

Scale, scaling and multifractality of geochemical landscape and identification of weak anomalies caused by buried sources

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While a map scale is commonly considered in the exploration geochemical field as an indicator of sampling density and coverage of study area, new developments of the of scaling and nonlinear modeling techniques have brought new ways for processing geochemical data and new ideas for interpreting geochemical anomalies in geological modeling and mineral exploration. Anomalies identified in geochemical maps are often scale-dependent in the sense that anomalies identified at one scale may not be the same or may not even exist at other scales. However, the nonlinear regulations, discovered in the field of geocomplexity, quantifying these types of changes of anomalies delineated at multiple scales, are known only among small group of researchers rather than among practitioners in the field of geochemical exploration.

Scaling has been found to be a common property of geochemical landscape, which characterizes the change regulations of patterns of geochemical landscape measured through scales. How to utilize the scaling property to assist in delineation of geochemical anomalies, especially weak anomalies caused by buried sources, is a challenging but promising research direction that will change the basic concept of anomalies and methods for anomalies delineation. Traditional statistics based on main variances of the geochemical data have limitations for characterizing small sample population such as anomalies associated with mineralization or other types of rare events.

This paper introduces several state-of-the-art concepts and methods in utilization of scaling properties in visualization and interpretation of geochemical data in assisting mineral exploration. These include singularity analysis, a powerful technique for identification of weak anomalies caused by buried sources, and a generalized self-similarity analysis for decomposing anomalies from complex background. The case study presented in this paper is for prediction of undiscovered Sn and Cu mineral deposits in Geijiu district of China.

Helium diffusion in accessory minerals

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We have recently published findings for He diffusion in apatite and zircon [1], and as a continuation of these efforts are characterizing He diffusion in other accessory minerals. Polished sections of monazite, rutile and sphene were implanted with 100 keV ³He at a dose of 5x10¹⁵/cm², and annealed in Pt capsules in 1-atm furnaces. ³He distributions in minerals following diffusion anneals were measured by Nuclear Reaction Analysis using the reaction ³He (d, p)⁴He.

For diffusion normal to (100) in natural monazite we obtain an activation energy of 150 kJ/mol and pre-exponential factor of 1.6x10⁻⁷ m²/sec. Diffusivities are similar to those measured for natural monazite in [2], and fall between the values measured in [3] for diffusion in synthetic monazite-structure orthophosphates CePO₄, NdPO₄, SmPO₄, and GdPO₄. Helium diffusion in monazite is similar to He diffusion in zircon normal to c, and about 4 orders of magnitude slower than in apatite [1]. Work is underway to assess the anisotropy of diffusion in monazite and to explore compositional effects on diffusion in monazite and HREE phosphates isostructural with zircon.

For diffusion in sphene, we obtain an activation energy of 143 kJ/mol and pre-exponential factor of 8.7x10⁻⁷ m²/sec. Diffusivities for sphenes from different localities and for different orientations are comparable, and similar to those measured in the outgassing experiments of [4]. Helium diffusion in sphene is about an order of magnitude faster than in monazite, and intermediate between He diffusion parallel and normal to c in zircon.

In synthetic rutile normal to (001), we obtain diffusivities similar to those for sphene, with an activation energy of 150 kJ/mol and pre-exponential factor of 2.2x10⁻⁶ m²/sec. Measurements of diffusion normal to (100) in rutile are in progress.

With these diffusivities, effective grain radii of 50 μm and cooling rates of 10°C/Ma, estimated closure temperatures for He would in these minerals would be 187°C, 145°C and 160°C for monazite, sphene, and rutile, respectively, assuming spherical geometry and isotropic diffusion.

[1] Cherniak, Watson, Thomas (2009) *Chem. Geol.* **268**, 155–166. [2] Boyce, Hodges, Olszewski & Jercinovic (2005) *G-Cubed* **6**, Q12004. [3] Farley (2007) *Geochim. Cosmochm. Acta* **71**, 4015–4024. [4] Shuster, Farley, Sisterson, Burnett (2003) *Earth Planet. Sci. Lett.* **217**, 19–32.