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Is the gold standard tarnished? – understanding the limitations of high volume resolution U-Pb geochronology

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Zircon (ZrSiO4) has for many decades been considered the “gold standard” of uranium-lead geochronology, an accolade that deservedly derives from its remarkable mechanical, chemical and thermal stability, enabling it to preserve a record of its original crystallization age, while at the same time recording later events via metamorphic or igneous reworking and/or overgrowths as well as preserving key petrogenetic information from other isotopes (oxygen and hafnium) and trace elements. Over time, the volume of zircon analysed has continued to fall with increasingly sophisticated methods applied both to high-precision ID-TIMS analysis and in situ high-spatial and volume resolution methods such as SIMS and LA-ICP-MS. While going down in scale for ID-TIMS analysis, together with physical and chemical abrasion methods and the use of dedicated tracers, has resulted in spectacular improvements in concordance and precision, increasingly higher volume resolution from in situ methods is beginning to encounter limitations caused by heterogeneity in the target zircon at the sub-micrometer to few nanometers scale, which in some cases can result in inaccurate and/or imprecise data. Pre-analytical imaging methods such as cathodoluminescence and/or back-scattered electron images may fail to reveal small features such as Pb nanoparticles, which preserve unsupported radiogenic Pb, their presence only really becoming obvious during an analysis or subsequent data reduction. Clearly, it is impractical to undertake pre-analytical screening using scanning ion imaging by SIMS, TEM and/or APT, which in any case will be at a scale smaller than a geochronologically useful analytical volume, so it is often a case of retrospectively understanding the causes of analytical bias resulting from sampling of domains at a scale much smaller than the analysed volume. Several examples will be presented that illustrate these challenges, but also show that in many cases, while not ideal, useful geochronological data may still be produced from zircon containing heterogeneities in its U and/or Pb distribution. Despite the growing evidence for such complexity, the gold standard geochronometer remains the most versatile and informative tool available to the geochronologist.