Successes and future challenges of mantle modeling

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In this introductory talk, I will try to illustrate some of the successes and challenges of mantle modeling in relation with mineralogy, geochemistry and rheological behavior. Of course the progresses and the new questions have been closely linked to those of seismology. As geodynamicists, we hope that all these fields will be understood and related by mechanical models of mantle convection.

Our understanding of the deep mantle mineralogy mostly comes from the comparison between seismological observations and laboratory measurements. In the last 20 years, the progresses have been striking, from the 1D velocity profiles to the complex 3D tomographic v_p and v_s images now available. Similarly, the equations of states of the major mineralogical phases have been measured. The challenges are however still huge. The anomalies seen by the seismologists are usually smaller than the percent, and the measurements of elastic parameters with a similar accuracy at simultaneous high pressure and temperature is still very difficult. In particular, our data base is still very poor for rigidities, minor phases, or ultra high pressures while the high quality of seismic velocity variations cannot be accurately translated into more direct mineralogical data such as density or incompressibility variations.

The geochemical data has benefited from technological advances that have improved the precision and resolution of observations by orders of magnitudes, and largely extend the number of isotopes that can be studied. The interpretation of the geochemical observations is now much closely linked to the mechanical processes of transport, mixing, and melting. The interpretation of all these observations in terms of mantle circulation is however still debated. The end-members models are either that the differences between hotspots and oceanic ridges are related to differences in mixing/melting or in differences of source composition. The differences in sources composition can themselves be due to the preservations of primitives heterogeneities, or to the generation of new heterogeneities through recycling or melting. Even some first order problems, i.e., the Ar balance or the total quantity of radioactive elements are still debated.

The radial models of mantle rheologies, from glacio-isostatic or geoid modeling, suggest a viscosity increase with depth in the mantle by 1 to 2 orders of magnitude and an upper mantle viscosity around 10^{20} Pa s. We know however that the mantle should contain huge variations of mechanical properties related to temperature, water content, grain size or mineralogy. We do not even know whether the rheology can itself be approximated by a linear time-independent viscosity. The major problem of our poor knowledge of the mantle rheology is clearly illustrated by our inability to take into account the existence of rigid plates in our convection models. Very interesting progresses have been however made theoretically, experimently and numerically.