are being conducted by individual investigators funded by existing programs within the USGS, NSF and DOE. In the context of the FZDP, one of the principal objectives of these studies is the development of sufficiently detailed geological models of the fault and its immediate environment to permit the selection of two viable sites for the deep hole. These investigations are also providing important new information on the geological, geophysical and hydrological setting of the San Andreas fault system, irrespective of whether or not the 10-km hole is ever drilled. The second stage of site selection, which would be funded using new money raised in support of the FZDP, would then consist of much more detailed geological and geophysical investigations of the crust and upper mantle along these two finalist segments. Data from both stages of site characterization will be integrated into a common data base, providing the information necessary both to select the best site for the 10-km hole and to extend results from this borehole to other segments of the San Andreas fault and to faults in other tectonic environments. The

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**Stephen Hickman**, Mark Zoback, and William Ellsworth

1 U.S. Geological Survey

2 Stanford University
Subsequent deep drilling phase of the project would make it possible to conduct the in-situ investigations that are crucial to the overall success of this project.

Since the site selection strategy outlined above will delay drilling of the 10-km-deep hole until about the year 2001, we are also proposing to drill a 2.5-km-deep "pilot" hole into the San Andreas fault zone as soon as possible. The drilling, sampling and down-hole measurements programs proposed for the pilot experiment are similar to those for the 10-km hole, including instrumentation of the hole for long-term monitoring of seismicity, deformation, temperature and fluid pressure directly within and adjacent to the fault zone. As there are strong arguments in favor of locating the 10-km hole along a section of the San Andreas that is locked and likely to produce great earthquakes, we propose drilling the pilot hole where the fault is currently slipping through a combination of small-to-moderate earthquakes and fault creep. By targeting an "active" patch of the fault, the pilot experiment would allow us to address a number of important issues related both to the physics of earthquake rupture nucleation and propagation and to the transition from creeping to locked fault behavior. Also, we can use the seismicity to tell us the precise location of the active trace of the fault where it is penetrated by the borehole - an important parameter in interpreting data and samples obtained through the fault zone. This experiment would also achieve two other important objectives. First, it would enable us to obtain direct information on the structure, composition and physical properties of the fault at intermediate depth. This information would improve current knowledge tremendously and greatly facilitate development of a comprehensive science plan for the deep hole. Second, it makes it possible to identify and begin dealing with the technical problems of drilling, coring, casing, down-hole measurements and long-term monitoring that will be encountered in the deep hole.

**Scientific Goals and Site Selection for the Pilot Drilling Project**

Although the 2.5-km pilot hole is not deep enough to answer many of the scientific questions about the physics of faulting that are driving the deep drilling project, it would allow us to address a number of first-order questions related to fault mechanics:

- **What are the mineralogy, deformation mechanisms and constitutive properties of the fault gouge?** Why does the fault creep? What are the strength and frictional properties of recovered fault rocks at realistic in-situ conditions of stress, fluid pressure, temperature, deformation rate and pore fluid chemistry? What do mineralogical, geochemical and microstructural analyses reveal about the nature and extent of water-rock interaction?
- **What is the fluid pressure and permeability within and adjacent to the fault zone?** Do super-hydrostatic fluid pressures exist within the fault zone and through what mechanisms are these pressures generated and/or maintained? How does fluid pressure vary during deformation and episodic fault slip (creep and earthquakes)? Do fluid pressure compartments exist at shallow depths and, if so, what is the nature of the seals between compartments?
- **What are the composition and origin of fault-zone fluids and gases?** Are these fluids of meteoric, metamorphic or mantle origin (or combinations of the three)? Is fluid chemistry relatively homogeneous, indicating pervasive fluid flow and mixing, or heterogeneous, indicating channelized flow and/or fluid compartmentalization?
- **How do stress orientations and magnitudes vary across the fault zone?** Are the principal stress magnitudes higher within the fault zone than in the adjacent country rock, as predicted by some theoretical models? What is the strength of the shallow creeping portion of the San Andreas and how does this compare with depth-averaged strengths inferred from heat flow and far-field stress directions? What do spatial variations in stress tell us about the extent of shear localization and secondary fault slip?
- **How do earthquakes nucleate?** Does seismic slip begin suddenly or do earthquakes begin slowly with an acceleration of fault slip with time? Do the size and duration of this precursory slip episode, if it occurs, scale with the magnitude of the eventual earthquake? Are there other precursors to an impending earthquake, such as pore pressure changes, anomalous fluid flow, crustal strain changes or electromagnetic signals?
- **How do earthquakes propagate?** Do earthquake ruptures propagate as a uniformly expanding crack or as a "slip pulse"? What is the effective (dynamic) stress during faulting? How important are processes such as shear heating, fault-normal opening modes and acoustic fluidization in lowering the dynamic frictional resistance to rupture propagation?
- **How do earthquake source parameters scale with magnitude and depth?** What is the minimum size earthquake that occurs on the fault? How is the long-term energy release rate at shallow depths partitioned between creep dissipation, seismic radiation, dynamic frictional
resistance, chemical reactions and grain size reduction (i.e., by integrating fault zone monitoring with laboratory observations on core)?

- **What are the physical properties of fault-zone materials and country rock (seismic velocities, electrical resistivity, density, porosity, etc.)?** How do they vary with position across the fault zone and with distance away from the borehole (i.e., depth of investigation)? How do physical properties determined from core samples and wireline logs compare with properties inferred from surface geophysical observations?
- **What processes control the localization of slip and strain rate?** Are the fault surfaces defined by background microearthquakes and creep the same? Would the active slip surface be recognizable (through core analysis and downhole measurements) in the absence of seismicity and/or creep? By comparing observations on core with results from fault zone monitoring, can we identify microstructures characteristic of rapid (i.e., seismic) slip.

To identify potential sites for the pilot hole we conducted a systematic search of strike-slip faults in California, identifying all faults exhibiting shallow seismicity. We then convened a workshop on the scientific goals, experimental design and site selection for the pilot hole at the USGS in Menlo Park that was attended by about 45 people. Although several candidate sites along the Hayward and San Andreas faults were considered, it became clear that San Andreas fault at Middle Mountain, near the town of Parkfield, was the best place to conduct this experiment because: 1) Surface creep and abundant shallow seismicity allow us to accurately target the subsurface position of the fault. 2) There is a clear geologic contrast across

Figure 1: (A) Geologic map of the Parkfield site, showing seismic reflection lines, 1-2 km south of the proposed drill site, and a magnetotelluric (MT) profile, through the site and crossing the San Andreas fault, conducted as part of site characterization for the pilot project. Also shown are geodetic (EDM) arrays and a creepmeter defining the creeping surface trace of the San Andreas fault.

Beginning in the summer of 1994, members of the Site Selection Working Group for the San Andreas Pilot Project conducted a number of relatively small-scale and detailed geophysical investigations to fill critical gaps in our knowledge about subsurface structure and microearthquake locations at the Parkfield site (see Figure 1a). A temporary seismic network was installed on and around Middle Mountain to calibrate crustal structure and study fault-zone guided waves near the proposed drill site. This experiment included deployment of temporary seismic stations (to augment the
permanent local networks), three chemical shot points and a 10-station REFTEK array crossing the surface trace of the San Andreas. Additionally, a small-scale seismic reflection survey was conducted along two 2-km-long orthogonal lines southwest of the San Andreas fault. The purpose of this survey, which employed a single vibroseis energy source and 128 receivers per line, was to determine the thickness of Tertiary sediments beneath the proposed drilling site. A continuous magnetotelluric profile was also conducted at Middle Mountain to determine the electrical conductivity structure of the fault zone and its surroundings. Finally, detailed geologic mapping helped to ascertain the geometry and recent faulting history near the Parkfield drill site.

**Experimental Plan for the Pilot Project**

Two phases of drilling are envisioned: rotary drilling and spot coring of a mostly vertical hole, followed by continuous coring through the fault zone (Figure 1b). The drill site will be located sufficiently far from San Andreas fault (as determined by surface fault creep, microearthquake locations and magnetotelluric imaging) to allow for continuous coring through the entire fault zone starting at a vertical depth of about 1.5 km and continuing until relatively undisturbed country rock is reached on the far side of the fault.

Our plan is for the Parkfield Pilot Project to last 5 years. Engineering, detailed planning and fabrication of a special coring string will be conducted in the first year. The rotary drilling phase of the project will be carried out in the second year, during which directional drilling techniques will be used to deviate the hole toward the fault zone at an angle of about 45°. Continuous coring through the fault zone and downhole measurements (before and after casing is cemented into the borehole) will occur in year 3. Years 4 and 5 will be used to finalize downhole measurements, analyze rock and fluid samples and install equipment for long-term fault zone monitoring. Development and testing of the fault-zone monitoring system will be spread out over the entire 5-year period.

We have a signed agreement with the landowner at Parkfield that will allow us to carry out drilling and downhole measurements and then access the site.

**Figure 1:** (B) Cross section along A-A’, schematically showing the proposed drill hole, where Phases 1 and 2 refer to the rotary drilled and continuously cored sections of the hole, respectively. The contact between Tertiary marine sediments (Tsm) and the underlying granitic basement (gr) was determined from the seismic reflection profiles shown in A (Peter Malin, written comm., 1995). The Franciscan mélange is denoted by KJf. The hypothetical location of the actively slipping fault surface, obtained through downward continuation of the creeping surface trace of the San Andreas fault, is shown as a heavy vertical line. The hachured region denotes a zone of extremely low resistivity (< 5 Ohm-m) determined from the MT profile shown in A (Martin Unsworth, written comm., 1996). This broad zone, presumably representing highly fractured and/or altered rock comprising the overall fault zone, makes continuous coring over an appreciable distance necessary.
for 20 years for fault zone monitoring.

While the direct costs for the Parkfield Pilot Project are appreciable ($12.6 M over 5 years), approximately half the cost is for drilling and coring and half is for science. Specifically, $7.6 M was requested from NSF to cover drilling and coring ($6.5 M); downhole stress, fluid pressure and permeability measurements and wireline logging ($0.9 M); and project management ($0.2 M). We requested that the remainder of the funds (~$5 M) be distributed by NSF ($1.9 M), USGS ($2.0 M) and DOE ($1.1 M) on a competitive proposal basis to enable critical scientific studies to be carried out. These include comprehensive laboratory studies of exhumed core and fluids, surface-to-borehole seismic and electrical studies, and construction and installation of an array of fault zone monitoring instruments. We also hope that there will be broad participation from the international scientific community as well, funded by the ICDP and foreign science programs.

Although this is not an easy time in which to initiate an expensive science project such as we are proposing, by pursuing multiple sources for funding and engineering support we hope to substantially improve our chances for success. If you would like to be involved in this project but are not already on our mailing list, please contact Steve Hickman, tel. 415-329-4807, fax 415-329-5163, e-mail hickman@thepub.wr.usgs.gov; or Mark Zoback, tel. 415-725-9295, fax 415-725-7344, e-mail zoback@pangea.stanford.edu.

PPEM Dinner
(continued from page 1)

were kept from this restaurant by its small size. Fortunately for us, it has now moved down the block to a space that can accommodate our group (but our group alone) for the evening.

Caffè Delle Stelle is located at 395 Hayes Street at Gough, two blocks west of Van Ness Avenue and Davies Hal. The restaurant can be reached by foot from Moscone Center or Union Square in perhaps 15 minutes (walk down Market from 4th to 9th, Hayes angles off on your right), via a brief cab ride, or via the number 21 bus which runs down Market. At the request of several PPEM members, dinner will start a bit later this year: the restaurant will open for socializing at 6:30, and dinner service will begin at 7:00. There is a wine bar located next door for those who wish to congregate earlier.

The menu will consist of the following:

**Two Appetizers**
- Bruschetta: garlic toasts topped with fresh tomatoes, basil and olive oil
- Rotolino: roasted eggplant rolls filled with ricotta and arugula

**Small Caesar Salad**

**Entree Combination**
- Pasta Cruda: Pasta tubes with fresh tomatoes, basil, garlic and olive oil
- Cannelloni de salmone: Roasted salmon cannelloni with wild mushroom sauce

(Inform your waiter if you would prefer a vegetarian alternative)

**Wine**
- Cabernet sauvignon and Greco di Tufo, about 1/2 bottle per person

**Desert**
- Tiramisu, lady fingers, espresso, mascarpone cheese cake
- Glass of vinsanto

We will maintain our tradition of facilitating student participation in PPEM by keeping their cost down relative to the cost for income-earners. The cost will remain at $25 per person for students and $45 per person for others.

A separate dinner invitation and registration form is enclosed with this newsletter, and available on the web at ftp://ftp.eas.slu.edu/pub/ppem.

Registration and payment (or, for foreign visitors, a promise to pay at the door) must be received by December 4. Questions, comments, forms and cheques should be sent to our outgoing dinner organizer: Mike Blanpied, USGS, Mail Stop 977, 345 Middlefield Rd., Menlo Park, CA 94025, 415-329-4969, mblanpied@usgs.gov.

ARMA
(continued from page 3)

York, NY 10027; Tel: 212-854-8337, Fax: 212-854-8362, E-mail: kk21@columbia.edu, Web Page: http://www.columbia.edu.kk21.

As one of its first services to its membership, ARMA is beginning a comprehensive assessment of the status of rock mechanics and rock engineering in the United States. The survey will compile information on rock mechanics and rock engineering within academic programs, government laboratories, and the private sector. The survey will identify laboratories and field programs including information on their equipment, facilities, and capabilities. It will also include information on current research topics for graduate theses, as well as providing information on the employment patterns of recent graduates.

Information on how to join ARMA can be obtained by contacting Peter Smeallie, Executive Director, ARMA, 600 Woodland Terrace, Alexandria, VA 22302; Tel: 703.683.1808, Fax: 703.683.1815, E-mail: psmealli@tmn.com.
Carrara Marble

Apuana Alps would be the best bet. Antonio and the quarrymen showed us several satisfactory blocks and chose a small one (only 10-tons) that had been cut out of the quarry wall that morning. The block was squared off and trucked down the mountain where it was weighed and graded. Because the cut on the quarry wall was still obvious, Massimo could record the block’s spatial orientation and structural location within the variably deformed Apuana metamorphic complex. The block was then sawed into smaller cubes and slabs of £50 kg. Each piece was labeled to correspond to the orientation with respect to and location within the large block. Marco Pieri (ETH-Zurich) had the enviable job of remaining in Carrara for an extra 10 days to oversee the cutting, labeling and boxing of the blocks and to play in the warm sun, sand and sea of the Mediterranean, while Lisa (Dell’Angelo), Isabella and I headed back to cold rainy Zurich.

Geologic history and structure: Carrara marble originated as a late Triassic-early Jurassic calcite carbonate shelf that was metamorphosed and deformed in the mid-Tertiary during the northern Apennine orogeny. The deformation manifests itself as large recumbent folds on the scale of meters to kilometers and as stretched pebbles (up to 16:1) in breccia zones, but is virtually unrecognizable at the grain scale. Lorano bianco Carrara marble is a medium-grained (average grain size = 200 μm) white calcite (99.9%) marble with a tint of blue-gray caused by veins of minor impurities (traces of dolomite, muscovite, feldspar, quartz and pyrite). Detailed chemical and microstructural analyses of samples from our block are in progress.

Update on obtaining your own sample: The initial response to my e-mails in April and June was very enthusiastic. As of this writing, we have more than 25 orders amounting to a total of over 5000 kg of marble! Orders range from souvenir-sized bricks to over 1000 kg. With the exception of two special orders (T. Tullis and P. Johnson), we selected three different sizes to minimize cutting time and costs: cubes (~280 mm on a side), rectangular slabs (~150 x 260 x 600 mm) and square slabs (280 x 280 x 160 mm). There are also smaller pieces that can be cut into brick-size samples (2-5 kg). One ~100 kg piece out of the center will be reserved for petrographic study and for making test samples to be distributed to all interested labs for cross-comparison purposes (ask for details).

The total price will include the price of the block and the costs of sawing, crating, handling, and shipping. A rough estimate of the total is US$2 to $3/kg plus shipping from one of the distribution centers. The marble will be distributed from three locations.

1) Brian Evans or Gunter Siddiqi, Dept. EAPS 54-720, MIT, Cambridge, MA 02139, USA; Tel: (617) 253-2856; Fax: (617) 253-1699; e-mail: brievans@mit.edu or gunter@barre.mit.edu. 4500 kg for North America and for the “library”.
2) Toshi Shimamoto, Earthquake Research Institute, University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113, Japan; Tel: +81-33812111-5757; Fax: +81-338161159; e-mail: shima@eri.u-tokyo.ac.jp. 250 kg for Japan.
3) Dave Olgaard, Geologisches Institut, ETH-Zentrum, CH-8092 Zurich, Switzerland, Tel: (+41 1) 632-3708, Fax: 632-1080; e-mail: dave@erdw.ethz.ch. 2000 kg for Europe and elsewhere.

If you have already placed an order, be patient, you will be contacted. If you haven’t ordered yet but would like to, please contact the distributor nearest you.

PPEM Bibliography

Researchers. Individuals will be asked to submit lists of papers they have authored or co-authored in a special format. The lists would be imported into a master bibliography which would then be distributed from a World Wide Web site. Dresen and Evans plan to solicit the contributions by e-mail from the readers of this newsletter, but contributions by anyone interested in the physical properties of minerals and rocks are encouraged. The exact format for submissions, further information, and a list of keywords will be available from a site on the World Wide Web under construction. Check it out in November at http://www.gfz-potsdam.de/bib/p pem. The Web site and the bibliography itself will be maintained by the staff at the GeoForschungsZentrum in Potsdam. If you have questions you can e-mail Georg Dresen at dre@gfz-potsdam.de or Brian Evans at brievans@mit.edu.
Meetings (continued from page 8)

a fresh approach to the difficult, but extremely important of the coupling of chemical and mechanical forces. Join us at Colby-Sawyer College this summer in what promises to be a stimulating and productive conference at the frontiers of research.

Conference Format

There will be nine formal morning and evening sessions spread over 5 days, three talks will be given in each morning session, and two in the evening; afternoons are free for discussion and informal activities. The free period in afternoon provides access for newcomers to the world's experts in the discipline and facilitates establishment of new collaborations between researchers in different disciplines. Two evening sessions will be devoted to posters contributed by the conference.

Poster sessions allow the most current research to be discussed in informal and highly interactive discussions. The conference commences with dinner and an evening session on Sunday, August 10, and ends with the evening session on Thursday, August 15. All attendees will have the opportunity to present posters, so we encourage participation by graduate students and post-doctoral researchers as well as established scientists.

Location

Colby-Sawyer, founded in 1837, is located in the Dartmouth-Lake Sunapee region of New Hampshire and sits on 80 acres of land, within walking distance of the main shopping area of New London. Opportunities for hiking, biking, swimming, golf and tennis are near the campus. There are B & Bs, motels, campgrounds, and many interesting restaurants that cater to Gordon conference. The Hogan Fitness Center located on campus has a pool, weight room, indoor track and gym and the GRC has a beach on Little Sunapee Lake reserved for conference and their guests.

The conference is easily reached by flying to Boston’s Logan Airport. A chartered bus will be available from Logan Airport to the site on Sunday, and from the site back to Logan on Friday To get to New London from the South by car (MA, CT, RI), take I-93 North to I-89 North, just South of Concord, NH. On I-89, use exit 11, turn right at the end of the exit and drive one mile to the blinking light. Take a left onto Main Street and you will see the college on your right (about one mile). From North or western New England/NY, take I-91 to I-89 South and get off at exit 11 and follow above directions.

Tentative Conference Schedule

Sunday Evening
Pressure-solution and related phenomena - Field observations.
- Dissolution and transport processes (Grain scale).
- Dissolution and transport processes (Field Scale): Stylolites, crenulation cleavage, crack-seal

Monday Morning
Pressure-solution and related phenomena
- Nonhydrostatic thermodynamics, theory of stylolites
- Experiments

Monday Evening
Poster Session #1: Pressure solution and partial melting posters

Tuesday Morning
Interactions between hydrothermal mineral reactions and deformation.
- Development of shear zones in retrograde (or progressive) terranes
- Interaction between mineral reactions and brittle deformation.

Tuesday Evening
Dynamic mantle melting beneath midocean ridges - Theory and experiment

Wednesday Morning
- Dynamic crustal melting
- Tectonic melting of continental rocks and/or sediments
- Experimental and field observations

Wednesday Evening
Poster Session #2: Fluid-free deformation, phase changes, mineral kinetics, rock memory

Thursday Morning
Interaction of solid-solid phase transformations and deformation.
- Transformation-induced faulting and deep earthquakes
- Superplastic flow and shear zone development
- Interaction of stress and phase transformations

Thursday Evening
How do rocks record the P-T-t-strain-stress conditions?
- Chemistry - Power and limitations
- Deformation microstructures - Power and limitations

Information on Registration and Fees

Science magazine will have a list of the topics, times and speakers of all Gordon Research Conferences in one of the February issues. There are three ways to register: by conventional mail; by e-mail; or using the WorldWide Web. For conventional registration, details may be obtained directly from the Gordon Conference Office: Gordon Research Conferences, University of Rhode Island, P.O. Box 984, West Kingston, RI 02892-0984, USA. Phone: (401) 783-4011/3372; FAX 783-7644. To obtain an e-mail form, send an e-mail message to grc@grcmail.grc.uri.edu

Applications are due 6 weeks before the commencement of the conference, but remember that there is a limit on the number of conference. Some conferences are oversubscribed. By
applying early, you will help in enabling us to plan for the conference.

For more information, contact: Prof. Harry W. Green II, Institute of Geophysics, University of California, Riverside, CA 92521, tel: 909-787-4505, fax: 909-787-4509, email: hgreen@ucrac1.ucr.edu.

Conference Reports

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Participants saw spectacular exposures of upper mantle and mid to lower crustal shear zones and related mylonites, ultramylonites, peridotites, mafic granulites and migmatitic metasedimentary country rocks.

All participants appeared to enjoy the conference immensely -- the scientific sessions, the discussions, the field excursions, the spectacular scenery, and especially the fine food and wine. Abstracts and other information regarding the conference are on the www site http://imiucca.csi.unimi.it/~petro/isprs.html. The most relevant papers will be published in a thematic issue of Journal of Structural Geology.

Faulting, Fault Seal and Fluid Flow in Hydrocarbon Reservoirs

Rob Knipe, Greg Jones and Quentin Fisher
University of Leeds

September 23-25, 1996
University of Leeds

Understanding fault sealing and compartmentalization in hydrocarbon fields is now recognized as a key factor in hydrocarbon exploration and reservoir management. The economic importance of fault behavior has lead to a rapid expansion of interest in faulting and fluid flow in sedimentary basins and is providing a wealth of new high quality data from 3D seismic to microstructural analysis of cores and from pressure compartment distribution to migration histories. This in turn allows researchers to provide a robust framework for interpretation and prediction of reserves. There is a clear opportunity for a "researcher" to "technology user" link here and the conference was aimed at exchanging ideas between these communities. The attendance of 232 delegates from a wide range of backgrounds guaranteed that the conference was multidisciplinary and achieved the required integration of geologists, geophysicists, reservoir engineers, explorationists, numerical modellers, experimentalists. The conference 'icebreaker' was a core workshop where core samples from faulted reservoirs from the North Sea, provided an excellent opportunity to assess deformation characteristics and characterization procedures. A total of 82 papers were submitted for the main two-and-a half day oral and poster sessions. The themes covered were:

- Structural geology in reservoir characterization.
- Fault array geometry and evolution.
- Fault zone internal structures and damage zones.
- Faulting processes and seal properties.
- Deformation and fluid flow
- Modeling of deformation and fluid flow.
- Fault seal analysis.
- Hydrocarbon field examples.

The conference highlighted the rapid progress which has been made of the last five years in: a) understanding the geometry of fault zones, b) characterizing of fault rock properties c) the development of tools for evaluating fault geometries, juxtaposition distributions and modeling flow behavior d) recognizing the value of detailed structural analysis for input into production strategies and the creation of fault rock databases which take note of different geohistories that impact on fault behavior.

The conference emphasized the need to incorporate geomechanics into reservoir behavior assessments, to evaluate the patterns and controls on the continuity, spatial distribution and petro-physical properties of fault rocks within fault zones, to assess the relative importance of order and chaos associated fault array evolution, to identify appropriate scaling relationships, and to validate the applicability of fault seal risk procedures. The field excursions to Flamborough Head and the Cheshire basin which followed the conference provided additional opportunities to discuss fault zone behavior and to "decompress". Thanks for support to Arco, BP, British Gas, Chevron Conoco, Elf, Mobil, Phillips, Shell, Texaco, as well as The Petroleum Group and The Tectonics Group of the Geological Society of London. Lastly, thanks to all those who came to Leeds and made the event a success.

Copies of abstracts can be obtained from the Rock Deformation Research Group at Leeds.

Rob Knipe (r.knipe@earth.leeds.ac.uk), Greg Jones and Quentin Fisher, Rock Deformation Research, University of Leeds.
Anisotropy of upper mantle

We know something about the geological meaning of seismic anisotropy? Does SH>SV (SV>SH) polarization anisotropy in the deep mantle imply horizontal (vertical) flow as is the case of the upper mantle?

Those are the examples of some of the interdisciplinary issues that immediately come to my mind. I believe that a good way to make mineral and rock physics a more lively subdiscipline in AGU is to make contributions that have impact on other subdisciplines. I imagine that there are several ways in which this committee could serve this purpose. Let me list a few that come to my mind. (i) To organize special sessions at AGU or at other meetings, not only on very specialized topics but occasionally also on topics with diverse interests for other areas of earth science. (ii) To improve the accessibility to some national facilities, such as high energy X-ray sources, to a wide community of scientists. (iii) To improve our visibility in the AGU community (one effective way is to publish more “mineral and rock physics” related articles in EOS). (iv) To promote new blood into this area (I am getting old, I suppose?). I think we need many more new students in this area, particularly from this country.

I think that addressing the issues (i) to (iii) will be relatively straightforward and, with your help, I am pretty confident that we can succeed. Getting more students in mineral and rock physics is a difficult task and I do not have a very optimistic view at this time - but here is one.

Student Award

The Mineral and Rock Physics Committee seeks nominations for the 1997 Student Award as means of recognizing outstanding contributions by promising young scientists to this interdisciplinary area of research. Student nominees may be members of any AGU section who have engaged in experimental and/or theoretical studies of minerals and earth materials with the purpose of unraveling the physics and chemistry that govern their properties. The award includes a $500 cash award, which may be used toward travel or other professional expenses. For the details of the application procedure, please contact Hartmut Spetzler at the University of Colorado (Hartmut.Spetzler@spot.colorado.edu).

Wine and Cheese Reception

Following the good tradition during the past few years, there will be a Mineral and Rock Physics wine and cheese reception at the fall AGU meeting. Al Duba will again make sure that we have an excellent selection of wine at the reception. Thanks Al! The tentative schedule and location are: December 15 (Sunday), 17:30-19:30, Room 236 Moscone Center.

Shun-ichiro Karato
Chair of the Mineral and Rock Physics Committee
University of Minnesota, Department of Geology and Geophysics, 108 Pillsbury Hall, Minneapolis, MN 55455, USA, tel. 612-624-7553, fax. 612-625-3819 karato@maroon.tc.umn.edu

Books

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stances delayed the completion of the project. In January 1994 the editors re-dedicated ourselves to completing the task, believing that there was still an un-met need for such a volume, and that a number of major advances in our understanding of faults and shear zones had occurred in the intervening years. We sent out letters to all the former contributors, as well as to a number of additional scientists who had become active in fault rocks research. We read all of the contributions and requested minor or major revisions, in order to ensure quality of photographs and a degree of uniformity in style and terminology. Art undertook the enormous task of scanning in all of the contributions and formatting them to a common standard, and Art and Jan wrote an introductory essay documenting aspects of terminology, deformation mechanisms and microstructures, and conceptual models of fault and shear zones. By August 1995 the manuscript of the book was sent to Princeton University Press for formal review; they sent it to John Christie and Rob Twiss, who made very useful suggestions for improvements. Editing of the atlas continued from fall of 1995 through June 1996; revisions to the introductory essay were greatly facilitated thanks to constructive review comments from Barbara John, Bruno Lafrance, Win Mins, Ernie Rutter, Rick Sibson, Carol Simpson, Vickie Todd and especially Rick Law.

The final version of the Atlas was sent to Princeton University Press in June 1996, and it should be published sometime in 1997. It consists of the approx. 20 page introductory essay plus 223 “double spreads” which have 1 to 3 photos on the right-hand page and accompanying explanatory text, together with any appropriate location map or other line drawings, on the facing left-hand page. The atlas is organized into 3 major sections, on Brittle behavior; Semi-Brittle Behavior; and Ductile Behavior. There are a number of sub-categories for each, such as fluid-related features, foliation development, and strain partitioning. Most of the contributions illustrate naturally deformed fault rocks and mylonites, but there are a number of contributions illustrating experimentally deformed rocks and analog materials. There is also an extensive bibliography of references cited. Our hope is that this Atlas will serve to document many of the important advances that have been made in understanding fault-related rocks, as well as to stimulate interest in helping to solve the many remaining problems.

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Shell Laboratory

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this allows determination of the coupled flow parameters (permeability, diffusivity, osmotic efficiency) together with the stress-strain properties of the mudrock. Developments of breakouts with time can be followed by performing the experiments in a Computer Tomograph, and after the experiments chemical and microstructural changes of the samples are studied by wet chemical and SEM techniques.

Compaction Laboratory

Sandstone reservoirs experience a two- to tenfold increase in effective vertical stress during the life of the field. This increase in effective stress leads to sliding, rotation and deformation of the grains, and leads to compaction and densification of the reservoir. This in turn may induce surface subsidence, change the reservoir permeability, increase the risk of casing damage and cause seismicity. These phenomena may have a technical, economical and social impact on hydrocarbon production.

In the compaction laboratory, the compressibility of reservoir rock is measured under in-situ stress and temperature conditions. Three different triaxial deformation machines are available, operating temperatures up to 180 deg C, and pressures up to 100 MPa. Fully automated measurement of ultrasonic velocities and monitoring of acoustic emissions is available. In a typical experiment, cylindrical samples cored from reservoir cores are enclosed in Viton sleeves and subjected to in-situ vertical and horizontal stress and pore fluid pressure (hydrocarbons and water). Then the pore pressure is reduced at a constant rate and the total radial and axial stress is simultaneously adjusted according to the boundary condition dictated by field data or numerical modeling. In all three machines, the axial deformation of the sample is measured using LVDT's. At high temperature the radial deformation is measured in the confining fluid with two LVDT's mounted in an aluminum ring, via a metal contact pad through the rubber sleeve. At room temperature the radial deformation is measured using a semi-circular copper ring with strain gauges glued to both sides. Calibrations show that we can measure rock compressibility with a precision of 10E-5/MPa. During a compaction experiment the permeability to brine can also be measured, both along the sample axis and along the sample diameter. In addition the usual elastic parameters like Youngs Modulus, Poisson's ratio and grain compressibility are determined.

Thin-section analysis and Scanning Electron Microscopy (SEM) are carried out to
investigate the influence of microstructural parameters on compressibility and acoustic wave velocities, such as grain size, shape and orientation, and the grain-to-grain contact area. Mechanical and microstructural data are correlated to wireline log data, in an attempt to link fundamental experimental rock physics to applied petrophysics.

**General Research Laboratory**

This laboratory has two main facilities. The Polyaxial Cell is used in research of the development of acoustic velocities in reservoir rocks as a function of stress, (testing models of crack orientation distribution functions); and at understanding stress memory effects for the development of new techniques for in-situ stress determination. The Polyaxial Cell can handle 5 cm cubic samples. It has a working capacity of 130 MPa in each of the three directions inside a box-type reaction frame. The load on the sample is applied through lubricated aluminum end platens, leaving small strips at the edges of the cube free. Ultrasonic wave velocities (P and S) can be measured in each direction. Loading in all three directions is fully servo-controlled, and multichannel Acoustic Emission measurements can be made. Research in the size effect on the strength of thick wall cylinders, and in the development of borehole breakouts with increasing stress is done using the Large Size triaxial cell. This is a conventional triaxial, self-contained cell capable of deforming cylindrical samples of 160 mm diameter and 400 mm long with an axial hole, at pressures up to 125 MPa and controlled pore pressure. Load control and data acquisition are done by a MTS Teststar II testing system. Strain measurement is in axial and two radial directions, and Multi-channel Acoustic Emission measurements are possible.

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**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.

**Editors for the ‘96 Newsletter**

Fred Chester & Janos Urai