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Hurst exponent used as a tool to differentiate between magmatic and fluid-induced processes as reflected in crystal geochemistry

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A self-similarity parameter, the Hurst exponent (H) (called also roughness exponent) has been used to show the long-range dependence of element behaviour during the processes. The H value ranges between 0 and 1; a value of 0.5 indicates a random distribution indistinguishable from noise. For values greater or less than 0.5, the system shows non-linear dynamics. $H < 0.5$ represents anti-persistent (more chaotic) behaviour, whereas $H > 0.5$ corresponds to increasing persistence (less chaotic). Such persistence is characterized as an effect of a long-term memory, and thus by a large degree of positive correlation. In theory, the preceding data constantly affect the next in the whole temporal series. Applied to chaotic dynamics, the system shows a subtle sensitivity to initial conditions. The process can show some degree of chaos, due to local variations, but generally, the trend preserves its persistent character through time. If the exponent value is low, the process shows frequent and sudden reversals e.g. the trends of such a process show mutual negative correlation of the succeding values in the data series. Thus, the system can be described as having a high degree of deterministic chaos.

Alkali feldspar megacrysts grown from mixed magmas and recrystallized due to interaction with fluids have been selected for the study (Słaby et al., 2011). Hurst exponent variability has been calculated within some primary-magmatic and secondary-recrystallized crystal domains for some elements redistributed by crystal fluid interaction.

Based on the Hurst exponent value two different processes can easily be recognized. In the core of the megacrysts the element distribution can be ascribed to magmatic growth. By contrast, the marginal zones can relate to inferred late crystal-fluid interactions. Both processes are deterministic, not random. The spatial distribution of elements in the crystal margins is irregular, with high-H values identifying the process as persistent. The trace element distributions in feldspar cores are almost homogeneous and only relatively small and irregular variations in trace element contents makes their growth morphology slightly patchy. Despite homogenization the fractal statistics reveal that trace elements were incorporated chaotically into the growing crystal.

The anti-persistent chaotic behaviour of elements during magmatic growth of the feldspars progressively changes into persistent behaviour within domains, where re-crystallization reaction took place. Elements demonstrate variable dynamics of this exchange corresponding to increasing persistency. This dynamics is different for individual elements compared to analogical, observed for crystallization process proceeding from mixed magmas. Consequently, it appears that fractal statistics clearly discriminate between two different processes, with contrasted element behaviour during these processes. One process is magma crystallization and it is recorded in the core of the megacrysts; the second is recorded in the crystal rims and along cleavages and cracks, such that it can be related to a post-crystallization process linked to fluid percolation.

Słaby, E., Martin, H., Hamada, M., Śmigielski, M., Domonik, A., Götze, J., Hoefs, J., Hałas, S., Simon, K., Devidal, J-L., Moyen, J-F., Jayananda, M. (2011) Evidence in Archaean alkali-feldspar megacrysts for high-temperature interaction with mantle fluids. Journal of Petrology (on line). doi:10.1093/petrology/egr056