Klára Kalousová: Dynamics of icy satellites with a liquid phase

Report of the supervisor

My cooperation with Klára Kalousová started already during her undergraduate studies when I was the supervisor of her bachelor and master thesis. At that time she dealt with the deformation of planetary lithospheres and later published her results in Geophysical Journal International. Klára was an excellent student and I was not surprised when she applied for admission to the PhD program in geophysics. She chose a difficult topic of two phase flow in icy moons and decided to pursue her studies in the "en cotutelle" regime. She started in Prague in 2010 and, one year later, she was also enrolled in the PhD program at the University of Nantes, with Gaël Choblet being her French supervisor. Klára spent in France 18 months and this stay was very beneficial for her – she was introduced into the international planetology community and had the opportunity to discuss her work with other icy moon specialists. Last but not least, she learnt the French language and acquainted herself with the French culture and society.

Besides her two supervisors, Klára also intensively cooperated with Gabriel Tobie in Nantes and Ondřej Souček in Prague, who both became the co-authors of her main paper published in Journal of Geophysical Research. Gabriel Tobie significantly helped Klára to define the conceptual framework of her thesis while Ondřej Souček provided her with a deeper insight into the mathematical theory of two-phase flow. Although she was helped by many people during the four years of her studies, Klára worked very independently and she is the main author of all the results presented in the thesis.

In her work, Klára used the two-phase flow formalism developed by Ricard, Bercovici and Šrámek and she applied it for the first time to study the water transport in icy moons. Although her papers on this topic address the problem in a simplified one-dimensional geometry, they are an important step towards a qualitative description of the melt-water migration in Jupiter's moon Europa, with possible generalization to other icy satellites. Besides the two-phase flow, she attempted to investigate also other physical aspects of water transport, such as elastic hydro-fracturing, role of anti-freezers and advection of molten water by convection currents.

Klára Kalousová has clearly proved that she is able to independently solve complex scientific problems and present her results in the form of a concise written text. I recommend her work to be accepted as the Ph.D. thesis.

December 15, 2014 *doc. RNDr. Ondřej Čadek, CSc.*

UNIVERSITÉ DE NANTES

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Gaël Choblet
Laboratoire de Planétologie et Géodynamique
2, rue de la Houssinière
44322 Nantes

Report of the supervisor for the PhD of Klára Kalousová

For the last four years, I have been the (french) advisor of Klára Kalousová's PhD in an *en co-tutelle* treatise involving the Department of Geophysics in Charles University in Prague and the Laboratory of Planetology and Geodynamics in the University of Nantes. An important aspect of Klára's work is that it involved collaboration not only with the two supervisors (Ondřej Čadek in Prague, myself in Nantes) but also with two other colleagues: Gabriel Tobie in Nantes (whose ERC starting grant EXOWATER specifically addresses questions involved in Klára's PhD - this grant also provided funds for Klára's stay in France) and Ondřej Souček in Prague (whose involvement was very strong regarding specific aspects of the PhD, namely the physics of two-phase flow and its numerical treatment). While exchanges between Klára and her advisors in the two labs have been continuous during this period of time, she spent approximately one year and a half in France where we mostly focused on the planetary applications of her work which corresponds to a specific expertise of our group.

The timeline of the PhD can be summarized along three stages:
• first, understanding the theoretical framework of two phase flow in a partially molten ice layer, and providing a numerical treatment in 1D - I emphasize here that such a treatment is not trivial. The specific tools developed by Klára involve one dedicated to the "zero compaction length" approximation where the coupling between ice matrix deformation and the flow of water is neglected, one where it is not neglected, as distinct phenomena and thus specific numerical methods need to be introduced. This effort led to the publication of a first article in *Geophysical and Astrophysical Fluid Dynamics*.
• second, application of these concepts and tools to the case of Europa, one of Jupiter's large moons ranking among the first objects of planetary sciences owing to its geological activity and its potential to harbor conditions favorable for the development of a complex chemistry. Klára considered the few geodynamical contexts that could lead to partial melting of Europa's icy crust and concluded after having described the fate of liquid water that only a very limited range of geological settings would allow to retain significant fractions of water close to the surface for periods longer than several tens of thousand years. These results are described in a second article published in *Journal of Geophysical Research: Planets*.
• finally, after having returned to Prague, Klára built yet another numerical tool that extends the method to 2D geometry thus allowing the treatment of the dynamics of the ice matrix. The results obtained with this tool, described in the PhD manuscript, should lead to another publication in the next months. Klára also envisioned other mechanisms than porous flow for water transport and provided guidelines to study these in the future.

From our point of view in Nantes, Klára's contribution was both rigorous and efficient. Klára became familiar with a wealth of studies dedicated to Europa in a relatively short period of time. Both Gabriel and I were extremely satisfied with her personal approach to scientific work: she demonstrated initially her specific ability to integrate the various conceptual clues related to the topic but soon also proved very active in the identification of potential obstacles or limitations of the approach we proposed. Over the course of her stay in Nantes, her personal implication in designing new paths to solve the problems testifies to Klára's scientific maturity. In addition, I wish to stress her skills at writing documents accounting for her work. This aspect was obvious when reading both first drafts of publications or chapters of her PhD manuscript: these proved extremely polished texts that in my personal experience often required several goings and comings between students and their advisors. The same is true about oral presentations which Klára offered to the community, some in French here in Nantes, a language she started learning at the beginning of her stay.

I shall conclude by emphasizing that Klára's PhD work already includes matter that should prove substantial when applied to icy bodies in the context of future scientific work. This probably explains the successful answers Klára received to her applications to postdoc positions in leading research groups in planetary science.

For all these reasons, I recommend that the work of Klára Kalousová be accepted as the PhD thesis.

Gaël Choblet