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Report on the dissertation "Modele d'ecoulement biphase en sciences de la terre: fusion partiell, compaction et differeciation" by Ondrej Sramek

This thesis deals with the physics (fluid dynamics and thermodynamics) of deformable two-phase media and its application to the earth's mantle and core formation. In many parts of the earth interacting two phases play an important role: In magmatic systems a fluid melt phase is generated due to melting and percolates through the deforming solid matrix; another important applications is the segregation of the liquid iron from a silicate mantle during the early evolution of the earth. Two phase physics has been investigated thoroughly starting with McKenzie 1984 who derived a complete set of equations describing a low-viscosity fluid moving through a high-viscosity matrix. An alternative set of equations, which has a higher degree of symmetry with respect to the two phases, has been derived by Bercovici, Ricard and Schubert on 2001. Sramek's dissertation is based on this set of equations, and extends it to consistently include the non-equilibrium thermodynamics of melting. Parts of the theses are presented in French, parts in English. Unfortunately I do not understand French, so my report will be based only on the English parts.

In chapter 2 (French) Sramek derives and discusses the equations of mass, momentum and energy of a two-phase medium. He compares them with McKenzie's equations, which is very interesting as to many researchers the limitations and advantages of either of these two different approaches is not very obvious. Unfortunately I cannot judge the outcome of this chapter (in French) and I am eagerly looking forward to an English version..

In chapter 3 (English) the separation of liquid iron from a silicate melt is investigated. The equations are clearly and well readably derived and presented. Perhaps the limiting factors should have been discussed (if not done in chapter 2), such as what are the assumptions for the generalized Darcy equation (3.11) if the melt fraction ϕ reaches 100%. For example, I do not see inertia forces. After an elegant non-dimensionalisation (temperature is scaled with the temperature increase due to release of potential energy) the problem of iron – silicate differentiation is solved first in 1D, then in spherical geometry and then in 2D. In contrast to McKenzie's approach, the melt solid differentiation can be modelled until complete liquid-solid separation has taken place. It is interesting to see the evolution of the gravity acceleration (which has been solved in the coupled system of equations) of the spherically symmetric case: Starting from a linear profile typical for a homogeneous planet it evolves nicely to the typical profile of a two layer planet. The total time for core formation is given in non-dimensional units, and it would be interesting to see how well this fits to estimates for the earth's core formation. To obtain the 2D solution a new approach for the momentum equation of the solid phase is formulated separating the velocity into an incompressible and a compressible contribution. The implementation of this scheme is nicely presented, as well as the formulation of a robust advection scheme for porosity. In summary, this chapter presents an innovative method of solving the two phase flow associated with core formation, which is very well presented, and the case example of a segregating and sinking metal body is very impressive! What is missing is a discussion of the applicability to the earth or other planets in terms of the parameters chosen.

Chapter 4 is the first part of an excellent Geophys. J. Int. paper, investigating the physics of melting in a deformable two-phase medium in a most consistent way. If in a deformable two-phase medium undergoing melting mass is transformed from one phase with a certain density into another phase with another density the pressure in the melt increases and viscous decompaction of the matrix takes place. While this effect has in principle been understood based on McKenzie's approach, Sramek has formulated the physics of this effect in his paper now also for the Bercovici-Ricard-Schubert formulation, and most importantly, for the fist time he included the feed back of this effect on the thermodynamics and kinetics of melting. He furthermore included another innovation, an interfacial layer between the two phases, which describes physical quantities affected by the microscopic behaviour of the two phases near the interface (broken molecular bonds). To my knowledge, this is the first paper which at the same time derives the fully consistent conservation equations of mass, momentum, and energy extended for non-equilibrium and equilibrium thermodynamics for a two-phase deformable medium undergoing melting. This will be a key paper for future applications investigating the physics of melting. As these equations are difficult to solve in their general formulation, Sramek applied some simplifying assumptions.

A first application is presented in chapter 5 for a sphere. As this chapter is in French I cannot examine it.

In chapter 6 the simplified equations of melting of a two-phase medium are solved in 1D assuming steady state. This scenario should represent a mantle volume undergoing decompressional melting upon rising. This chapter is the second part of the above mentioned GJI-paper. Systematically, and for the first time, three parameter regimes are identified ("squirting", where decompaction stresses balance Darcy flow stresses, "visco-gravitational" where buoyancy stresses are balanced by decompaction stresses and "Darcy" where Darcy flow stresses are balanced by buoyancy). Due to the dynamic pressure which depends on which of the above mentioned mechanisms dominate, a feed back between melting, melt segregation and the depth of onset of melting is found. As one exciting result, Sramek predicts that depending on melt buoyancy, melt viscosity or compaction length, the depth of onset of melting in the mantle undergoing two-phase flow may be different by a few kilometres from what one expects if only equilibrium thermodynamics is accounted for. In summary, these chapters on fully consistent melting of a two-phase flow are highly innovative, they provide a new theoretical framework, and they have a high potential of becoming a key paper in mantle melting literature.

A final short chapter 7 (in French) of surface tension concludes the thesis. An overall conclusion chapter 8 has obviously been planned, but is missing.

In summary, despite the few minor draw backs mentioned above (application of core forming model to a planet, missing overall conclusion) this is one of the most excellent theses I have ever seen (even though I only have examined the English parts). I strongly recommend to accept this dissertation with the highest grade "excellent".

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