

## Modeling the chemical evolution of the atmosphere and oceans

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We have simulated the long-term (4 billion years) changes in the concentrations of atmospheric gases (O<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>S, SO<sub>2</sub>), the concentrations of aqueous species in the oceans (O<sub>2</sub>, CO<sub>2</sub>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, H<sub>2</sub>S, Fe<sup>2+</sup>, and other redox sensitive elements), and the amounts and isotopic compositions of organic C, carbonate C, sulfide S and sulfate S in sedimentary rocks under a variety of scenarios for the growth of continental crust, volcanic flux, and H<sub>2</sub> escape to the space. Our model is not a box model, but is a dynamic model [1] where equilibrium (i.e. input = output) is not assumed for each subsystem. The results of these simulations put severe constraints on possible scenarios for the evolution of biosphere and environment on early Earth.

For example, if the atmosphere was H<sub>2</sub>-rich and the volcanic flux of reduced volcanic gas was >10X the present value, within ~500 Ma of the emergence of photoautotrophs (oxygenic or non-oxygenic) the atmospheric (and volcanic) CO<sub>2</sub> would have been completely converted to organic matter (and carbonates) in sediments, resulting in the Snowball Earth. If the flux of reducing volcanic gas was less than ~7X of the present value and if the land area was greater than ~10% of the present value, the atmospheric pO<sub>2</sub> would have risen to ~1 PAL in less than 30 Ma after the emergence of oxygenic photoautotrophs. If the volcanic flux gradually decreased and the land area increased to the present values, the pO<sub>2</sub> would have remained at ~1 PAL. The pCO<sub>2</sub> would have gradually decreased from 1000 PAL to the present level over a 4 Ga period, while the concentrations of sulfur, Fe, and other redox species in the oceans have remained essentially the same as those in the present oceans. Such a scenario is consistent with the sedimentary records of concentrations and isotopic compositions of C, S, and Fe.

[1] Lasaga & Ohmoto (2004).

## Bimodal magmatism in the Andriamena belt, Madagascar. Implications for continental crust evolution in Neoproterozoic times

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The Andriamena greenstone belt belongs to the Tsaratanana sheet which was thrust onto the central northern Antananarivo block. The Andriamena belt is associated with N-S trending upper crustal migmatites, comprising amphibolite to granulite-facies orthogneiss to paragneiss. The synformal structure of the greenstone belts is the result of the ca. 600-550 Ma collision between India and Congo blocks.

Before the final collision, the 820-740 episode is related to the development of an arc magmatic sequence with gabbro and granitoid intrusives. Ultramafic rocks within the Andriamena belt, dated at 787±6 Ma, occur within small scale intrusives bodies, the shape of which is controlled by subvertical large scale shear zones. Dunite, harzburgite, orthopyroxenite and pyroxenite are found in narrow N-S conduits or within larger magma chambers, however less than one km wide. Within the orthogneiss commonly surrounding the ultramafic massifs, a charnokite magma suite has been found. The suite comprises a high proportion of intermediate terms which show high TiO<sub>2</sub>, K<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub>, LILE elements and incompatible elements as Zr (up to 1230 ppm). Rocks are also characterized by more or less prominent negative anomalies of Rb, K, Sr, P and Ti, indicative of strong fractionation processes. The presence of a charnokite type suite devoid of negative anomalies of Nb and Ta may be indicative of a rift environment during Neoproterozoic times. Strong interaction between crustal melt components and mantle magma is otherwise attested by their respective trace element evolution and isotopic data.