SUPPORT OF MSA AND GS SHORT COURSES AND THE COMPANION *REVIEWS* VOLUMES

Submitted by

Mineralogical Society of America
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Grant No. DE-FG02-01ER15127 – Amendment No. A005

Report for August 1, 2007 – July 31, 2008

This is the requested report about the progress, list of publications, and statement of the unexpended funds for the budget and performance period for Grant No. DE-FG02-01ER15127 Amendment No. A005. The short course organizers wrote more detailed descriptions about each short course during the current performance period. These are attached at the end of this report. This report also contains a cumulative summary of attendance and book distribution statistics for the DOE-supported MSA/GS short courses February 1, 2001 through July 31, 2008

Short Courses and Publications

[1] **Fluid-fluid Equilibria in the Crust: Petrology - Geochemistry - Economic potential**. August 16-17, 2007 (preceding the Goldschmidt Conference 2007 in Cologne, Germany). Conveners are *Axel H. Liebscher* and *Christoph A. Heinrich*. The course had 43 participants (16 students and 16 professionals + 11 speakers).

Reviews in Mineralogy and Geochemistry volume 65: **Fluid-Fluid Interactions,** Axel Liebscher and Christoph A. Heinrich, editors, i-xii and 430 pp. ISBN 978-0-939950-77-5 ($40 non-members, $30 MSA, GS, and CMS members) - 2500 copies printed on 07/13/2007.

[2] **Paleoaltimetry: Geochemical And Thermodynamic Approaches**. October 26-27, 2007 (preceding the GSA Annual Meeting in Denver, Colorado). Convener is *Matthew J. Kohn*.

Reviews in Mineralogy and Geochemistry volume 66: **Paleoaltimetry: Geochemical and Thermodynamic Approaches**, Matthew J. Kohn, editor, i-x and 278 pp. ISBN 978-0-939950-78-2. ($40 non-members, $30 MSA, GS, and CMS members) - 2200 copies printed on 10/23/2007.

Unexpended Funds at the End of the Budget Period

There are no unexpended funds.

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Cumulative Summary of DOE-supported short course attendance

Year	Course Title	Volume	professionals	students	speakers	totals
2001	Molecular Modeling Theory and Applications in the Geosciences	42	39	16	19	74
2001	Stable Isotope Geochemistry	43	32	34	13	79
2001	Nanoparticles and the Environment	44	53	31	8	92
2002	Phosphates: Geochemical, Geobiological and Materials Importance	48	23	19	11	53
2002	Applications of Synchrotron Radiation in Low-Temperature Geochemistry and Environmental Science	49	32	29	10	71
2003	U-Series Geochemistry	52	54	22	14	90
2003	Zircon: Experiments, Isotopes, and Trace Element Investigation	53	27	20	12	59
2003	Biomineralization	54	40	48	13	101
2004	Non-Traditional Stable Isotopes	55	26	21	6	53
2005	Low-Temperature Thermochronology: Techniques, Interpretations, and Applications	58	18	53	11	82
2005	Molecular Geomicrobiology	59	39	82	16	137
2006	Water in Nominally Anhydrous Minerals	62	34	31		65
2006	Neutron Scattering in Earth Sciences	63	32	17	17	66
2006	Medical Mineralogy and Geochemistry	64	38	27	11	76
2007	Fluid-Fluid Equilibria in the Crust	65	16	16	11	43
2007	Paleoaltimetry	66	6	17	12	35
		totals	509	483	184	1176

Cumulative Summary of DOE-supported short courses publications
number of volumes distributed as of 12/31/2007

Year	Volume	course	reviewers	libraries	sales	total
2001	42 Molecular Modeling	74	25	858	718	1675
2001	43 Stable Isotopes	79	35	858	1711	2683
2001	44 Nanoparticles	92	23	874	786	1775
2002	48 Phosphates	53	25	853	908	1839
2002	49 Synchrotron	71	19	853	632	1575
2003	52 U-Series	90	10	885	793	1778
2003	53 Zircon	60	14	888	1109	2071
2003	54 BioMineralization	101	24	888	1198	2211
2004	55 NonTradtional Isotopes	53	21	861	890	1825
2005	58 Thermochronology	82	27	777	590	1476
2005	59 Molecular GeoMicroBiology	137	29	777	384	1327
2006	62 Water in Nominally Anhydrous Minerals	120	19	698	390	1227
2006	63 Neutron Scattering in Earth Sciences	80	13	703	226	1022
2006	64 Medical Mineralogy and Geochemistry	80	21	703	274	1078
2007	65 Fluid-Fluid Equilibria in the Crust	48	29	648	188	913
2007	66 Paleoaltimetry	44	24	648	106	822
		1264	358	12772	10903	25297

Electronic versions of volumes 49, 52, 53, 54, 55, 56, 58, 59, 62, 63, 64, 65, 66 are posted on *GeoScienceWorld*. (GSW). As of September 2007, GSW had 242 subscribers of which only a fifth overlap the MSA institutional subscribers listed as “libraries” above.

Summary Report on
Fluid-Fluid Equilibria in the Crust
Short Course and RiMG Volume 65

The MSA/GS Short Course on "*Fluid-Fluid Equilibria in the Crust*" was held in Cologne, Germany, on August 16 & 17, 2007, prior to this years´ Goldschmidt Conference. 43 scientists coming from the industry and academic and government institutions from 13 countries attended the Short Course; approximately half of them were graduate students. The Short Course was organized and convened by Axel Liebscher (Technical University of Berlin, Germany) and Christoph Heinrich (ETH Zürich, Switzerland), who also edited the corresponding volume of the Reviews in Mineralogy and Geochemistry Series (Volume 65, entitled "Fluid-Fluid Interactions"), which was handed to each of the Short Course participants.

The Short Course greatly benefited from financial and logistic support by various groups. These supports helped to keep costs and registration fees low. DOE support was critical in keeping registration fees for graduate students low (only $ 55 for MSA/GS members and $95 for non-members) and was a likely reason for the high proportion of student attendance. The Institute of Geology and Mineralogy, University of Cologne, provided the lecture room and supplied most of the A/V equipment, thus minimizing facility and on-site equipment rental costs. Additional A/V equipment (laptop, pointer) and material (pencils, writing pads) were provided by the GeoForschungsZentrum Potsdam, Germany. Short Course presenters covered their own travel and lodging costs with individual support from their respective institutions. A joint dinner the evening between the two days at the Hellers Brewery was attended by most participants on a self-pay basis.

The motivation for this Short Course was to provide a series of lectures on the various aspects of fluid immiscibility in the different lithospheric environments. The main objectives were to i) present the fundamental phase relations and physicochemical and thermodynamic properties of fluid-fluid interactions, ii) make aware the important geochemical, petrologic, and economic role of fluid-fluid interactions in the diverse geologic environments, and, last but not least, iii) bring together people, knowledge and ideas from the different geological disciplines.

Fluids in general play a fundamental role in the geochemical and geophysical evolution of the Earth. Submarine hydrothermal systems link the chemistry of the oceans with that of the mantle and the oceanic crust. By convection they significantly contribute to the heat transfer from the mantle to the oceans. In volcanic systems magmatic fluids affect degassing and eruption style and transport volatile constituents like CO_2, sulfur and nitrogen species and halogens into the atmosphere. Fluid convection cells in volcanic systems that are fed by meteoric and/or oceanic water efficiently cool the systems and may result in economically important geothermal systems. Within the crust fluids may trigger partial melting, dehydration or alter and metasomatise pre-existing rocks. Around intrusions fluids are important constituents of contact metamorphism. Finally, hydrothermal fluids, which form in a variety of geologic environments, formed most of the Earth's ore deposits.

However, geofluids are usually not pure H_2O but contain significant quantities of dissolved components, salts like NaCl and KCl and volatile components like CO_2, CH_4 and different nitrogen and sulfur species are the most important ones. Depending on quality and quantity of the additional components, fluid immiscibility may prevail over large portions of crustal pressure and temperature conditions. Such fluid immiscibility or fluid phase separation is

a very efficient way to fractionate and concentrate certain elements. It is, e.g., responsible for most of the chemical variations found in submarine hydrothermal systems and a key process in the formation of magmatic-hydrothermal ore deposits. Knowledge of the properties of fluid immiscibility is therefore necessary for any geochemical and geophysical study on the role of fluids in the diverse geological settings. The topic of the Short Course was thus truly interdisciplinary, which was also reflected by the lectures that covered geochemical, petrologic, experimental, field-based, thermodynamic, and economic aspects of immiscible fluids in the diverse geologic environments as well as by the interdisciplinary list of participants.

The individual lectures were scheduled for 50 minutes, including 30 minutes for presentation, 15 minutes for discussion and 5 minutes additional buffer time for any unforeseen circumstances. During each morning and afternoon session 30 minutes were scheduled for coffee breaks with refreshments and cookies, which were served in front of the lecture room allowing for further discussion and conversation between the participants. Continued discussion and conversation between the participants was also supported by the joint lunch, which was included for both days in the registration fees and which was served in the nearby mensa (about 200 m walking distance) in a separate room. Overall, the schedule i) was flexible enough to account for any need for discussion, ii) ensured that all participants spent as much time together as possible, and iii) was well balanced between lectures and breaks.

After registration and a welcome, the Short Course started with a general introduction on the principles of fluid-fluid systems by Axel Liebscher. This lecture focused on water, water-salt, and water-salt-non polar gas systems and provided the participants with some fundamental aspects of coexisting fluids necessary for the understanding of the following, more specific lectures. The Thursday morning session was then completed by lectures on the principles and potentials (but also pitfalls) of fluid inclusions for studying fluid immiscibility by Bob Bodnar and on equations of state for complex fluids by Matthias Gottschalk. The latter nicely showed that the thermodynamic framework for complex fluids, especially electrolytes, is much less robust than for the rock forming minerals and even less than for melts. After the joint lunch, Bernd Krooß in his presentation on hydrocarbon systems demonstrated that the principles of phase relations and thermodynamic aspects of “aqueous” fluids, which were addressed in the morning session, equally well apply to hydrocarbon systems, thus highlighting the interdisciplinary nature of fluid-fluid equilibria. Any potentially emerging fatigue after almost 6 hours of fluid-fluid science was then abolished by a very spirited lecture by Alan B. Thompson on liquid immiscibility in anhydrous silicate melt systems, which was peppered with lots of British humor. After the coffee break, Alistair Hack added water to the anhydrous silicate melt systems and extended the topic addressed by Alan B. Thompson to hydrous silicate melt-high-pressure aqueous fluid systems. The afternoon session then ended with a fascinating lecture by Wilhelm Heinrich on fluid-fluid interactions in metamorphic systems. He demonstrated that even in these systems fluid immiscibility is a widespread, albeit mostly overlooked, and important phenomenon, contrary to the intuitive thinking of many petrologists. After these nine very interesting and informative hours, most participants were happy to study fluid phase separation *in-situ* in the local Kölsch-beer during the joint dinner in the relaxing surrounding of Hellers Brewery. Here scientific and non-scientific discussions continued and were partly extended till the early morning hours.

The Friday morning session was devoted to three specific geological environments in which fluid-phase separation plays a fundamental role: Dionysis Foustoukos not only presented a

review but also new, exciting data on fluid-fluid interaction in oceanic hydrothermal systems. Although fluid immiscibility is widely accepted as a prime geochemical process in these systems, Dionysis Foustoukos nicely showed that we are far from a complete understanding of its role and its impact on the geochemical and biological evolution of these systems. Andri Stefánsson then switched to geothermal systems and in his fascinating presentation made the participants aware of the economic aspects of fluid immiscibility in such complex fluid-rock systems. Fridays´ morning session ended with the talk by Jim Webster on volcanic systems. He demonstrated that the role of fluid immiscibility in these systems has not yet been adequately addressed in the different studies and that much will be learned about the physicochemical evolution of volcanic systems once fluid immiscibility is considered. After second days' joint lunch, Christoph Heinrich and Thomas Driesner presented a combined lecture on fluid-fluid interactions in magmatic-hydrothermal ore formation and the current state of numerical simulation of multiphase fluid flow in such magmatic-hydrothermal systems. This lecture excellently exemplified the potential of combining experimental data, fieldwork and numerical simulations in solving geological problems. Such an interdisciplinary combination of knowledge, results, and individual potentials from the different disciplines is probably the most promising approach for future studies on fluid mediated or fluid dominated systems. After the coffee break the Short Course ended with brief presentations by Dionysis Foustoukos, Andri Stefánsson and Thomas Driesner on various computer programs useful when working with fluid-fluid systems.

Overall, lively and stimulating presentations and discussions characterized this Short Course. The different lectures well demonstrated that fluid-fluid interactions in the diverse environments base on some fundamental processes, common to all the environments, but that each environment also has its own specific problems. It also turns out that our knowledge of fluids in general and fluid-fluid interactions in particular is much less than for solids and melts and that there are large gaps of knowledge. "Fluid-fluid" systems are therefore definitely promising topics of future research. Such research will surely provide new insights in the physicochemical evolution of geological systems.

Short-Course Program
Thursday, August 16, 2007

08.30 – 09.00	Registration	
09.00 – 09.10	Welcome	*A. Liebscher (TU Berlin, Germany)*
09.10 – 10.00	Introduction on Fluid-Fluid Systems	*A. Liebscher (TU Berlin, Germany)*
10.00 – 10.50	Fluid Inclusions Trapped in Immiscible Fluid Systems	*R. J. Bodnar (Virginia Tech, U.S.)*
10.50 – 11.20	Coffee Break	
11.20 – 12.10	Equations of State for Complex Fluids	*M. Gottschalk (GFZ Potsdam, Germany)*
12.10 – 13.40	Joint Lunch	
13.40 – 14.30	Fluids in Hydrocarbon Systems	*B. Krooss (RWTH Aachen, Germany)*
14.30 – 15.20	Liquid Immiscibility in Anhydrous Melt Systems	*A. B. Thompson (ETH Zürich, Switzerland)*
15.20 – 15.50	Coffee Break	
15.50 – 16.40	Phase Relations Involving Hydrous Silicate Melts, Aqueous Fluids, and Minerals	*A. C. Hack (ETH Zürich, Switzerland)*
16.40 – 17.30	Fluid Immiscibility in Metamorphic Rocks	*W. Heinrich (GFZ Potsdam, Germany)*
18.00 – ?	Joint Dinner	

Friday, August 17, 2007:

09.10 – 10.00	Fluid Phase Separation Processes in Submarine Hydrothermal Systems	*D. Foustoukos (Geophysical Lab, U.S.)*
10.00 – 10.50	Fluid-Fluid Interactions in Geothermal Systems	*A. Stefánsson (University Iceland, Iceland)*
10.50 – 11.20	Coffee Break	
11.20 – 12.10	Fluid Immiscibility in Volcanic Environments	*J. D. Webster (AMNH, U.S.)*
12.10 – 13.40	Joint Lunch	
13.40 – 14.30	Fluid-Fluid Interactions in Magmatic-Hydrothermal Ore Formation	*C. A. Heinrich (ETH Zürich, Switzerland)*
14.30 – 15.20	Numerical Simulation of Multiphase Fluid Flow in Hydrothermal Systems	*T. Driesner (ETH Zürich, Switzerland)*
15.20 – 15.50	Coffee Break	
15.50 – 16.50	Presentation of Computer Programs Applicable to Fluid-Fluid Research	
	SalTherm	*D. Foustoukos (Geophysical Lab, U.S.)*
	WATCH	*A. Stefánsson (University Iceland, Iceland)*
	Hydrotherm, SoWat	*T. Driesner (ETH Zürich, Switzerland)*

Summary Report on the
Paleoaltimetry: Geochemical and Thermodynamic Approaches
Short Course

A short course entitled "Paleoaltimetry: Geochemical and Thermodynamic Approaches" was held in Denver Colorado on October 26 and 27, 2007. Matthew J. Kohn of Boise State University organized the course. The short course, which preceded the 2007 Annual Meeting of the Geological Society of America in Denver, covered many of the most important and timely aspects of the methods by which paleoelevations are determined from the rock record, and interpreted in terms of geodynamic causes. The short course was sponsored primarily through financial support provided by the U.S. Department of Energy, Office of Basic Energy Sciences, Chemical Sciences, Geosciences and Biosciences Division (Nicholas B. Woodward, Geosciences Research Program Director), and by the Tectonics division of the National Science Foundation. The Mineralogical Society of America and the Geochemical Society provided logistical support for the organization of the short course and in the publication of the accompanying short course volume. Thirty-four people attended the course, of which almost 50% were students (16), and represented the United States, the Netherlands and Germany, including university and government representatives.

Elevation is a direct reflection of the internal force balance of an orogenic system, and consequently paleoelevation histories yield one of the best discriminators of competing orogenic models, particularly for the formation of plateaus. In addition, because elevation reflects the complex interplay between tectonic and climatic processes, changes to elevation have fundamental influences on changes to regional climate, flora and fauna, erosion, and structural and sedimentation styles. That is, elevation changes provide a means of understanding and linking together a wealth of geological phenomena spanning numerous traditional disciplines. The shortcourse was designed to review the principal chemical and thermodynamic means of inferring past elevations, with applications that included geodynamics, geomorphology, paleoclimatology, structural geology and tectonics. The shortcourse focused on 4 general areas: the geomorphologic and geodynamic rationale for studying paleoelevations, proxies for atmospheric properties, radiogenic and cosmogenic nuclides, and stable isotopes.

The introduction to the course considered geomorphology and geodynamics as a rationale for studying paleoelevations. Geomorphologic techniques have advanced rapidly in the last ~5 years, and relict erosion landscapes coupled with quantitative estimates of incision provide first-order estimates of the amount of surface uplift that have occurred in an area. These results, in turn, are used to test various geodynamic and tectonic models, especially the importance of lower crustal flow. The middle part of the course examined atmospheric thermodynamics and atmospheric pressure proxies as means for inferring elevation, mainly through records of leaf macro- and micro-morphologies, but also from bubble size distributions in vesicular basalts. The remaining ~50% of the course examined in detail the various isotopic techniques that are used for inferring paleoelevations. These included U-Th/He and fission track methods for inferring topographic relief and its evolution, the elevation-dependence of cosmogenic radionuclides, and numerous stable isotope proxies that mainly link either to the elevation-dependence of the $^{18}O/^{16}O$ and D/H ratios in precipitation. One exciting highlight of the course included fresh results on calibration of the clumped isotope technique in paleosols for inferring both

temperature and precipitation $^{18}O/^{16}O$ ratios. These results showed both the problems in blindly using laboratory calibrations of calcite fractionations, yet also excellent promise for refining paleoaltimetric estimates with this method.

The content of the course was geared toward students and professionals interested in paleoaltimetric methods, geodynamics, and tectonics, and provided a lively forum for discussions of geochemical and thermodynamic methods with diverse applications to different mountain belts and tectonic problems. The lecture room for the short course and the first-rate facilities of the Crowne Plaza Hotel (formerly Holiday Inn Denver City Central – one of the GSA preferred hotels) provided an excellent environment for the presentation of the formal course materials and for informal discussions during lecture breaks and meals. The lectures were presented on Friday and Saturday October 26 and 27.

Speakers/Authors and Topics

Matthew J. Kohn, Boise State University: Introduction and geodynamic rationale
Herb Meyer, National Park Service: Temperature lapse rates
Chris Forest, Massachusetts Institute of Technology: Atmospheric thermodynamics
Dork Sahagian, Lehigh University: Basalt vesicularity
Lenny Kouwenberg, University of Chicago Field Museum: Plant stomatal indices and P_{CO2}
Peter Reiners, University of Arizona: Low-temperature thermochronology
Catherine Riihimaki, Bryn Mawr: Cosmogenic radionuclides
David Rowley, University of Chicago: Stable isotopes in precipitation
Jay Quade, University of Arizona: Stable isotopes in paleosols
Andreas Mulch, University of Hannover: Stable isotopes in silicates
Matthew J. Kohn, Boise State University: Stable isotopes in fossils

Short Course Volume

As customary for Mineralogical Society of America and the Geochemical Society short courses, a Reviews in Mineralogy and Geochemistry volume (#66) was published and distributed at the course. The book *Paleoaltimetry: Geochemical and Thermodynamic Approaches*, edited by M. J. Kohn, includes chapters authored by the short course speakers with the technical content closely following the lecture materials presented at the short course. Jodi Rosso of the Mineralogical Society of America was instrumental in formatting the book and coordinating the publication effort. The book (ISBN 978-0-939950-78-2) has eleven chapters complete with references and 278 total pages.