ABSTRACT

Integrated approach of advanced data-guided techniques, such as artificial intelligence, statistical methods, along with thermodynamic modelling can significantly advance the understanding of igneous processes. It can detect patterns and non-linear relationships in large, complex geochemical data. This research aims to develop techniques for investigating Earth's crust and mantle evolution, and tectonic setting and source discrimination on modern-day Earth. It attempts to track continental crustal evolution using stacked probability density estimation, change-point analyses and phase equilibria modelling. A significant change in Archean sodic granitoid composition is noted in the 3.9–3.75 Ga period, possibly marking gradual shift from stagnant-lid to intermittent mobile-lid-type plate tectonics, involving deeper subduction of oceanic lithosphere that allowed more voluminous continental crust production as well as crustal recycling post 3.9–3.75 Ga. The evolution of Earth's crust and mantle is interconnected through plate tectonics, magmatism, and chemical differentiation. Mantle redox evolution influences mantle melting, magma composition, volatiles and redox elements speciation, and chemical equilibrium between lithosphere, hydrosphere, and atmosphere. Machine learning (ML) models have been trained to constrain fO_2 of experimentally-derived basalts and applied to a global data of natural, unaltered mantle-derived rocks, spanning from Archean age to present-day, to estimate the P-T-fO_2 conditions of mantle melting. The results show oxygen fugacity has broadly remained constant throughout Earth's history within 0.4 log units of FMQ. The strong correlation between trace element systematics of mantle-derived rocks and mantle oxygen fugacity between 3 to 2.5 Ga period possibly reflects the onset of global-scale plate tectonics. Although the existence of horizontal plate tectonics in Archean is debated, it is well established in post-Archean Earth. Magmatic biotite composition is a potential indicator of modern-day tectonic environment of its host rocks. Here, machine learning classifier models are applied to classify biotite in igneous rocks from different tectonic settings with ~90%accuracy. Case study highlights usefulness of ML classifiers in constraining geodynamics of Neoproterozoic magmatism in the Aravalli Delhi Fold Belt, western India. The mineral quartz incorporates several trace elements in its structure during crystallization/precipitation from magma/fluid. Being physically and chemically resilient, it can retain the signatures of physicochemical environment of its formation. Robust ML classifiers have been built to discriminate quartz from a wide variety of magmatic/magmatic-hydrothermal host rocks based on their trace element chemistry. These models are used to constrain sedimentary provenance using detrital quartz from sediments in the catchment area of the Bega River in the Lachlan Fold Belt, Australia, demonstrating the usefulness of the technique in sedimentary provenance studies.

Keywords: Plate tectonics, Archean TTGs, mantle oxygen fugacity, biotite, quartz, trace elements, tectonic setting discrimination, source discrimination, machine learning model, phase equilibria, change-point analyses