Europlanet TA Scientific Report

PROJECT LEADER

Project number: 20-EPN-034
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Home Institution: KU Leuven, Belgium
TA Facility visited: Ion probe facility (IPF), CRPG, Nancy, France

Project Title: Calibration of the Al-in-olivine thermometer: Insight into the thermal history of type II chondrules

Scientific Report Summary.
(plain text, no figures, maximum 250 words, to be included in database and published)

Chondrites are the most primitive agglomerates formed in the solar system. In this project, we want to develop a thermometer based on Al-in-olivine/spinel equilibrium to calculate the temperature of formation of chondrites. or this project, we have performed a large number of new low- to high-pressure (1 atm – 10 GPa) experiments relevant to chondrule formation at the KU Leuven. Experiments were run at high temperature (1200-1800°C), under variable oxygen fugacity conditions (IW+1 to IW+5, IW = iron-wustite) From October 18th to 22nd 2021, Thomas van Gerve and Kat Shepherd (KU Leuven) worked with the Cameca IMS 1270 E7 ion probe at CRPG, Nancy, under the supervision of Dr. Johan Villeneuve and M. Nordine Bouden. We have measured the following masses ^{12}C, $^{16}O^{1}H$, ^{18}O, 19F, ^{27}Al, ^{30}Si, ^{32}S and ^{35}Cl in olivine, glass and glass inclusions. During our analytical session, we measured ~ 150 points in olivine and glass in addition to the standards. Results are extremely reproducible and show a trend of slightly increasing Al content in olivine as a function of the Fo content (molar Mg/(Mg+Fe)) of olivine. Using our new SIMS results, we are in the process of developing a thermodynamically rooted model taking into account major components in spinel and olivine. This should provide much robust temperature estimates for chondrites.

Full Scientific Report on the outcome of your TNA visit

Chondrites are the most primitive agglomerates formed in the solar system. One of the most fundamental aspects of chondrites is the presence of ferromagnesian silicate spherules of igneous origin, the chondrules. Chondrules are dominated by olivine, pyroxene, and melt and can be categorized as magnesian type I and ferroan type II based on the FeO content of olivine and pyroxene. Al partitioning between olivine and spinel is well suited to estimate the temperature of crystallization of type II chondrules because these two phases are important components of type II chondrules (Fig. 1). It is particularly useful for chondrules and other planetary bodies because Al diffuses slowly and is therefore not prone to significant re-equilibration during low- to medium temperature metamorphism. The partitioning (Kd) $Al_2O_{3\ olivine}/Al_2O_{3\ spinel}$ was experimentally shown to be strongly dependent on temperature and spinel major element composition [Cr# = Cr/(Cr+Al)]. However, the currently available Al-in-olivine thermometer was regressed on a limited number of experiments performed under a very narrow range of conditions and compositions (~ 30 dry experiments at 1 atm, 1250-1450°C, QFM-1.5 [QFM= quartz-fayalite-magnetite]). Although this thermometer may be relatively accurate for some terrestrial rocks (±20-40°C), it cannot be readily applied to ferroan type II chondrules which formed under drastically different conditions (i.e. potentially much higher temperature; more reducing conditions).

For this project, we have performed a large number of new low- to high-pressure (1 atm – 10 GPa) experiments relevant to chondrule formation at the KU Leuven. Experiments were run at high temperature (1200-1800°C), under variable oxygen fugacity conditions (IW+1 to IW+5, IW = iron-wustite). The objectives of the project are: (1) accurately measure the experimental products for major (done during summer 2020) and trace elements (Europlanet proposal; measurement done in October 2021); (2) develop a new parametrization for the Al-in olivine thermometer.

From October 18th to 22nd 2021, Thomas van Gerve and Kat Shepherd (KU Leuven) worked with the Cameca IMS 1270 E7 ion probe at CRPG, Nancy, under the supervision of Dr. Johan Villeneuve and M. Nordine Bouden. We have measured the following masses ^{12}C, $^{16}O^1H$, ^{18}O, 19F, ^{27}Al, ^{30}Si, ^{32}S and ^{35}Cl in olivine, glass and glass inclusions. $^{12}C/^{18}O$ and $^{16}O^1H/^{18}O$ ratios were used to estimate concentrations in CO_2 and H_2O respectively. Each mass was during 10 cycles for 5 seconds on each element. Data were usually homogeneous over the 10 cycles and reproducible. Relatively low standard deviations were obtained for most samples. Calibration curves were based on several standards (VG2, SCol, N72, KL2-G, T1G, M35, M40, M43, M48, TAN25, KE12, 47963) that were measured every morning.

During our analytical session, we measured ~ 150 points in olivine and glass in addition to the standards. Results are extremely reproducible and show a trend of slightly increasing Al content in olivine as a function of the Fo content (molar Mg/(Mg+Fe)) of olivine [Fig. 2]. Data in the melt phase still must be processed. Prior to the SIMS analytical session, major element compositions of spinel were also obtained and show a range comparable to those observed in chondrites. The correlation we observe between Fo and Al is a good sign that our experimental olivine crystals are fully equilibrated, also for slow-diffusing minor elements such as Al, and that our SIMS results can be used to derive a new Al-in-olivine/spinel thermometer adequate for chondrite samples. Our first attempts of multiple linear regressions however show that the simple, empirical, formalism previously used for the Al-in-olivine/spinel thermometer is too simple to capture the full complexity particularly for the spinel compositions (Fig. 3). Using our new SIMS results, we are therefore in the process of developing a thermodynamically rooted model taking into account major components in spinel and olivine. This should provide much robust temperature estimates for chondrites.

The final steps of the project will be: (i) Calibrate an Al-in-olivine thermometer applicable to type II chondrules; (ii) Apply the thermometer to type II chondrules to (1) constrain their thermal histories and (2) refine our understanding of their mechanisms of formation.

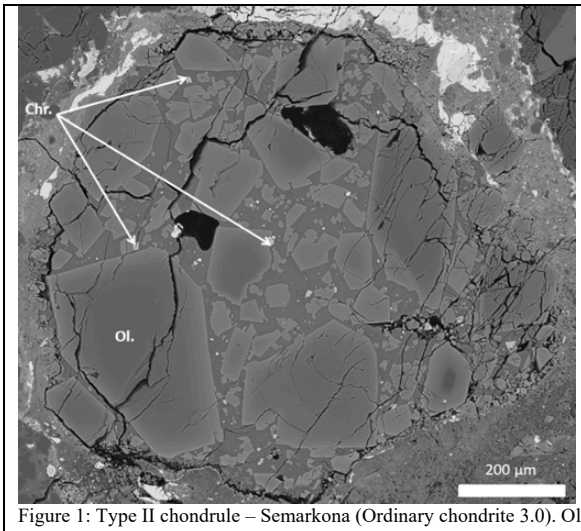

Figure 1: Type II chondrule – Semarkona (Ordinary chondrite 3.0). Ol = olivine; Chr = spinel phase.

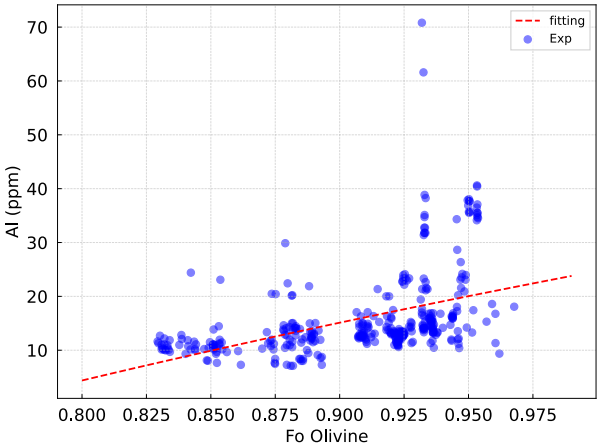

Figure 2: Al in olivine (ppm) vs Fo content [molar Mg/(Mg + Fe)]

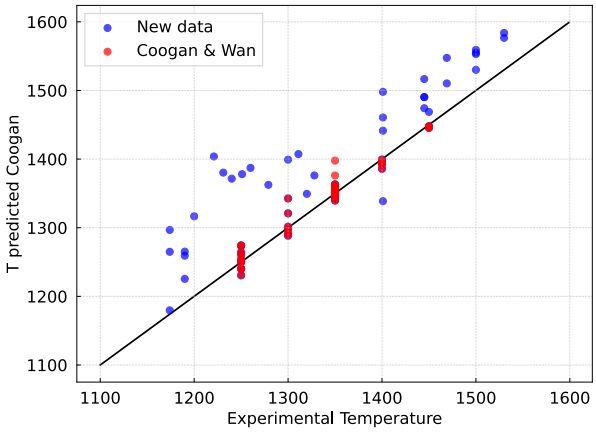

Figure 3: Experimental vs predicted temperature using the published formalism of Al-in-olivine/spinel thermometer

- Give details of any publications arising/planned (include conference abstracts etc)

- Host confirmation

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Dates for travel to accommodation for TA visit (if physical visit by applicant)	Start Date of TA project at facility	Number of lab/field days spent on TA Visit pre-analytical preparation	Number of days in lab/field site for TA Visit	Number of days spent in lab for TA Visit data analysis	End Date of TA project at facility	Dates for travel home (if physical visit by applicant)
Departed: 17/10/21 Arrived: 17/10/21	18/10/21	0	0	5	22/10/21	Departed: 23/10/21 Arrived: 23/10/21

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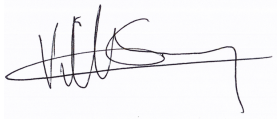
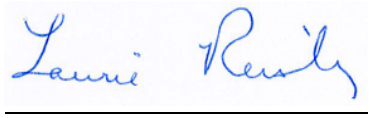
Host Signature	**Johan Villeneuve, lab manager of IPF CRPG platform**  **Laurie Reisberg, CRPG Europlanet coordinator** 
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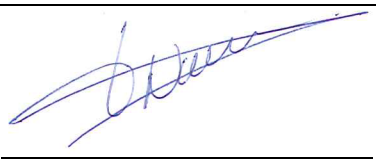
Project Leader Name	Olivier Namur

Project Leader Signature	
Date	**27/10/2021**