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Gamma radiation-induced thermoluminescence, trace element and paramagnetic defect of quartz from the Sambagawa metamorphic belt, Central Shikoku, Japan

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ABSTRACT

This study analyzes the Thermoluminescence (TL) emissions for five emission bands, trace element concentrations and defects in quartz grains extracted from metamorphic rocks and quartz veins in the Sambagawa metamorphic belt, central Shikoku. An emission of 500 nm with 195, 245, and 320–325 °C glow peaks are observed through the lowest to highest grade samples. A 450 nm emission band with intense 195 and 245 °C glow peaks and a 320–325 °C shoulder peak is found in the higher grade samples. A 570 nm emission band with a 170 °C glow peak is observed in the samples derived from the lower grade zones. These characteristics of TL emissions of quartz suggest that they can be an indicator for the identification of rock derived from different metamorphic grades. The higher metamorphic grade samples with 450 nm emission bands in particular show higher intensities of the E_1' center. This relation indicates that the activation of the E_1' center in higher metamorphic conditions possibly contributed to the 450 nm emission band. Also, the 500 nm emission band is generally observed in the samples with the signal intensities of the Aluminum hole center, suggesting that the center is the source of this emission band. We also observed that the lower metamorphic grade samples contain lower signal intensities of the Aluminum hole center, despite higher aluminum concentrations. This inconsistency indicates that the formation of interstitial aluminum ions cause local lattice distortion regions, where self-trapped excitons can be formed and presumably provide the 570 nm emissions.

1. Introduction

Quartz is an essential constituent of igneous, sedimentary, and metamorphic rocks and is a major phase in veins. The crystallization of quartz under various geological environments introduces a number of defects into its crystal lattice. Common defects in quartz can be classified into two types: intrinsic and extrinsic (impurity-related) point defects. The former is formed at vacancies of cations or anions in the crystal lattice, creating, e.g., a group of oxygen-deficient centers (i.e., neutral oxygen vacancy, E_1' center), a group of oxygen-excess centers (i.e., peroxy linkage, peroxy radical), or non-bridging oxygen hole center (NBOHC). The latter is caused by a substitutional or interstitial incorporation of foreign impurity ions in the crystal lattice (i.e., aluminum ion (Al^{3+}), titanium ion (Ti^{4+}), iron ion (Fe^{3+}), and germanium ion (Ge^{4+})), giving rise to the formation of a variety of common impurity-related point defects (Götze, 2009). The intrinsic and extrinsic point defects in the crystal are responsible for a wide variety of thermoluminescence (TL) emissions. The emission of TL from natural and irradiated quartze have generally been found from near-ultraviolet to red spectral regions in a wide range of heating temperature (Franklin et al., 1995; Fujita and Hashimoto, 2007; Hashimoto et al., 1986a, 1986b, 1987; Mckeever, 1984; Rink et al., 1993; Topaksu et al., 2013). It has been known that the TL emission pattern of quartz represents strong dependence on the host rock type (Krbetsche et al., 1997). The TL emission of metamorphic quartz has been reported in a few studies (Sawakuchi et al., 2011; Tan et al., 2009; Topaksu et al., 2012, 2014). However, their properties in relation to trace elements and the point defects included in quartz in relation to

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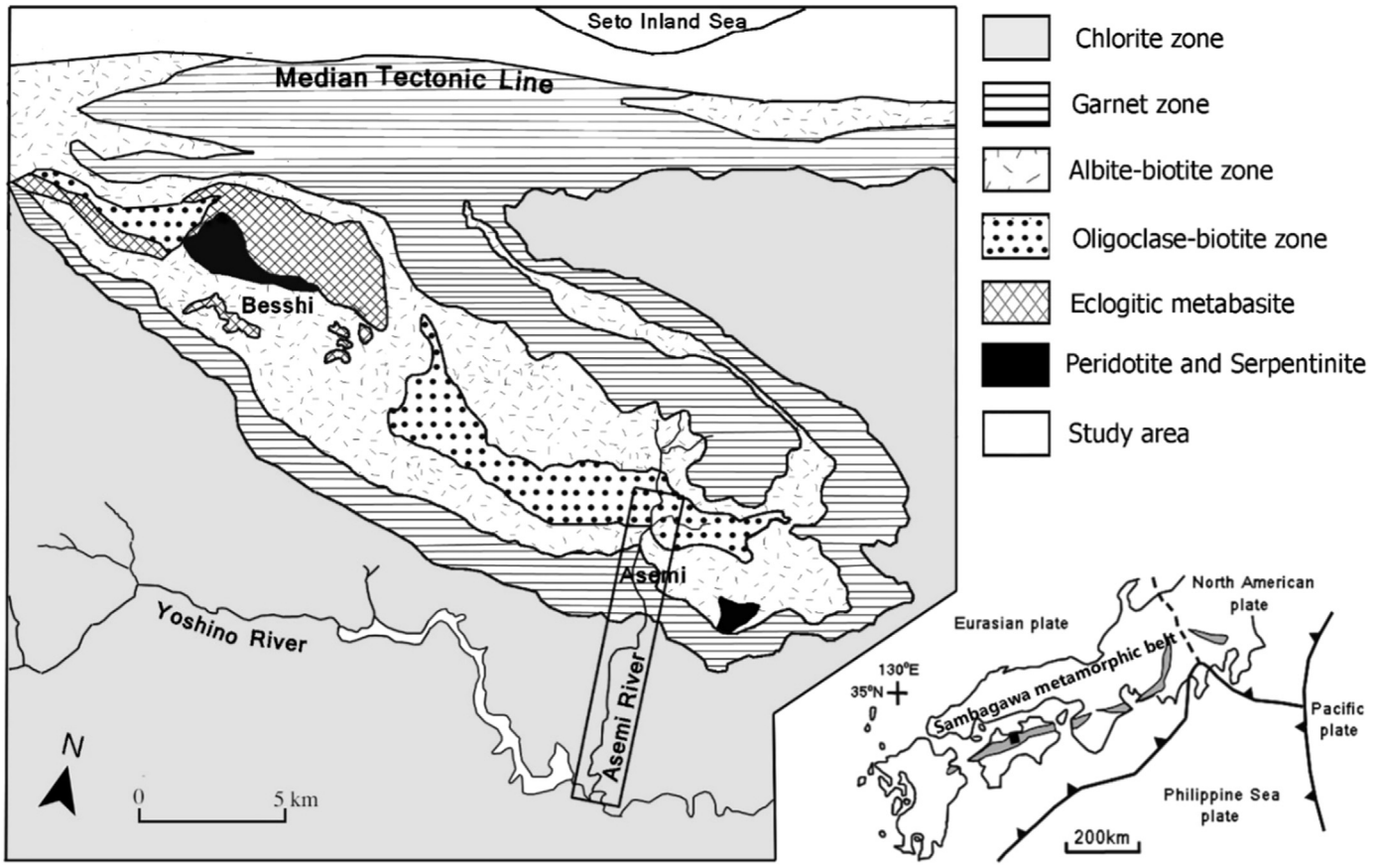

Fig. 1. Metamorphic zonal map of the Sambagawa metamorphic belt in central Shikoku (modified from Higashino, 1990).

the degree of metamorphism are insufficiently understood; this issue serves as the topic of investigation for this paper.

The Sambagawa metamorphic belt is a Cretaceous subduction-related high-pressure type metamorphic belt in southwest Japan. A large number of studies on metamorphism and tectonics have been performed in central Shikoku, where several numbers of zones of metamorphic grade are established. Therefore, this area provides an ideal field for studying TL and related properties of quartz in relation to metamorphism. We measured gamma radiation-induced TL emission, trace element compositions, and paramagnetic point defects of quartz collected along the Asemi River in central Shikoku. The aim of this paper is to clarify how the TL emissions change with metamorphic grade, and how the trace elements and the paramagnetic point defects influence the TL emissions of metamorphic quartz. The information of our study can contribute to establish a catalog of TL emission patterns for source rock identification of quartz grains included in young sediments as a future application.

2. Geology and samples

The Sambagawa metamorphic belt (Fig. 1) extends approximately 800 km from east to west from eastern Kyushu through Shikoku Island to the Kanto Mountains in central Japan, with a width ranging from approximately 20–50 km. The Sambagwa belt is bordered to the north by a large right-lateral strike-slip fault system, the Median Tectonic Line, and is composed of metamorphosed trench-fill deposits, predominantly pelitic schist, psammitic schist, greenschist and siliceous schist and ultramafic bodies (Hide, 1961; Kojima et al., 1956; Okamoto et al., 2000).

Petrological and structural studies have been extensively carried out in central Shikoku, where the lowest-grade pumpellynite-actinolite facies to highest-grade epidote-amphibolite to eclogite facies metamorphic rocks are best exposed (Banno and Sakai, 1989). Based on the appearances of index metamorphic minerals in pelitic schists, the metamorphic grade of the Sambagawa belt can be classified into chlorite, garnet, albite-biotite, and oligoclase-biotite zones in central Shikoku (Higashino, 1990). The peak pressure-temperature (P-T) conditions have been estimated to be 0.55–0.65 GPa and 300–400 °C for the chlorite zone, 0.7–0.85 GPa and 440 ± 15 °C for the garnet zone, 0.8–0.95 GPa and 520 ± 25 °C for the albite-biotite zone, and 0.8–1.1 GPa and 600–650 °C for the oligoclase-biotite zone (Enami et al., 1994). The distribution of those metamorphic grades is due to pile-nappe structure, with the nappes undergoing different P-T paths before integration (Hara et al., 1990; Takasu and Dallmeyer, 1990). In association with the metamorphism, rocks in Sambagawa belt underwent at least three phases of multiple ductile deformation (Hara et al., 1992; Nishikawa et al., 1994; Wallis, 1992).

Samples were collected along the Asemi River in central Shikoku, which transects the metamorphic grade from lowest to highest. The rock types exposed are pelitic schist, greenschist and siliceous schist. Pelitic schist is predominantly exposed trough this river. Greenschist and siliceous schist are distributed in a higher metamorphic grade from the upper chlorite zone. The occurrence of psammitic schist is limited to several outcrops in the mid-chlorite zone. Quartz veins are ubiquitous through the river with pervasive development around the lowest reach of the river in the lower-chlorite zone. In this study, six siliceous schist samples, two pelitic schist samples and nine associated quartz vein samples that are interlaid in the main schistosity forming a tight to isoclinal fold were collected along this river (Fig. 2).