



## **Fluid inclusions - Petrography and genetic interpretation of fluid inclusions. Application of Cathodoluminescence techniques**

Monday, August 27 until Friday, August 31, 2012

Departamento de Ciencias Geológicas. Facultad de Ciencias Exactas y Naturales. Universidad de Buenos Aires

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Fluid inclusions are small volumes of paleofluid trapped in minerals and the only direct evidence of the role of the fluid in geological processes. This short course gives an overview of fluid inclusions in different disciplines of earth sciences and related analytical techniques.

The textural relationship between fluid inclusions and the host rock is the subject of "fluid petrography", an essential part of any rock study and an important issue in this course. Cathodoluminescence techniques have shown to be helpful in the study of paleofluids and are also included here.

Attention is paid to the physico-chemical properties of the most important geological fluid systems, which are essential for interpreting fluid inclusion data sets. Microthermometry, the study of phase transitions in fluid inclusions at varying temperature under the microscope is fundamental for any fluid inclusion study. Therefore the principles of this technique and related computer programs are explained in more detail. Special attention is also paid to Laser-Raman microspectrometry, a technique which has proved to be highly powerful for fluid inclusion analysis.

Fluid inclusions provide indispensable information about geological processes, from high temperatures at depth towards low temperatures near the Earth's surface. Discussed are examples of magmatic fluids, hydrothermal ore deposits, metamorphism, and diagenesis.

The course is meant for any earth scientist, student or professional, who has not been in touch with fluid inclusions so far and wants to include this interesting and varied topic in her/his future research.

### **Program**

#### **Monday, August 27, 2012**

9:00-13:00 Introduction. Definitions, historical notes, literature, classification of fluid inclusions, daughter phases, mechanisms of fluid inclusion forming, Roedder's rules, primary and secondary inclusions, fracture healing, post-trapping modification of fluid inclusions, autoclave experiments

14:00-18:00 Training: microscopy exercises.

#### **Tuesday, August 28, 2012**

9:00-13:00 Working procedure (sample preparation, equipment), destructive and non-destructive fluid inclusion analysis, crushing stage, acoustic emission analysis, Laser ablation ICPMS, principles of microthermometry, isochore definition, computer programs, Raman analysis



SORBY HC (1858) On the microscopic structure of crystals, indicating the origin of minerals and rocks. *Geol. Soc. London Quart. J.*, 14, pt. I, 453-500.



### Regular issues

FLUID INCLUSION RESEARCH - Proceedings of COFFI (1968-1998) Roedder E & Kozlowski A (eds.) Ann Arbor. The University of Michigan Press.  
ECROFI Abstracts (biannual from 1970). Abstract volumes. Selections of contributions published in special issues of *Eur. J. Mineral.*  
PACROFI Abstracts (biannual from 1984). Abstract volumes (some published in special issues of *Geochim. Cosmochim. Acta*).

### Literature selection "geofluids"

BODNAR RJ (1983) A method of calculating fluid-inclusion volumes based on vapor bubble diameters and P-V-T-X properties of inclusion fluids. *Econ. Geol.* 76, 535-542.  
DUBESSY J, POTY B., RAMBOZ C (1989) Advances in C-O-H-N-S fluid geochemistry based on micro-Raman spectrometric analysis of fluid inclusions. *Eur. J. Mineral.* 1, 517-534.  
HALL DL, BODNAR RJ (1990) Methane in fluid inclusions from granulites: A product of hydrogen diffusion? *Geochim. Cosmochim. Acta* 54, 641-651.  
HUIZENGA JM (1995) Fluid evolution in shear zones from the late Archean Harare-Shamva-Bindura Greenstone Belt (NE Zimbabwe). Thermodynamic calculations of the CO-H system applied to fluid inclusions. Ph.D. Dissertation. Free University -Amsterdam. 55  
KONNERUP-MADSEN J (1979) Fluid inclusions in quartz from deep-seated granitic intrusions. *Lithos* 12, 13-23.  
KREULEN R (1987) Thermodynamic calculations of the C-O-H system applied to fluid inclusions: are fluid inclusions unbiased samples of ancient fluids? *Chem. Geol.* 61, 59-64.  
LAMB WM, VALLEY JW, BROWN PE (1987) Post-metamorphic CO<sub>2</sub>-rich fluid inclusions in granulites. *Contr. Mineral. Petrol.* 96, 485-495.  
NEWTON RC (1989) Metamorphic fluids in the deep crust, *Ann. Rev. Earth Planet. Sci.* 17, 385-412.  
ROEDDER E (1979) Fluid inclusions as samples of ore fluids. In: HL Barnes (ed.) *Geochemistry of hydrothermal ore deposits*. 2nd ed. 684-737. Wiley- New York  
ROEDDER E (1990) Fluid inclusion analysis - Prologue and epilogue. *Geochim. Cosmochim. Acta* 54, 495-507.  
SWANENBERG HEC (1980) Phase equilibria in carbonic systems and their application to freezing studies of fluid inclusions. *Contr. Mineral. Petrol.* 88, 3303-3306.  
TOURET JLR (1977) The significance of fluid inclusions in metamorphic rocks. In: Fraser (ed.), *Thermodynamics in Geology*, 203-227, D. Reidel - Dordrecht.  
TOURET JLR (1987) Fluid inclusions and pressure-temperature estimates in deep-seated rocks. In: Helgeson (ed.) *Chemical transport in metasomatic processes*. NATO ASI Series C: Mathematical and Physical Sciences. Vol. 218, 91-121.  
TOURET JLR (1992) CO<sub>2</sub> transfer between the upper mantle and the atmosphere: temporary storage in the lower continental crust *Terra Nova* 4, 87-98.  
VAN DEN KERKHOFF AM, HEIN UF (2001) Fluid inclusion petrography. In: ANDERSEN T, FREZZOTTI ML, BURKE EAJ ed. *Fluid inclusions: phase relationships - methods - applications* (special issue). *Lithos* 55 (1-4), 320 pp.  
VITYK MO, BODNAR RJ (1995) Do fluid inclusions in high grade metamorphic terranes preserve peak metamorphic density during retrograde decompression? *American Mineralogist*.

### Fluid systems

BISCHOFF JL, PITZER KS (1989) Liquid vapor relations for the system NaCl-H<sub>2</sub>O; summary of the P-T-X surface from 300 to 500°C. *Am. J. Sci.* 289, 217-248.



14:00-18:00 Fluid inclusion petrography, fluid-rock interaction, fluid-induced textures. Water-salt (ionic) systems with KCl, NaCl, and CaCl<sub>2</sub> in different geological environments.

Training: Microthermometry, crushing stage, software (isochore calculation), videos.



### **Wednesday, August 29, 2012**

9:00-13:00 Water-gas systems. Clathrate hydrate stability, fluid-mineral equilibria and graphite stability, oxygen fugacity in rocks, COHN equilibria calculations, non-aqueous systems CO<sub>2</sub>-CH<sub>4</sub> and CO<sub>2</sub>-N<sub>2</sub>, working with VX diagrams

14:00-18:00 Training: Microthermometry, software (COHN), videos.

### **Thursday, August 30, 2012**

9:00-13:00 Basic principles of cathodoluminescence microscopy and application to fluid petrology. Equipment. "Cold" and "hot" cathodoluminescence. Crystalline materials. Activators, sensitizers, quenchers. Wavelength, energy.

14:00-18:00 Microstructures as a result of fluid-rock interaction: fluid pathways, paleoporosity, diffusional textures, healed microfractures. Examples.

### **Friday, August 31, 2012**

9:00-13:00 Fluid inclusions in the granitic-pegmatitic system, fluid inclusions in ore deposits, fluid inclusions in metamorphic rocks (examples).

14:00-18:00 Free exercises, presentations of participants and discussion. Examination.

## **Literature selection**

### **Textbooks**

- ANDERSEN T, FREZZOTTI ML, BURKE EAJ eds. (2001) Fluid inclusions: phase relationships - methods- applications (special issue). Lithos 55 (1-4), 320 pp.
- SHMULOVICH KI, YARDLEY B, GONCHAR GG (1995) Fluids in the crust. Equilibrium and transport properties. Chapman & Hall, 323 pp.
- De VIVO B, FREZZOTTI ML (1994) Fluid inclusions in minerals: methods and applications. Short course of the working group (IMA) "Inclusions in Minerals" (Siena) Fluids Research Laboratory, Department of Geological Sciences, YPI, Blacksburg
- GOLDSTEIN RH, REYNOLDS TJ (1994) Systematics of fluid inclusions in diagenetic minerals. SEPM Short Course 31. Society for Sedimentary Geology. SEPM, Tulsa, Oklahoma
- PARNELL J ed. (1994) Geofluids: Origin, Migration and Evolution of Fluids in Sedimentary Basins. Geol. Soc. Spec. Publ. 78, 372 pp.
- WALTHER JV, WOOD BJ eds. (1986) Fluid-rock interactions during metamorphism. Advances in physical chemistry 5, Springer-New York
- LEEDER O, THOMAS R, KLEMM W (1987) Einschlüsse in Mineralien. VEB Deutscher Verlag für Grundstoffindustrie, Leipzig., 180 pp.
- SHEPHERD TJ, RANKIN AH, ALDERTON DHM (1985) A practical guide to fluid inclusion studies 239 pp. Blackie-Glasgow.
- ROEDDER E (1984) Fluid inclusions. Reviews in Mineralogy, Vol. 12, 644 pp. Mineralogical Society of America, Washington.
- HOLLISTER LS, CRAWFORD ML eds. (1981) Short course in fluid inclusions: application to petrology. 304 p. (Calgary, Mineralogical Association of Canada)
- SAMSON I, ANDERSON A, MARSHALL D eds. (2003) Fluid inclusions - Analysis and Interpretation. Short Course Series Vol. 32, Mineralogical Association of Canada. 374 pp.





- BODNAR RJ, BURNHAM CW, STERNER SM (1985) Synthetic fluid inclusions in natural quartz. - III. Determination of phase equilibrium properties in the system  $H_2O-NaCl$  to  $1000^\circ C$  and 1500 bars. *Geochim. Cosmochim. Acta* 49, 1861-1873.
- BURRUSS RC (1981) Analysis of fluid inclusions: Phase equilibria at constant volume. *Amer. J. Sci.* 281, 1104-1126.
- CHOU I.-M., STERNER SM, PITZER KS (1992) Phase relations in the system  $NaCl-KCl-H_2O$ . IV. Differential thermal analysis of the sylvite liquidus in the  $KCl-H_2O$  binary, the liquidus in the  $NaCl-KCl-H_2O$  ternary, and the solidus in the  $NaCl-KCl$  binary to 2 kb pressure, and a summary of experimental data for the thermodynamic PTX analysis of solid-liquid equilibria at elevated PT conditions. *Geochim. Cosmochim. Acta* 56, 2281-2293.
- DIAMOND LW (1994) Salinity of multivolatile fluid inclusions determined from clathrate hydrate stability. *Geochim. Cosmochim. Acta* 58, 19-41.
- FALL A, TATTITCH B, BODNAR R (2011) Combined microthermometric and Raman spectroscopic technique to determine the salinity of  $H_2O-CO_2-NaCl$  fluid inclusions based on clathrate melting *Geochim. Cosmochim. Acta* 75, 951-964.
- FISHER JR (1976) The volumetric properties of  $H_2O$  - a graphical portrayal. *Jour. Research U.S. Geol. Survey* 4 (2), 189-193.
- HALL DL, STERNER SM, BODNAR RJ (1988) Freezing point depression of  $NaCl-KCl-H_2O$  solutions. *Econ. Geol.* 83, 197-202.
- HANOR JS (1980) Dissolved methane in sedimentary brines: potential effect on the PVT properties of fluid inclusions. *Econ. Geol.* 75, 603-617.
- JOYCE DB, HOLLOWAY JR (1993) An experimental determination of the thermodynamic properties of  $H_2O-CO_2-NaCl$  fluids at high pressures and temperatures. *Geochim. Cosmochim. Acta* 57, 733-746.
- ROSSO KM, BODNAR RJ (1994) Detection limits of  $CO_2$  in fluid inclusions using microthermometry and Laser Raman Spectroscopy and the spectroscopic characterization of  $CO_2$ . *Geochim. Cosmochim. Acta*.
- SEITZ JC, PASTERIS JD (1990) Theoretical and practical aspects of differential partitioning of gases by clathrate hydrates in fluid inclusions. *Geochim. Cosmochim. Acta* 54, 631-639.
- STERNER SM, HALL DL, BODNAR RJ (1988) Synthetic fluid inclusions. V. Solubility relations in the system  $NaCl-KCl-H_2O$  under vapor-saturated conditions. *Geochim. Cosmochim. Acta* 52, 989-1005.
- STERNER SM, CHOU I-M, DOWNS RT, PITZER KS (1992) Phase relations in the system  $NaCl-KCl-H_2O$ . V. Thermodynamic -PTX analysis of solid-liquid equilibria at high temperatures and pressures. *Geochim. Cosmochim. Acta* 56, 2295-2309.
- TAKENOUCHI S, KENNEDY GC (1965) The solubility of carbon dioxide in  $NaCl$  solutions at high temperatures and pressures. *Amer. J. Sci.* 263, 445-454.
- THIÉRY R, VAN DEN KERKHOFF AM, DUSESSV J (1994) vX properties of  $CH_4-CO_2$  and  $CO_2-N_2$  fluid inclusions: modelling for  $T < 31^\circ C$  and  $P < 400$  bars. *Eur. J. Mineral.* 6, 753-771.
- VAN DEN KERKHOFF AM (1988)  $CO_2-CH_4-N_2$  in fluid inclusions: theoretical modelling and geological applications. Ph.D. Diss. Free Univ., Amsterdam, 206 pp.
- VAN DEN KERKHOFF AM (1990) Isochoric phase diagrams in the systems  $CO_2-CH_4$  and  $CO_2-N_2$ : application to fluid inclusions. *Geochim. Cosmochim. Acta* 54, 621-629.
- VAN DEN KERKHOFF AM, OLSEN SN (1990) A natural example of superdense  $CO_2$  inclusions: Microthermometry and Raman analysis. *Geochim. Cosmochim. Acta* 54, 885-901.
- KISCH HJ, VAN DEN KERKHOFF AM (1991)  $CH_4$ -rich inclusions from quartz veins in the Valley-and Ridge province and anthracite fields of the Pennsylvania Appalachians. *American Mineral.* 76, 230-240.
- WALTHER J. (1981) *Fluide Einschlüsse im Apatit des Carbonatits vom Kaiserstuhl (Oberrheingraben) Ein Beitrag zur Interpretation der Carbonatitgenese.* Doctoral Thesis University of Karlsruhe, 195 pp.
- ZHANG YG, SCHWARTZ JD (1989) Experimental determination of the compositional limits of immiscibility in the system  $CaCl_2-H_2O-CO_2$  at high temperatures and pressures using synthetic fluid inclusions. *Chem. Geol.* 74, 269-308.





Universidad de Buenos Aires  
Facultad de Ciencias Exactas y Naturales

Referencia Expte. N° 501.207/2012

Buenos Aires, 6 AGO 2012

**VISTO:**

la nota 21/06/2012 del Dr. Pablo R. Leal, Director Adjunto del Departamento de Ciencias Geológicas, mediante la cual eleva información sobre el curso posgrado **Fluid inclusions- Petrography and genetic interpretation of fluid inclusions. Application of cathodoluminescence techniques**, que será dictado en el Segundo Cuatrimestre de 2012 (27 al 31 de agosto 2012) por el Dr. Alfonsus Martinus Van den Kerkhof y la Dra. Graciela Miriam Sosa (Geoscience Center, University of Göttingen, Germany)

la nota de la Dra. Teresita Montenegro obrante a fs 18 del expediente de la referencia,  
Los CV de Alfonsus Martinus Van den Kerkhof y Graciela Miriam Sosa

**CONSIDERANDO:**

Lo actuado por la Comisión de Doctorado el día 10/07/2012,  
lo actuado por la Comisión de Enseñanza, Programas, Planes de Estudio y Posgrado,  
lo actuado por la Comisión de Presupuesto y Administración,  
lo actuado por este cuerpo en Sesión Ordinaria realizada en el día de la fecha,  
en uso de las atribuciones que le confiere el Artículo N° 113° del Estatuto Universitario,

**EL CONSEJO DIRECTIVO DE LA FACULTAD DE  
CIENCIAS EXACTAS Y NATURALES  
RESUELVE:**

**Artículo 1°:** Autorizar el dictado del curso de posgrado: **Fluid inclusions- Petrography and genetic interpretation of fluid inclusions. Application of cathodoluminescence techniques**, de 40 hs. de duración.

**Artículo 2°:** Aprobar el programa del curso de postgrado **Fluid inclusions- Petrography and genetic interpretation of fluid inclusions. Application of cathodoluminescence techniques** obrante de fs 6 a 10 del expediente de la referencia.

**Artículo 3°:** Aprobar un puntaje máximo de un (1) punto para la Carrera de Doctorado.

**Artículo 4°:** Aprobar los siguientes aranceles: 100 módulos para docentes de dedicación simple de la UBA; 250 módulos para doctorandos de otras Universidades Publicas Nacionales, 400 módulos para Profesionales de Organismos de Ciencia y Tecnología y 1000 módulos para profesionales de empresas privadas y disponer que los montos recaudados sean utilizados conforme a lo dispuesto en la resolución CD N° 072/03.

**Artículo 5°:** Comuníquese a la Dirección del Departamento de Ciencias Geológicas, a la Biblioteca de la FCEN y a la Subsecretaría de Postgrado (con fotocopia del programa incluida fs 6 a 10). Comuníquese a la Dirección de Alumnos (sin fotocopia del programa) Cumplido, archívese.

Resolución D N°

-- 1801.

SPI med / 13/07/2012

Dra. MARIA ISABEL GASSMANN  
SECRETARÍA DE CIENCIAS ADJUNTA

Dr. JORGE ALIAGA  
DECANO





ZWART EW, TOURER JLR (1994) Melting behaviour and composition of aqueous fluid inclusions in fluorite and calcite: applications within the system  $H_2O-CaCl_2-NaCl$ . Eur. J. Mineral. 6, 773-786.

### Equations of state /technical

- BAKKER RJ (2001) FLUIDS: new software package to handle microthermometric data to calculate isochores (available from the author)
- BAKKER RJ (1997) Clathrates: computer programs to calculate fluid inclusion V-X properties using clathrate melting temperatures. Computer & Geosciences 23,1-18.
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- BROWN PE (1989) FLINCOR: A fluid inclusion data reduction and exploration program (abstr.). 2nd Biennial Pan-American Conf. on Research on Fluid Inclusions Abstr., 14.
- BROWN PE, LAMB WM (1989) P-V-T properties of fluids in the system  $H_2O+CO_2+NaCl$ : New graphical presentations and implications for fluid inclusion studies. Geochim. Cosmochim. Acta. 53, 1209-1221.
- HOLLOWAY JR (1977) Fugacity and activity of molecular species in supercritical fluids. In: DG Frazer (ed.) Thermodynamics in Geology, D. Reidel - Dordrecht, 161-181.
- MACDONALD AJ, SPOONER ETC (1981) Calibrations of a LINKAM TH600 programmable heating-cooling stage for microthermometric examination of fluid inclusions. Econ. Geol. 76, 1248-1258.
- SHEPHERD TJ (1981) Temperature-programmable heating-freezing stage for microthermometric analysis of fluid inclusions. Econ. Geol. 76, 1244-1247.
- ZHANG YG, FRANTZ JD (1987) Determination of homogenization temperatures and densities of supercritical fluids in the system  $NaCl-KCl-CaCl_2-H_2O$  using synthetic fluid inclusions. Chem. Geol. 64, 335-350.

### Fluid inclusion experiments

- BAKKER RJ, JANSEN JB (1990) Preferential water leakage from fluid inclusions by means of mobile dislocations. Nature 345, No.6270, 58-60.
- BODNAR RJ, STERNER SM (1985) Synthetic fluid inclusions in natural quartz. - II. Application to PVT studies. Geochim. Cosmochim. Acta 49, 1855-1859.
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- CORDIER P, DOUKHAN JC, RAMBOZ C (1994) Influence of dislocations on water leakage from fluid inclusions in quartz: a quantitative reappraisal. Eur. J. Mineral. 6, 746-752.
- STERNER SM, BODNAR RJ (1989) Synthetic fluid inclusions - VII. Re-equilibration of fluid inclusions in quartz during laboratory-simulated metamorphic burial and uplift. J. metam. Geol. 7 (2), 243-260.
- WATSON EB, BRENNAN JM (1987) Fluids in the lithosphere, 1. Experimentally-determined wetting characteristics of  $CO_2-H_2O$  fluids and their implications for fluid transport, hostrock physical properties, and fluid inclusion formation. Earth Planet. Sci Letters 85, 497-515.