Hf isotope evidence for a transition in the geodynamics of continental growth after 3.2 Ga

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Earth's lithosphere likely experienced an evolution toward the modern plate tectonic regime, due to secular changes in mantle temperature. Gradually declining growth rates of the continental crust through time has been suggested, and recent estimates suggest that ≥70% of the present continental crustal reservoir was extracted by the end of the Archaean [1]. Patterns of crustal growth and reworking in rocks younger than 3.0 billion years (Ga) are thought to reflect the assembly and breakup of supercontinents by Wilson Cycle processes and mark an important change in lithosphere dynamics. It has been argued that subduction settings and crustal growth by arc accretion go back to 3.8 Ga in southern West Greenland [2-4]. We present in-situ zircon U/Pb, Hf and O isotope data from basement rocks in southern West Greenland across the time-period where modern style tectonic regimes might have started. Our data show that pronounced differences in the εHf-time patterns occurred, implying changing source rock characteristics. The observations suggest that 3.9-3.5 Ga rocks differentiated from a ≥3.9 Ga initially chondritic to slightly depleted mafic proto-crust. In contrast, rocks formed after 3.2 Ga register the first additions of juvenile depleted material since 3.9 Ga. Crustal growth after 3.2 Ga is characterised by upward εHf shifts and correlate in age with regional meta-volcanic supracrustal belts, stabilised felsic crust are characterised by downward εHf excursions, a pattern that compare with Phanerozoic accretionary orogens [5,6]. The isotope data reveal a transition from a crustal evolutionary signature unlike that of modern subduction-related orogens that didn't seem to generate or stabilise juvenile zircon-bearing crust, to an isotope-time pattern after 3.2 Ga that is compatible with arc accretionary processes and plate tectonics.

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Oxygen isotopic exchange reaction between silicate melt and ambient gas

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Oxygen Isotopic Variation of Planetary Materials

Chondrite, nonchondritic meteorites, and planets show wide variations of oxygen isotopic compositions, which incude mass-dependent and mass-independent fractionations. Mass-independent oxygen isotopic fractionation has been one of the most extensively studied subjects of meteorite study, whereas mass-dependent isotopic fractionation has not been paid attentions. It is, however, contorlled by physics, and is potentially an excellent indicator for environments. Here, we quantitatively study the role of isotopic exchange reaction between silicate melt and gas, and evaluate mixing lines on the oxygen three isotope plot.

Method

We have developed a kinetic condensation model that assumes totally molten silicate melt sphere cooling from an above liquidus temperature in a closed or open system, which has a composition of the solar abundance except for hydrogen. The model includes three free parameters; cooling rate of the system, initial oxygen abundance in gas relative to metallic elements, and oxygen isotpopic exchange efficiency. The model consists of the Hertz-Knudsen equation that describes condensation/evaporation flux and isotopic exchange reactions.

Results

We found that isotopic exchange reactions play a critical role in evolution of condensing silicate melt: silicate melt gets highly mass-fractionated composition if isotopic exchange does not work, which results in deviation of a straight mixing line but in formation of a fractionation trend with a slope of 1/2 on a oxygen three isotope plot. An isotopic exchange reaction greatly suppresses mass-dependent isotopic fractionation, which is tends to form a straight mixing line. The effect of fractionation is more conspicuous when the relative abundance of oxygen in the ambient gas against silicate melt is small. The degree also depends on isotopic exchange efficiency, but it is not dependent on cooling rate of the system. If the oxygen isotopic exchange efficiency does not change largely, the degree of deviation from a straight mixing line corresponds to the melt/gas ratio in a planetary environment or dust/gas ratio in a protoplanetary disk environment.

Discussions

The calculation results show that the straight mixing lines observed in various chondritic components such as CAIs and chondrules are explained by condensation in the presence of oxygen in the ambient gas by more than two orders of magnitude than the metallic elements. Otherwise, the mixing lines should be curved toward □^{18}O-rich side. The average O/M ratio (M: metallic elements) of the solar abundance is ~100, which suggests that CAIs and chondrules that show straight mixing lines were formed in an oxygen enriched environment than the average solar abundance. The model is further applied to the Earth-moon system, where homogenization of oxygen isotopic composition is easy at the stage of magma ocean.