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A wholistic approach to the measurement of trace elements and stable isotopes in fluid inclusions using laser ablation

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Laser ablation (LA) has become a routine micro-analytical technique in geochemical laboratories due to its ability to sample almost any geological material *in-situ* and at high spatial resolution. One important application is the analysis of fluid inclusions - typically 5 to 50 μm pockets of fluid trapped within crystals during growth. These inclusions preserve direct samples of magmatic, metamorphic, and hydrothermal fluids, enabling reconstruction of ore-forming processes, fluid-rock interaction, and crustal evolution. LA-inductively coupled plasma mass spectrometry (ICP-MS) analysis of fluid inclusions is commonly used to determine their trace element geochemistry, providing insights into the formation environment.

Analysing fluid inclusions by LA-ICP-MS, however, presents significant challenges. The primary difficulty arises from the unpredictable rupture of inclusions during ablation, caused by the heating of the host mineral by the laser as well as the laser hitting the fluid once the cavity wall has been breached. This often results in the ejection of the fluid, producing short-lived, highly transient signal in the ICP-MS. This unpredictability can lead to incomplete or missed capture of the ablated material, variable signal durations, and reduced analytical precision. Quadrupole ICP-MS instruments, in particular, must cycle rapidly through multiple isotopes to maximise data acquisition during these brief events, often compromising counting statistics and limiting the number of elements that can be measured reliably.

In this contribution, we demonstrate an alternative approach using the Teledyne Photon Machines CRYO-COBALT sample chamber to freeze fluid inclusions prior to and during ablation. By converting the liquid to a solid, the inclusion can be ablated more like a conventional mineral grain, producing a longer, and more stable, time-resolved signal. This extended signal improves counting statistics and allows a greater suite of elements to be analysed. To our knowledge, this represents the first application of cryogenic-LA-ICP-MS for fluid inclusion analysis.

We also present, stable carbon isotope ($\delta^{13}C$) measurements on CO_2 trapped in bubbles within silicate melt inclusions, using isotope ratio mass spectrometry (IRMS). By utilising the IsoScell Δ200 sample chamber for LA-IRMS, these measurements provide proof-of-concept for direct isotopic analysis of CO_2 from fluid inclusions.