Gamma radiation effects on quartz Al and Ti center electron spin resonance signal intensity: Implications for quartz provenance discrimination

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Abstract

Quartz is one of the most common rock-forming minerals and crystallizes over a wide range of temperature and pressure conditions. This diversity of quartz crystallization environments is reflected by trace-element compositional variations, which can be used to distinguish between different source sediments. Trace elements that are incorporated into the quartz lattice form corresponding paramagnetic centers (impurity centers, such as Al and Ti centers), which can be detected using the electron spin resonance (ESR) method. However, whether the quartz impurity center ESR signal intensity (quartz ESR-SI) can be used for quartz sediment provenance tracing remains uncertain. In the present study, five present-day (modern) fluvial sediments from the Songhua, Yellow, Yangtze, Huai, and Pearl rivers in China and eight ancient fluvial sand lenses from the Yichang Gravel Layer (YGL) located in the middle Yangtze River were sampled for major- and trace-element determinations by ICP-OES and ICP-MS for the purpose of provenance discrimination. A total of 1404 ESR spectra were also collected to evaluate the effect of γ-ray dose (varying from 50 to 50,000 Gy) on quartz ESR-SI to establish the relationship between quartz element contents and quartz ESR-SIs and thereby to assess the potential utility of quartz ESR-SI for sediment provenance analysis. Results indicate that: (1) quartz collected from the different studied locations can be distinguished by element contents; (2) the quartz Al center ESR-SI increases with increasing γ-ray dose from 50 to 50,000 Gy; (3) the quartz Ti center ESR-SI increases within a γ-ray dose of 10,000 Gy and decreases beyond 10,000 Gy; (4) quartz Al and Ti center ESR-SIs are closely related to the contents of Al and Ti in quartz; and (5) a plot of quartz Ti center ESR-SI vs. Al center ESR-SI using data for a γ-ray dose range of 4000–7000 Gy is the best indicator of fluvial sediment provenance using the ESR method.

Keywords: Source-to-sink system, provenance tracing, quartz, electron spin resonance (ESR), Al center, Ti center

Introduction

Quartz is one of the most abundant minerals in Earth’s crustal and surficial systems and is widely distributed in aeolian and fluvial-lacustrine sediments. Its resistance to physical, chemical, and biological weathering has enabled its use for distinguishing sediment sources/provenances (Jacamon and Larsen 2009; Tan et al. 2015; Yan et al. 2017; Götze 2018; Jaeger et al. 2019). Quartz provenance indicators include O18 composition (Jackson 1981; Marin-Carbonne et al. 2011; Aléon et al. 2002; Tanner et al. 2013; Yan et al. 2014), major- and trace-element contents (Rottier et al. 2017; Monnier et al. 2018; Hong et al. 2019), oxygen vacancy detected by electron spin resonance (ESR) (Sun et al. 2007, 2008, 2013; Toyoda et al. 2016; Wei et al. 2017, 2019) and luminescence (Lü and Sun 2011; Chang and Zhou 2019; Nian et al. 2019) methods, and infrared (IR) spectroscopic measurements (Stalder and Neuser 2013; Stalder et al. 2019; Frigo et al. 2019). Previous studies have shown that trace-element contents are useful indicators of provenance (e.g., Goetze and Ploetze 1997; Götze et al. 2004; Chemiak et al. 2007; Jacamon and Larsen 2009; Larsen et al. 2009; Breiter et al. 2013; Ackerson et al. 2015; Rottier et al. 2017; Trail et al. 2017; Tailby et al. 2018), and the substitutional incorporation of trace elements Al, Ge, and Ti into the Si position of quartz has been well established (e.g., Weil 1984, 1993). Trace elements incorporated into the quartz lattice form its corresponding paramagnetic centers (impurity centers, such as Al and Ti centers), which can be detected using ESR analysis (Götze et al. 2004). As these impurity elements reflect the geochemical and geophysical conditions of quartz crystallization, the ESR signal intensities of quartz impurity