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(Research Article)

Mechanism of Opal-CT deposit from the Lam Narai Volcanics in Lop Buri, Thailand by using Petrography

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Abstract

Common opals were discovered in the rhyolite host rock, where various structural features such as cavities, fractures, and veins are observed. These voids served as pathways for the infiltration of silica-rich fluids originating from meteoric water, establishing a hydrothermal connection. The aqueous solution derived from meteoric water actively dissolves silica from the rhyolite host rock, thereby increasing the silica saturation within the fluid. Subsequently, the silica-saturated hydrothermal fluid fills the cavities and veins within the host rock. The margin of the host rock underwent alteration as it interacted with infiltrating hydrothermal fluid in a phenomenon known as hydrothermal fluid-rock interaction. At the periphery of the cavities, quartz crystals begin to form, effectively reducing the concentration of dissolved silica in the solution. As a result, the subsequent precipitation of amorphous opals occurs, predominantly within the inner part or central region of the vein or cavity. The formation of opals associated with Lam Narai volcanic activity occurred at a relatively high temperature of about 105-170 °C through a hydrothermal process.

Keywords: Common opal; Opal-CT; Origin; Petrography

1. Introduction

Opal has the chemical formula $SiO_2.nH_2O$. The absence of crystallinity in opal results in the peculiar optical phenomenon known as opalescence (Marlow, Sharifi, Brinkmann, & Mendive, 2009). According to their structure and crystallinity, opals are divided into three categories: opal-A for amorphous opal, opal-CT for opals with disordered cristobalite and tridymite stacking, and opal-C for opals with cristobalite.

According to Kile (2002), the precipitation of opal is influenced by several factors, including silica content, temperature, and pressure. The formation of opal and quartz involves the infiltration of silica-supersaturated fluids, followed by crystallization under relatively low-temperature conditions (typically below 300°C) and low-pressure conditions. The silica within these fluids is presumed to exist in a monomeric form, such as $Si(OH)_4$. This infiltration process occurs through cracks and microscopic pores in the surrounding geological matrix.

The filling of silica-rich cavities originates from hydrothermal fluids that develop during the later stages of geological processes. These fluids derive from the surrounding host rock as well as local groundwater sources. It is important to emphasize that the silica present in opal represents a secondary alteration and dissolution product of the enclosing rhyolite. As a result of this process, the formation of siliceous gel, clay, and zeolites can occur.

One of the significant places in Thailand for researching the genesis processes of hypothetical volcanic opals is Lop Buri, which features opal deposits linked to the Lam Narai Volcanics. Common opals and varieties of quartz, including

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chalcedony, quartz, and agate, have been extracted from in situ soil or basalt and rhyolitic tuff rubble. The volcanic succession in this area is composed of Late Cenozoic basaltic flows, Tertiary andesite, rhyolite and rhyodacite, and Upper Permian-Lower Triassic andesite porphyry. The primary objectives are to elucidate the mechanism of opal using petrography.

2. Methodology

2.1. Geology of Lam Narai Volcanics, Lop Buri Province

Lam Narai rhyolitic lavas are associated with pyroclastic deposits such as massive rhyolite, glassy breccia, pitchstone perlite, and pyroclastic deposit separated into pyroclastic flow deposit and lithic lapilli layer (Figure 1). The volcanic eruption created layers of acidic pyroclastic deposits at the bottom, overlain by glassy layers with rhyolite on top. The pyroclastic flow deposits and rhyolite are found associated with glassy rocks, overlain by more glassy rock. Rhyolite lava occurs in plugs and domes, displaying flow layers overlying pyroclastic flow and a glassy bed. Typically, rhyolite is found overlying trachyandesite and basalt. However, basalt is found underlying rhyolite in some areas.

In a comprehensive study conducted by Panjai (2015), a detailed examination of chalcedony localities in Lop Buri province was carried out, focusing on their association with three types of host rocks: rhyolite, basalt, and perlite or pyroclastic layers. These localities revealed intriguing characteristics and variations, shedding light on the diverse formations of chalcedony in the region.

Chalcedony and agate, composed of 98-99 wt% SiO_2, are not genetically related to their host rocks, such as rhyolite, dacite, and basalt. The silica necessary for the formation of agate and chalcedony is believed to have originated from hydrothermal fluids infiltrating through the underlying high-silica volcanic rocks and subsequently precipitating in cavities. The observed mineral textures in these samples suggest that the precipitation likely occurred at relatively low temperatures (up to 200°C) (Khotchanin, 2004).

Common opal showed SG of samples ranging between 1.820-1.950, and RI varied within 1.43-1.44. The rhyolite host rock had a silicic composition and showed a sub-alkaline magma series. The initial silica required for opal formation may have infiltrated through the underlying high-silica volcanic rock and precipitated in the hollow from fluids. According to SEM results, the fluid was hydrothermal. The XRD results indicated that opal samples were opal-CT and showed morphology with fibrous/platelet/tablet texture. The XRD pattern displayed the characteristic diffraction line of the cristobalite-tridymite-type paracrystalline structure, identifying a volcanic source and distinguishing a complex opal with elevated contents of metal impurities (Thitiwatthanakarn, Suntikoon & Wisessan 2023).

2.2. Materials and equipment

The rock samples for the petrographic study were collected from outcrops in the study area and were subsequently processed at Chiang Mai University. These samples were prepared as thin sections and polished sections for analysis under a microscope.

3. Result and discussion

3.1. Lithology and Petrography

3.1.1. Megascopic Characters

The rock exhibits a brownish-red to red color with a porphyritic texture. Plagioclase phenocrysts are commonly observed, usually appearing in a tabular or platy shape, with sizes ranging up to 1.00-2.00 mm across. These phenocrysts often exhibit an alignment texture. The rock surface shows high weathering, appearing in shades of brown to brownish-red. Opal small veins frequently cross-cut the rhyolite samples, and opal is found in vesicle and fracture fillings.

3.1.2. Microscopic Characters

The fine-grained rock samples are moderately porphyritic. Phenocrysts and microphenocrysts consist of plagioclase/K-feldspar + biotite ± opaque mineral. Plagioclase phenocrysts are generally anhedral to subhedral, with sizes up to 0.5-1.5 mm across, exhibiting zonal patterns and polysynthetic twins. Plagioclase also shows rounded edges, embayed outlines, and sieve textures, with some crystals possibly replaced by clay minerals and sericite.

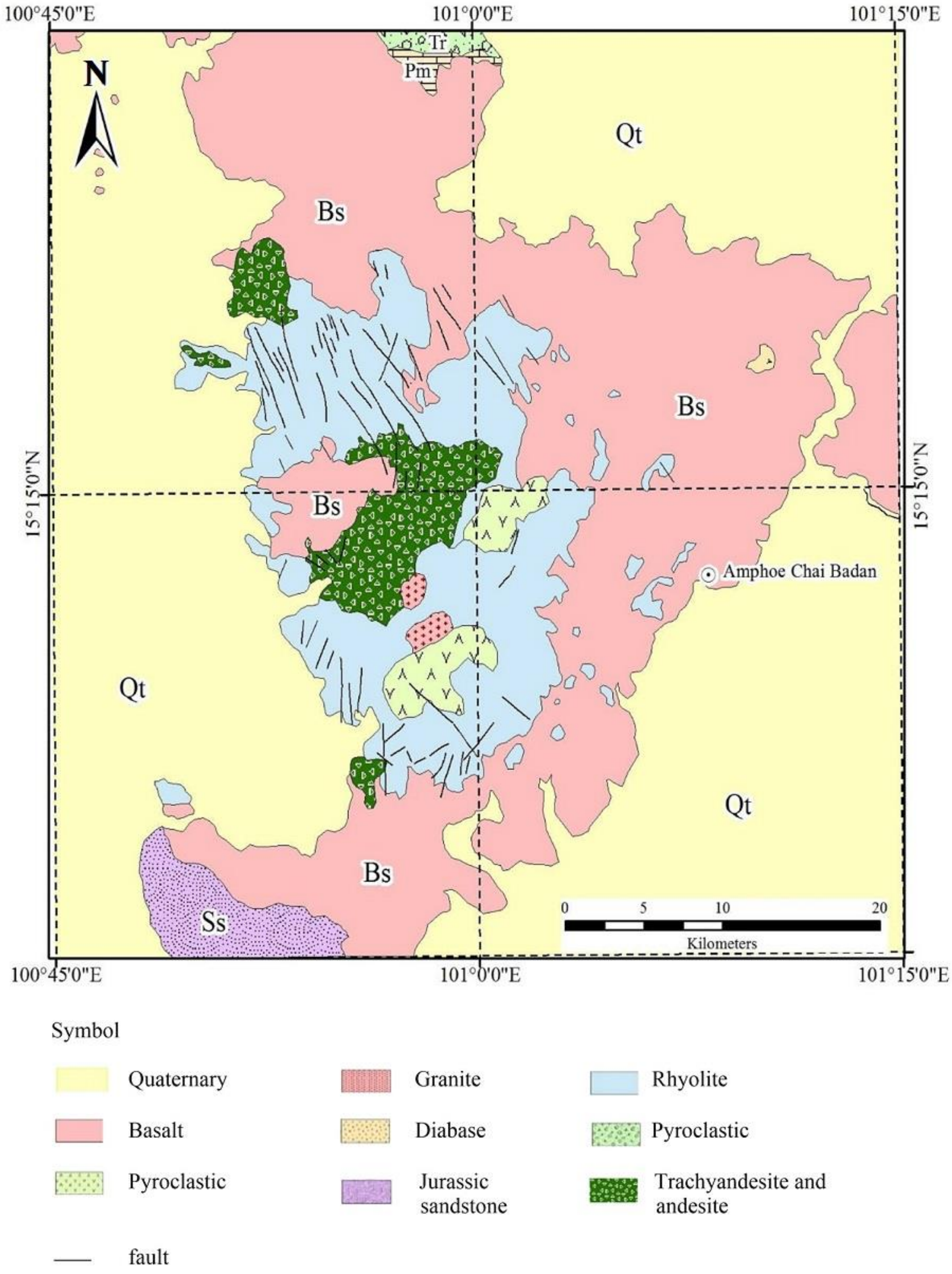

Figure 1 Geological map of the Lam Narai area shows distribution of rock type , with study areas represented by bold squares. Lines present topographic map sheet (scale 1:50,000) at right top corner (Modified from (Intasopa,1995))

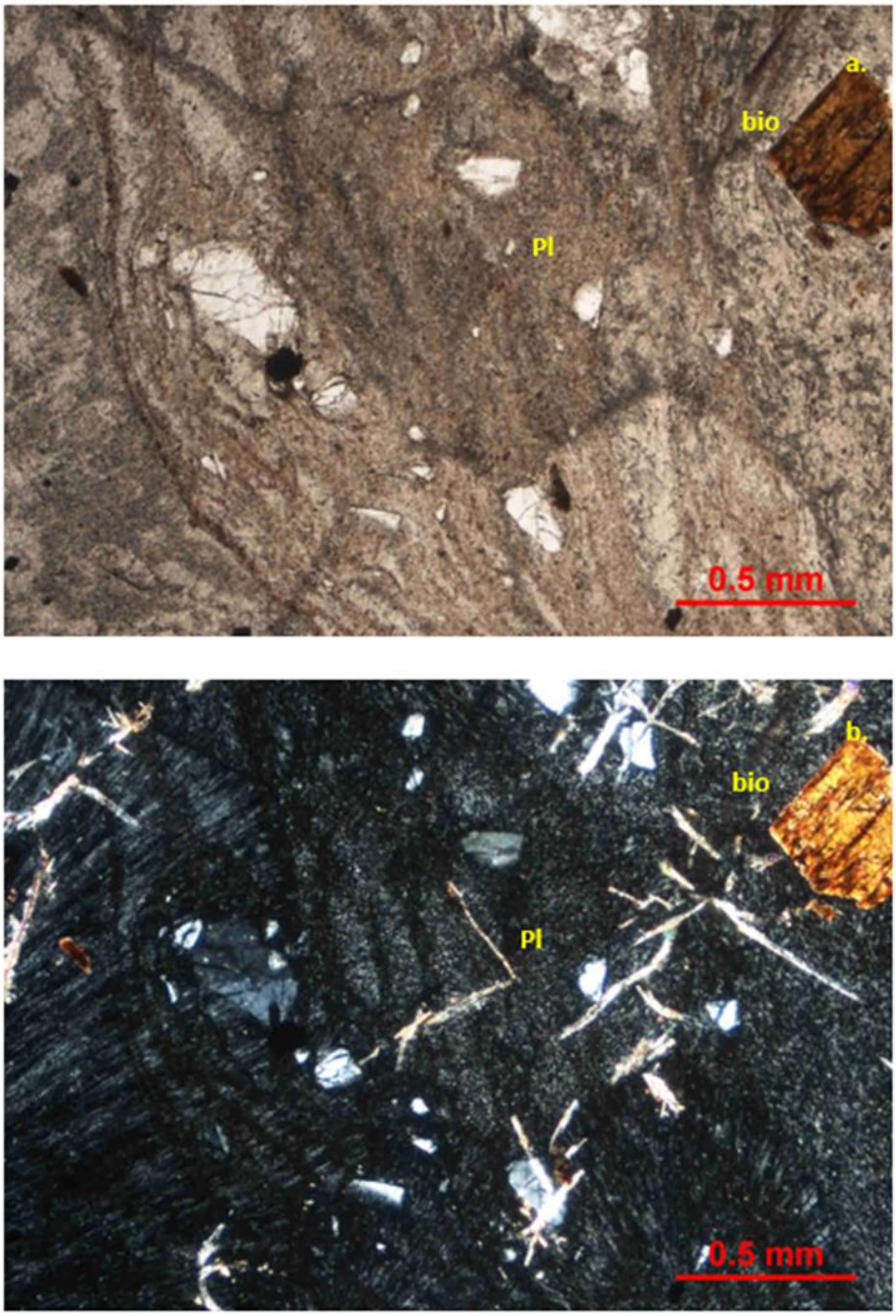

Figure 2 Photomicrographs of sample R 007 shows porphyritic texture with biotite megacryst and rounded edge plagioclase phenocrysts in glassy groundmass that devitrified to spherulite in a. ordinary light and b. crossed polar.

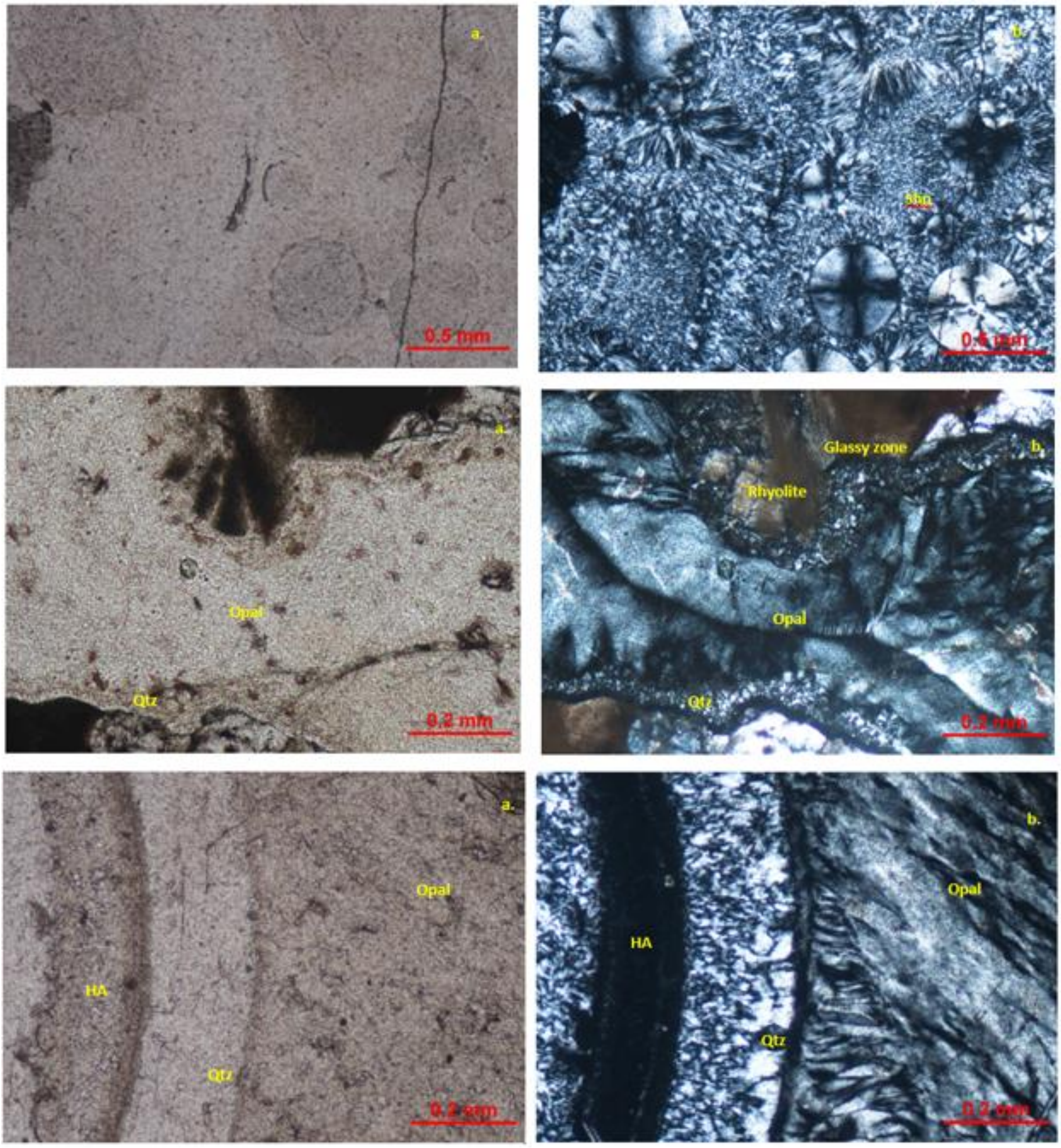

Figure 3 Photomicrographs of sample shows "spherulite-liked" (Shp) of quartz aggregate (R001), layering texture that composed of hydrothermal alteration (HA) rind, quartz (Qtz) band, and opal (Opal) within a horizontal layer with a close-packed spherical or divergent aggregates in a. ordinary light and b. crossed polar.

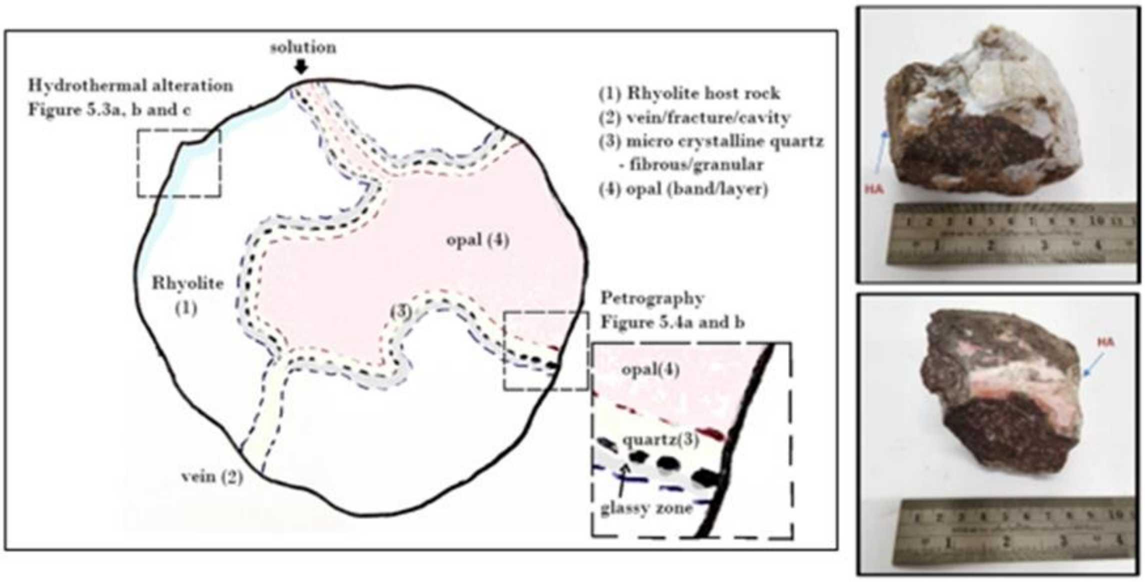

Figure 4 Model shows the formation of opal associated with quartz depicted from petrographic studies of in situ opal in the host rhyolite and hydrothermal alteration (HA) rind in opal sample.

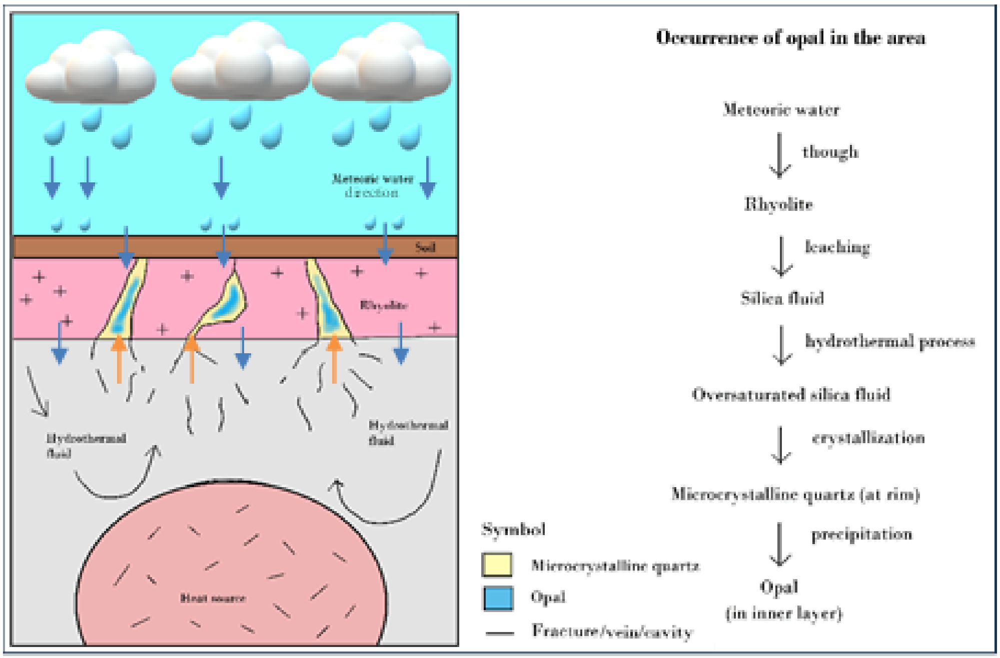

Figure 5 Model shows the occurrence of opal in the rhyolite host rock.

K-feldspar phenocrysts are commonly anhedral to subhedral, showing rounded edges and occasional embayment. Some crystals may be replaced by clay minerals. Biotite phenocrysts are subhedral to euhedral, with some flakes slightly replaced by Fe-Ti oxide and hematite/iron oxide. Opaque microphenocrysts exhibit anhedral to subhedral outlines and can be both primary and secondary minerals.

The groundmass is mostly glassy and has undergone both high-temperature devitrification and low-temperature recrystallization. Plagioclase is the dominant component, with minor amounts of biotite, spherulite, and opal. Spherulitic groundmass with diameters up to 0.5-4 mm is present, resulting from high-temperature devitrification. Isolated spherulites nucleated on pre-existing phenocrysts, primarily plagioclase. Opal is a common secondary mineral found in rock samples, often filling tiny fractures or veins.

Cavities or fractures within the rocks were typically filled with silica fluid, which over time crystallized into microcrystalline quartz. Opals, formed during this process, were observed in the inner layer of the cavity. Petrographic studies indicated that microcrystalline quartz exhibited a fibrous microstructure, with fibers oriented perpendicularly to both layering and exposed surfaces.

Strata-form horizontal layering was exclusively observed within certain cavities, appearing as quartz layerings that transitioned sharply to opal in the central part. This layering was categorized into two forms: horizontal-layered fine quartz and opal. Fibrous quartz aggregates within the horizontal layer often exhibited a close-packed semispherical to spherical or divergent configuration, occasionally appearing deformed or compressed.

The wall layer and the strata-form horizontal layering, consisting of fine quartz or densely packed radiating fibers, often transitioned into opal, with some zones showing signs of hydrothermal alteration. Opals primarily occurred in the central portion of the cavity or within the inner part of the vein.

When observed in thin sections, microcrystalline quartz exhibited a distinctive phenomenon known as rhythmic extinction banding, appearing as zigzag optical extinction bands along the fibers when viewed between crossed nicols. A similar occurrence was frequently observed in chalcedony as well (Frondel, 1978).

3.2. Mechanism of Opal-CT deposit

The petrographic analysis of microcrystalline quartz and opal samples within various host rocks reveals distinctive fibrous textures. These fibers are oriented perpendicular to both the layering and the exposed surfaces. In the wall layering, numerous nucleation points on the wall surface give rise to fibers that radiate towards the center of the cavity, resulting in a variety of fibrous textures. When a cross-section is cut parallel to the elongation of the fibers, a characteristic rhythmic extinction banding known as "Runzelbanderung" becomes apparent when viewed between crossed polarizers. The layering can be classified into two types: horizontal-layered fine quartz and opal. The horizontal-layered quartz exhibits various fibrous forms, with long fibrous or closely packed radiating spherulite-liked quartz being the most common, often appearing compressed. Opal, on the other hand, predominantly occurs within the inner part or central region of the vein or cavity.

Depicted in Figure 4, within the rhyolite host rock (1), various structural features such as cavities, fractures, and veins (2) can be observed. These voids provided a pathway for the infiltration of silica-rich fluids originating from meteoric water, thereby establishing a hydrothermal connection.

The aqueous solution derived from the meteoric water actively dissolves silica from the rhyolite host rock, consequently elevating the silica saturation within the fluid. Subsequently, the silica-saturated hydrothermal fluid proceeds to fill the cavities and veins present within the host rock. The margin of the host rock has undergone alteration as it interacted with infiltrating hydrothermal fluid in a phenomenon known as hydrothermal fluid-rock interaction (Figure 4). At the periphery of the cavities, quartz crystals (3) begin to form, effectively reducing the concentration of dissolved silica in the solution. As a result, the subsequent precipitation of amorphous opals (4) ensues.

It is worth noting that the crystallization time of quartz greatly influences its resulting texture. Rapid crystallization leads to the formation of a fibrous texture, while a slower crystallization process gives rise to a granular texture (Dunbar and McLemore, 2000).

4. Conclusion

The widespread occurrence of opal and other silica minerals such as chalcedony, agate, and quartz associated with Lam Narai volcanics in Lop Buri poses a genetic puzzle in Thailand's mineral deposits. The volcanic rocks, exhibiting both mafic and felsic compositions, erupted in several episodes during the Tertiary and Cenozoic periods, covering a vast area. This geological setting provides a unique opportunity to investigate the characteristics of opals and their genetic connection with the host volcanic rocks.

The host rocks, compositionally rhyolite of the sub-alkalic magma series, exhibit a porphyritic texture with quartz, K-feldspar, plagioclase, and biotite phenocrysts in a vitreous groundmass. The glassy groundmass suggests rapid cooling of the magma, likely caused by the rapid release of volatile content, also known as gas escaping.

Opal samples (Figure 5) were deposited at the surface as a secondary phase; therefore, it is generally believed that meteoric water derived from precipitation at Earth's surface, heated in geothermal settings up to 350 ^{O}C

(Schwarzenbach and Steele-MacInnis, 2020), served as a major source of fluid involved in opal crystallization. Opals formed at low temperatures through hydrothermal alteration in volcanic rocks, and the type of hydrothermal fluid was derived from meteoric water, as indicated by its pH and temperature related to opal precipitation.

Compliance with ethical standards

Acknowledgments

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Disclosure of Conflict of interest

We declare that there are no conflicts of interest or competing interests associated with the publication of this manuscript. We have no financial or personal relationships with any individuals or organizations that could inappropriately influence our work. Additionally, we confirm that there are no affiliations with any institutions or products mentioned in the manuscript that could pose a conflict of interest.

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