The punctuated evolution of the Earth: Geodynamic constraints and model predictions

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The preserved Precambrian crustal record is strongly episodic, and observation that has been attributed to preservational effects or episodic crustal production. These age peaks are associated with juvenile crustal production, voluminous high-temperature volcanism, massive mantle depletion, widespread orogeny and mineralisation, large apparent polar wander velocity spikes, and subsequent paleointensity increases. The impact of these events impinged on the glaciation record, atmospheric and ocean chemistry, and on the rise of oxygen. Here we assess a variety of geodynamic models for Precambrian dynamics against the swath of observational constraints available. We find that episodic behaviour from non-linear slab-driven models - such as mantle avalanches or episodic subduction events - are best able to simultaneously satisfy the majority of geological constraints. In such models, rapid descent of subducted material into the mantle drives fast plate motions and convergence at the surface. This is accompanied by large-scale upwellings of deep hot mantle which contribute to voluminous volcanism. Currently, it is not possible to differentiate the ultimate cause of non-linear plate behaviour solely from the geological record, however, dynamic simulations under Earth-like conditions may be able to secern.

Redox variable trace elements

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As a change in the oxidation state of an element is usually accompanied by a profound change in its geochemical properties, redox variable elements are potentially sensitive indicators of mantle differentiation processes. Prominent redox variable elements include V, Cr, Mo, the PGEs, Re and U, as well as the volatiles C, H, and S. While Fe is the most abundant redox variable element, likely amounts of Cr, C and S are enough to affect the complex interactions between oxygen content and oxygen chemical potential (or oxygen fugacity, fO_2) that must be understood to quantify the redox state of a system. The presence of abundant Fe^{3+} and Fe^{2+} may obscure the redox state of a trace element in glasses quenched from natural silicate melts because electron exchange reactions (e.g. $Cr^{2+} + Fe^{3+} = Cr^{3+} + Fe^{2+}$) can be too fast for the high temperature speciation to be preserved. Hence spectroscopic measurements on natural materials at room temperature may be misleading.

V occurs in three oxidation states under terrestrial mantle conditions, V^{3+}, V^{4+} and V^{5+}, with a huge variation in incompatibility, making this element a good monitor of mantle redox processes. Its properties may be utilized either through whole-rock abundances to deduce redox conditions during partial melting, or from phenocryst/matrix partitioning, to study magma crystallization. When applied to arc basalts, the two methods show disconcertingly disparate results, crystallization mostly being under oxidized conditions (long known from Fe^{3+}/Fe^{2+} ratios), but from a source of similar redox character to MORB source. Mo systematics show promise for further investigation of this conundrum. U is of particular interest because of the importance of U-Th-Pb systematics in evaluating mantle evolution, and of U series disequilibria in understanding rate processes. While U^{4+} is slightly less incompatible than Th, U^{5+} and U^{6+} are much more incompatible. Significant fractions of U^{6+} are expected at natural fO_2s, with U^{5+} making an unexpected but intriguing appearance at low pressures.