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Controls on Rare Metal Concentration in the Crust: Implications for Future Exploration

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Technological advances, many driven by the need to address the global warming issue, have created enormous demand for a variety of rare metals that will continue for the foreseeable future. These metals include the REEs, Co, Nb, and Zr. Here, we review the processes that concentrate rare metals to economic levels in the crust. Ultimately, they originate in the mantle, but their paths to the crust are quite different. Whereas Nd, Dy, Nb, and Zr are incompatible elements, Co is compatible and Sc partially compatible. Thus, Nd, Dy, Nb, and Zr partition strongly into magmas forming after small degrees of partial melting and concentrate in peralkaline igneous rocks and carbonatites as REE minerals, pyrochlore, and zirconosilicate minerals. In contrast, Co is released only after high degrees of partial melting and reaches its highest concentration in ultramafic magmas, commonly concentrating in immiscible sulphide liquids. The behaviour of scandium is more complex. Although it partitions strongly into magmas representing intermediate degrees of partial melting, it may be present in sufficient concentration in magmas from low degrees of partial melting to reach economic levels through other processes. Indeed, at Kovdor (Russia), Sc is interpreted to have reached economic concentrations in phoscorite derived by liquid immiscibility from carbonatitic magma. The same process may be applicable to Nb. Moreover, Nd and Dy are interpreted to have been concentrated by an immiscible fluoride liquid in the Strange Lake REE-Nb-Zr pegmatite deposit (Canada). Elsewhere, Sc has concentrated through fractional crystallisation of clinopyroxene into which it partitions preferentially. Despite the importance of magmatic processes, aqueous fluids play a pivotal role in the formation of economic rare metal deposits. Thus, both Co and Sc form exploitable deposits due to weathering of ultramafic rocks that releases them from olivine and clinopyroxene, respectively, to mildly acidic surface waters as simple ions. With increasing pH, they accumulate at depth in laterites. The REEs are commonly mobilised as chloride complexes by fluids exsolved from carbonatitic and alkaline silicate magmas and in some cases, e.g., Bayan Obo (China), this is the primary ore-forming process. Chloride complexation in hydrothermal fluids is also the major means by which Co is concentrated. Although Zr and Nb are much less mobile than other rare metals, they can be concentrated hydrothermally as hydroxyfluoride complexes. In summary, rare metals are mobilised by partial melting of the mantle to a degree consistent with their compatibility and transported by magmas into the crust. There, they are concentrated to mineable levels by these magmas, hydrothermal fluids, and weathering fluids. Understanding these processes is the key to their future successful exploration.