Cosmochemical fractionation by collisional erosion during the Earth's accretion. A. Boujibar[1,2], D. Andrault[1], N. Bolfan-Casanova[1] and M. A. Bouhifd[1], [1]Laboratoire Magmas et Volcans, Université Blaise Pascal, CNRS UMR-6524, 5 rue Kessler, 63000 Clermont-Ferrand, France, [2]Now at NASA Johnson Space Center, 2101 Nasa Parkway, Houston, TX 77058, USA.

Introduction: Numerical models have shown that colliding objects do not simply merge. Catastrophic disruption inducing collisional stripping of the embryos' mantles and excavation of the planetary surfaces have commonly occurred during planetary accretion [1]. On the other hand, planetary bodies with a radius >200 km formed ~1.5 Ma after the CAIs formation are likely composed of a differentiated interior [2]. It is still unclear how chemical fractionation occur on mantles of planetary bodies. This could have been caused by small-scale melting [3], or by the presence of a magma ocean [4]. Since planetary embryos could have differentiated early in the history of the Solar System, their partial destruction have produced heterogeneous bodies. The aim of this study is to investigate how collisional erosion processes [5] can modify the chemical composition of planetary bodies.

The chemical composition of the building blocks that accreted to form the Earth remain uncertain. However, enstatite chondrites (EC) and especially those of EH-type show remarkable similarities in isotopic compositions (for Ca, N, Mo, Ru, Os, Cr, Ni, and Ti). Therefore, these meteorites likely formed in the same region of the solar nebula than Earth. However EC and Earth present important chemical differences, such as (i) the absence of FeO in the chondrites in contrast to the 8 wt% FeO present in Earth's mantle, (ii) a low Mg/Si ratio (~0.63) relative to the terrestrial value (~1.1) together with (iii) low abundances in refractory lithophile elements and high concentrations of moderately volatile elements in EC in comparison to Earth's mantle. While several internal processes have been proposed to explain the difference in FeO content in Earth and EC [6], all the other issues remained unsolved until now. In the present study, we tested how much the chemical divergence between the bulk Earth and EC can be unravelled by the processes of early crust collisional erosion.

Experimental methods: We investigated experimentally the composition of melts produced by low degrees of partial melting of EC at the pressure conditions expected for melt segregation in partially molten planetary embryos. High pressure experiments were conducted using multi anvil press apparatus at pressures ranging 5 to 25 GPa and temperatures close to the solidus in order to extract the chemical compositions of the first melts. Mass balance calculations al-lowed us the estimation of the degree of melting in our charges.

Melting results:
Our experiments provide the chemical compositions of the pseudo-eutectic melts at 5, 10, 20 and 25 GPa. The change of these compositions with pressure are in very good agreement with a previous experimental study of partial melting of enstatite chondrites at 1 bar [7]. These first melts are all characterized by high concentrations of SiO_2 (up to 75 wt%), Al_2O_3 and alkali elements (Na_2O and K_2O) and low concentrations of MgO. The most striking features are the increase of MgO and decrease of SiO_2 and Al_2O_3 contents with increasing pressure. Their compositions are equivalent to that of rhyolites at 1 bar and become progressively trachy-basaltic as the pressure increases (Fig. 1).
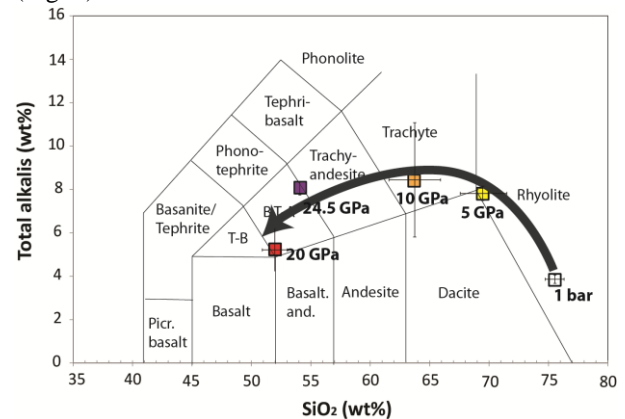

Figure 1: *TAS diagram (total alkali (Na_2O+K_2O) versus SiO_2 concentrations) showing the evolution of the composition of the pseudo-eutectic melts with pressure, obtained in the present study (5 to 25 GPa) and in a previous study at 1 bar [7].*

In partially molten planetesimals, the ascent of such melts towards the planetary surface could occur relatively easily due to their low melt densities, even for low degrees of partial melting [3].

Evolution of the chemical composition of the Earth:
These experimental results are then used to evaluate how the collisional erosion of planetary surfaces can change the chemical composition of differentiated EH-type planetary embryos. We calculate the evolution of the Mg/Si ratio of the planetary body, after the ascent then impact erosion of pseudo-eutectic melts equilibrated at different pressures. This ratio is then

compared to the terrestrial value (~0.9). As the pseudo-eutectic melts have high SiO_2-content, the Mg/Si ratio of the differentiated planetary body increases with increasing the amount of crustal erosion and evolves toward the present day BE (Bulk Earth) ratio (Fig. 2). With low pressures of melt-solid equilibration, less extensive crustal erosion is needed due to higher SiO_2-contents in the melts. The BE Mg/Si ratio can be achieved from an EH-type precursor, by erosion of a crust of 15 to 18% the planetary mass for solid-melt equilibrium pressures lower than 10 GPa.
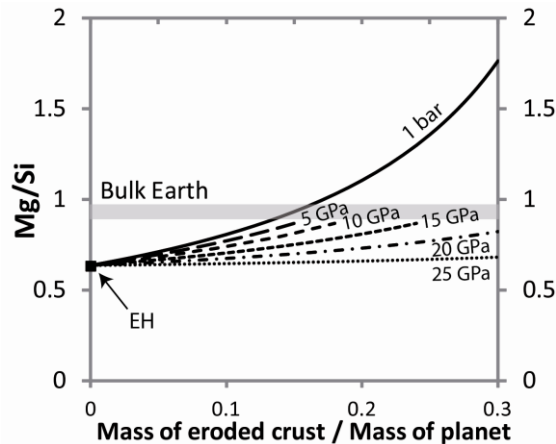

Figure 2: *Change of the planetary Mg/Si ratio after an erosion of a crust with a composition equivalent to that of pseudo-eutectic melts generated at pressures comprised between 1 bar and 25 GPa. The black square and the grey area represent the values of the EH chondrites and the Bulk Earth respectively.*

The formation of such SiO_2-rich crusts necessitates low degree of partial melting. Therefore removing proto-crust to a level of 15-18 wt% of the planetary mass calls for repeated processes of proto-crust formation and collisional erosion.

These differentiation processes affect also the concentrations of the other major elements. The obtained concentrations of Na, Ca and Al are different from that of the present Earth and their misfits are correlated with the temperature of condensation of the considered elements. These misfits could therefore be resolved if the processes of crustal erosion are associated to a re-condensation of elements that lead to a chemical fractionation: with a larger loss of the most volatile elements and a preferential condensation of the most refractory elements. A number of models of collisional erosion/re-condensation of elements can yield the terrestrial composition. The model with the lowest amount of surface erosion necessitates a re-condensation of 100% the refractory elements while an additional erosion of a fraction of the planetary mantle requires less fractionation of the elements (Fig. 3). The

dual processes of collisional erosion and re-condensation of refractory elements can also solve the previously reported dramatic consequences on the thermal history of Earth that could have the loss of incompatible and refractory heat-producing elements, such as U and Th [5, 8].
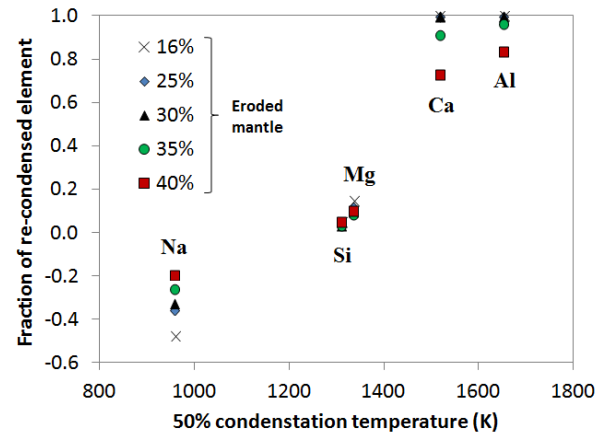

Figure 3: *Degree of chemical fractionation required by our model, for different amount of collisional erosion. 15% of the planetary mass required to match the terrestrial Mg/Si ratio is considered in addition to the eroded mantle. For example, with a total erosion of 15 to 45% the planetary mass, 100% of Ca and Al, 10% of Mg and 5% of Si have to re-condense to reach the present-day composition of the Earth.*

Possible interactions with nebular material

Furthermore if collisional erosion occurred early in the history of the Solar System, it would affect both planetary bodies and the nebular material. Due to their higher surface/volume ratio, the chondritic material that was left over from the accretion may have preferentially reacted with the gas enriched in SiO_2 and volatile lithophile elements produced with the vaporization of the eroded crust. This could explain the enrichments in Na, S and Si observed at the edges of chondrules [9] and the contrasted behaviours of the lithophile and non-lithophile volatile elements in the non-carbonaceous chondrites [10].

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