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# Lead and noble gas isotopic constraints on the origin of Te-bearing adularia-sericite epithermal Au-Ag deposits in a calc-alkaline magmatic arc, NE China

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## Abstract

Tellurium (Te)-bearing adularia-sericite epithermal Au-Ag deposits are widely distributed in calc-alkaline magmatic arcs and are an important current and future source of precious and critical metals. The source of ore-forming fluids in these deposits remains unclear due to the lack of in situ isotopic evidence on Au-, Ag-, and Te-bearing minerals. To advance the understanding of the source and evolution of Te and precious metals, herein, we combine in situ Pb isotope analysis with He, Ne, and Ar isotope and microthermometric analysis of fluid inclusions in ore and gangue minerals from two Te-rich and two Te-poor epithermal Au-Ag deposits that occur in an Early Cretaceous magmatic arc in the North Heilongjiang Belt, northeastern China. Ore minerals (hessite, petzite, calaverite, altaite, pyrite, chalcopyrite, and galena) from Te-rich Au-Ag deposits, including Sandaowanzi and Yongxin, have the least radiogenic Pb isotope compositions ($^{206}Pb/^{204}Pb$ from 18.1 to 18.3) and the lowest μ1 values (the $^{238}U/^{204}Pb$ ratio of the lead source down to 9.14) of the deposits studied. For these Te-rich deposits, noble gas isotope data show that fluid inclusions in ore minerals contain a large proportion of mantle He (up to 25%), whereas barren early-stage minerals do not (<1%). The Pb, noble gas isotope, and fluid inclusion microthermometric results suggest that Te-rich ore-forming fluids were likely discharged from mafic magmas into convecting meteoric flow systems at shallow levels (<2 km). In contrast to the Te-rich deposits, ore minerals from the Te-poor Dong'an Au-Ag deposit have radiogenic Pb isotope compositions ($^{206}Pb/^{204}Pb$ from 18.8 to 18.9) and the highest μ1 values (up to 10.54). Fluid inclusions in ore minerals contain a small proportion of mantle He (1% to 5%). The results suggest that metals and ore-forming fluids in these deposits were discharged from either more crustally contaminated intermediate-felsic magmas or leached from upper crustal rocks by convecting meteoric flow systems. Although the Te-poor Tuanjiegou Au-Ag deposit has a non-radiogenic Pb isotope composition consistent with a mafic magma source, Te is much less abundant (electrum [>95%] is the major gold- and silver-bearing mineral) than Au. The main exploration implication of these results is that unexplored volcano-plutonic centers in the northeast Xing'an Block with less radiogenic Pb isotope compositions ($^{206}Pb/^{204}Pb$ < 18.3) and containing fluids with a high proportion of mantle He are more likely to generate Te-rich epithermal Au-Ag deposits than other volcano-plutonic centers in NE China.

**Keywords:** In situ Pb isotope, noble gas, Te, epithermal, Au-Ag deposit, NE China

## Introduction

Tellurium (Te)-bearing adularia-sericite epithermal Au-Ag deposits are often associated with calc-alkalic volcano-plutonic centers, such as those in the Golden Quadrilateral, Romania, numerous Cretaceous-Quaternary deposits in Japan, and Early Cretaceous deposits in northeastern China (Shikazono et al. 1990; Ciobanu et al. 2006; Cook et al. 2009; Sun et al. 2013a; Goldfarb et al. 2016, 2017; Gao et al. 2017a, 2018a, 2021, 2022; White et al. 2019; Keith et al. 2020), although many deposits are associated with alkalic volcano-plutonic centers (e.g., Cripple Creek, Colorado, U.S.A.; Kelley et al. 1998; Kelley and Spry 2016). These Te-bearing deposits are economically important and are a potential source of Te, which is a critical commodity for modern technology, if current metallurgical and economic impediments are resolved (Spry et al. 2004; Ciobanu et al. 2006; Cook et al. 2009; Kelley and Spry 2016; Goldfarb et al. 2016, 2017; Jenkin et al. 2019).

The source of Te in these deposits is generally thought to be derived from igneous intrusions in continental magmatic belts that metasomatized subcontinental lithospheric mantle (SCLM) during subduction (Jensen and Barton 2000; Saunders and Brueseke 2012; Kelley and Spry 2016; Holwell et al. 2019). However, the abundance of Te-bearing minerals varies among adularia-sericite epithermal Au-Ag deposits within the same calc-alkaline magmatic arc, e.g., Te-rich Sandaowanzi and Te-poor Dong'an deposits in NE China (Zhang et al. 2010; Yu et al. 2012; Han 2013; Liu et al. 2013; Zhai et al. 2015, 2018; Gao et al. 2017a, 2021; Zhao et al. 2019a, 2019b and reference therein). This observation suggests that the source of and/or enrichment process for Te varies in each Au-Ag deposit in the arc. Previous work on the S, Pb, H, O, He, and Ar

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