The origin of trapiche-like inclusion patterns in quartz from Inner Mongolia, China

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ABSTRACT

Fibrous amphibole and clay mineral inclusions that form striking trapiche-like star patterns within quartz crystals from Inner Mongolia, China, present a challenge to uncover how these crystals grow and incorporate inclusions in a geological context. We propose that the patterns formed as a result of protogenic clay (ferrosaponite or nontronite) inclusions that were preferentially trapped on rough surfaces during quartz crystal growth. The rough surface texture of these crystals is the result of multiple growth centers during 2D nucleation and spread and split crystal formation. Observations via optical microscopy, cathodoluminescence, and three-dimensional micro-CT scanning highlight how the exterior surface textures on the termination of a complete quartz crystal mimic its interior inclusion patterns. Cathodoluminescence images, as well as varying aluminum concentrations along a core-to-exterior transect in a quartz crystal slice, suggest that the formation fluid underwent a heterogeneous chemical history. Measurements of Ti and observations of fluid inclusions suggest the quartz formed at a temperature of under 348 °C. This study presents the details surrounding split crystal growth in quartz in a natural geological setting, which has implications for inspiring new materials and may serve as an indicator for turbid and highly supersaturated formation fluid conditions in geological formations.

Keywords: Split crystal growth, quartz, inclusion incorporation, trapiche-like, Huanggang deposit, micro-CT scanning

INTRODUCTION

Quartz is the predominant mineral in continental supracrustal rocks. Colored and/or patterned quartz varieties (e.g., smoky quartz, pink rose quartz, golden yellow citrine, purple amethyst) are much sought after as cut gems (Webster 1995) or as hand specimens for mineral collectors (Rykart 1995; Lauf 2012). During growth, quartz crystals may entrap fluids or mineral species that help unravel their growth conditions and history (e.g., Ihinger and Zink 2000). In this study, we investigated mineral inclusions in quartz crystals from the Huanggang Fe-Sn skarn deposit in Inner Mongolia, China, which are arranged in trapiche-like patterns observed in slices cut perpendicular to the quartz c-axis (Fig. 1). This particular form of included quartz was first described by Laurs (2016) as being similar to quartz slices with radiating fibers described from Colombia (Krzemnicki and Laurs 2014). Star patterns in minerals have long enchanted mineralogists, gemologists, and materials scientists, with stars ranging from trapiche emeralds (Pignatelli et al. 2015); to trapiche-like patterns in quartz (Okada et al. 2017; Sun et al. 2018) and cordierite (Vertriest et al. 2016); to asterism in corundum (Nassau 1968); to cordierite-indialite intergrowths (sakura ishi) altered to muscovite colloquially known as cerasite or “cherry blossom stone” (Rakovan et al. 2006); and pinwheels of color variation in sector zoned crystals (Vasconcelos et al. 1994; Rakovan 2009).

All of these examples of stars form through very different mechanisms, and the patterns we observe in these quartz slices from the Huanggang mine are no exception. Here, we use a multi-method approach to characterize the mineral inclusions and explain how the growth history of these quartz crystals led to the striking oriented inclusion patterns. Understanding how crystal growth is linked to inclusion incorporation in nature to form these remarkable interior patterns is a fundamental topic in mineralogy and may be applicable to materials science. In this case, we suggest that the growth history of the quartz crystal had a profound influence on the incorporation and formation of inclusion patterns. In particular, we examine split crystal growth and two-dimensional nucleation growth mechanisms. The macroscopic surface roughness associated with these two mechanisms leads to entrapment and inclusion of foreign phases, and the spatial distribution of rough areas accounts for the internal patterns observed.

GEOLOGICAL SETTING

The included quartz crystals studied here are reported as originating from the Huanggang Fe-Sn skarn deposit in Inner Mongolia, China (Laurs 2016). This deposit is known to produce a plethora of minerals from the seven mines that span across an area of ~2.5 by 20 km (Wang et al. 2001; Ottens and Neumeier 2012). Many of these minerals exhibit morphologic characteristics similar to the those seen in our quartz samples (Ottens and Neumeier 2012). Other quartz specimens from these Huanggang Sn-skarn deposits include the aggregate “artichoke...