

## **Applications of triple quadrupole ICP-MS (ICP-MS/MS, or ICP-MS QQQ) in economic geology**

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Triple quadrupole ICP-MS (Inductively Coupled Plasma – Mass Spectrometry) is the latest generation quadrupole ICP-MS. The front quadrupole set and the reaction cell before the traditional quadrupole set make it possible to minimize isotope interferences that are not separable before, e.g.,  $^{87}\text{Rb}^+$  vs  $^{87}\text{Sr}^+$ , and  $^{32}\text{S}^+$  vs  $^{16}\text{O}^{16}\text{O}^+$ . Coupled with a laser ablation system, it has several new applications in economic geology research and mineral deposit exploration, including in-situ Rb-Sr dating, measurement of low concentration sulfur, in-situ sulfur isotope analysis, and molybdenite Re-Os dating.

In-situ Rb-Sr dating methodology is being developed in several labs. At Colorado School of Mines, with an Agilent 8900 ICP-MS/MS, a Resolution-SE 193nm laser system,  $\text{O}_2$  cell gas, Mica-Mg-NP nano-pellet standard, laser downhole fractionation corrected using an averaging method, and machine drift with an exponential model, we achieve ~2% relative uncertainty at two sigma level. This is demonstrated by the dating of a muscovite. Our result is  $304 \pm 6\text{Ma}$  (MSWD = 1.3), which is statistically indistinguishable from the Ar-Ar ages of  $305 \pm 3$  and  $308 \pm 3\text{Ma}$  and Re-Os ages of  $306 \pm 3$  and  $306 \pm 2\text{Ma}$  of molybdenite of the same paragenesis stage [1]. For low concentrations of sulfur, using the MS/MS mode,  $\text{O}_2$  cell gas, BAM-S005B external standard, 50-100 $\mu\text{m}$  spot, 5 Hz and 3-4J/cm<sup>2</sup> laser, the detection limit (DL) is reduced to 3-10 ppm, significantly lower than the ~200 ppm DL at single quadrupole mode. This capacity is applied on hydrothermal calcite around a porphyry-skarn deposit and the S content shows a trend, adding another distal vector for exploration of skarns [2] and porphyry deposits hosted in carbonates. Sulfur isotope analysis using LA-ICP-MS/MS is at an early stage, with an uncertainty of ~1‰ (2SD).

[1] Cheng, Y., Spandler, C., Chang, Z., and Clarke, G., 2018, Volcanic-plutonic connections and metal fertility of highly evolved magma systems: a case study from the Herberton Sn-W-Mo Mineral Field, Queensland, Australia: *Earth and Planetary Science Letters*, v. 486, p. 84-93.

[2] Chang, Z., Shu, Q., and Meinert, L.D., 2019, Skarn deposits of China: *Society of Economic Geologists, Special Publication 22*, p. 189–234.