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Can a sinking metallic diapir generate a dynamo?

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Metallic diapirs may have strongly contributed to core formations during the first million years of planetary evolutions [1]. The length-scales of these diapirs can range from several centimeters (e.g. droplets within an early magma ocean) [2] to several hundred kilometers (e.g. Rayleigh-Taylor instabilities after the formation of a metallic layer at the bottom of a magma ocean, large scale differentiation events or core merging after a giant impact) [3, 4, 5]. The aim of this study is to determine whether or not this sinking dynamics can drive a dynamo and to characterize the required conditions on the size of the diapir, the mantle viscosity, and possibly the rotation of the planet.

The velocity of a dense diapir sinking through a less dense material strongly depends on the size of the diapir and on the rheology of the surrounding material [6, 4]. During the early times of planetary formation, impact heating, radiogenic heating and gravitational energy release during core formation have heated up and softened the mantle. Hence, the sinking of metallic diapirs obeys a Stokes velocity [4]:

$$U \propto \frac{(\rho_{Fe} - \rho_{Si}) g R_{Fe}^2}{\eta_{Si}} \quad (1)$$

where ρ_{Fe} and R_{Fe} are the density and radius of the metallic diapir, ρ_{Si} and η_{Si} are the density and viscosity of the surrounding mantle and g is the gravity at the depth of the diapir. Within the early mantle, $\eta_{Si} = 10^{10\pm3}$ Pa.s [7] and the sinking velocity could have reached several km/s, leading to potentially very large magnetic Reynolds numbers.

The pattern of the flow within a sinking diapir has been determined both theoretically [8] and experimentally [9]. The circulation pattern within the diapir consists of a purely poloidal one-roll velocity field. Simple laminar dynamos in a conducting fluid are inefficient in generating a dynamo and require to overcome large critical magnetic Reynolds number [10, 11, 12]. Even if the helicity is not indispensable in the dynamo process, these models have shown that it is a favorable factor.

We use kinematic dynamo simulations to determine the critical magnetic Reynolds number above which the flow strength is sufficient to amplify a magnetic field seed. We consider the simple flow pattern of a viscous bubble, but also the flow patterns obtained when taking into account planetary rotation and inertial forces, which can help the dynamo action by adding helicity to the flow.

Depending on the duration and strength of diapir-driven magnetic fields, a signal could have been recorded within the crust of the planet and may have contributed to the intensity and location of the magnetic sources observed on Martian or Moon surfaces [13, 14]. Our model therefore introduces an alternative explanation to the observed magnetic fields of Mars and the Moon.

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