DEPARTMENT OF GEOLOGICAL SCIENCES
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Review of the habilitation thesis "Mathematical modelling of thermomechanical processes in terrestrial and planetary icy bodies" submitted by Dr. Ondřej Souček

Dear habilitation committee

It has been my pleasure to review the habilitation of Dr. Ondřej Souček at the Faculty of Mathematics and Physics at Charles University. I do not know Dr. Souček personally, but I have been following his work since 2017, when I began working on icy ocean worlds. Since then, I have followed his and his students work closely. Before receiving the request to review this habilitation I have been familiar with his work on tidal heating of Enceladus (manuscripts P3 to P7 in the habilitation) and his work on brine drainage in Europa's ice shell (manuscripts P8 to P10 in the habilitation). I have always greatly valued Dr. Souček's contributions, and they have influenced my own work in related areas.

The habilitation of Dr. Souček is very well written and provides an accessible overview and summary of the manuscripts submitted for his habilitation. The habilitation highlights the connection between the different areas of Dr. Souček's work and has further increased my appreciation of his contributions. He has chosen three challenging topics connected to the deformation of ice masses:

1. Dynamics of large terrestrial and planetary ice sheets.
2. Tidal deformation and energy dissipation of planetary ice shells.
3. Partial melting and brine migration in planetary ice shells.

Each of these subjects is highly complex, both in terms of the physical models employed and the numerical challenges that must be overcome to solve them. As such a contribution to only one of these areas would be sufficient for a habilitation and many researchers restrict themselves to just one of these areas. The fact that Dr. Souček has made substantial contributions to all three of them is very impressive.

I am most familiar with the topic of multi-phase flow that arises the third topic. Like most multiphase flows, our mathematical models for melt migration are imperfect, under constant development and often lead to numerical problems. I consider this to be one of the most challenging topics in the broad field of geodynamics as well and ice sheet modeling and only a few groups have developed successful numerical models. In manuscript P8 Dr. Souček presents a detailed scaling analysis of the relevant two-phase flow equations and develops an innovative numerical approach to solving them.

While others have speculated about the role of brine migration in the ice shell Jupiter's moon Europa, Dr. Souček and his collaborators were the first to develop a rigorous multi-phase flow model. The development of such model allows them to investigate questions about the generation and persistence of brines within the ice shell. This work is timely, because it generates hypotheses about the location of brines within the ice that can be tested by the upcoming JUCE (ESA) and Europa Clipper (NASA) missions. Dr. Souček is clearly a leader in this rapidly evolving field.

Tidal deformation is of central importance to the field of icy ocean worlds because tidal heating provides the energy source that maintains these internal oceans. The analysis of tidal deformation and the associated energy dissipation is a complex subject that integrates orbital mechanics, potential fields, petrophysics and geodynamics. Dr. Souček's work on the tidal deformation of Enceladus is among the most advanced work I have read. His work stands apart from others, because he has developed a fully 3D numerical approach that allows him to include complex geometries. This is essential to understand the role of the Tiger stripes, a set of near-parallel fractures at Enceladus south pole, in tidal dissipation.

In a series of contributions (P3 to P6) he has shown that these fractures have a first order effect on the energy dissipated in the ice shell. This contrasts with all other authors that rely on low-degree spherical harmonics that cannot represent the complex fracture geometries. Another important conclusion of this work is the recognition that the tidal heating of the ice shell is not sufficient to explain the required heat flow. This implies that Enceladus core must dissipate more heat than previously assumed. This has numerus implications on the dynamics of the internal oceans and energy and material transfers across it. Dr. Souček is clearly a leader in this important field and his work sets the standards for others to follow.

I was not aware that Dr. Souček also works on gravitational spreading of ice sheets, but this complements the other areas of his work. While I am not an expert on ice sheet modeling, I have experience with other vertically integrated shallow-water-type theories. I am aware of both the popularity of these models for large-scale applications and the limitations of these theories. As such the search for improvements that increase accuracy without sacrificing computational efficiency of these models is very important. The iterative improvement of the shallow ice approximation developed by Dr. Souček is a novel and useful idea that likely extends to other shallow theories.

In summary, Dr. Souček is a world leading researcher in the modeling ice deformation and the work submitted for this habilitation is clearly his own. The automatic plagiarism detection software (Turn-it-in) confirms my assessment. This habilitation makes many creative new contributions and exceeds the standard required for a habilitation thesis. I congratulate Dr. Souček for his excellent work and look forward to future contributions. If the committee has any questions, please don't hesitate to contact me either by email mhesse@jsg.utexas.edu or by phone +1 (512) 471-0768.

Sincerely yours,

Marc A. Hesse 22nd May 2023

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