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Opal as a U–Pb geochronometer: Search for a standard

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Abstract

We report structural, geochemical, and TIMS U–Th–Pb and U-series isotopic data for several samples of precious and common opal, which we tested as potential standards for ion microprobe and LA-ICPMS isotopic studies. The precious opals are low in U, contain high concentration of common Pb, and are not suitable for U–Pb age determinations. In contrast, all studied samples of common opal are enriched in uranium and contain sufficiently radiogenic Pb for precise calculations of $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ dates. Complications in the U–Pb systematics are due to the presence of ubiquitous unsupported ^{206}Pb, probably derived from initial excess ^{234}U and possibly other intermediate products of ^{238}U decay, elevated concentrations and possibly anomalous isotopic composition of initial Pb in some of the opals, and the presence of two opal generations of different ages in one of the samples. Despite these imperfections, two out of five studied common opals are acceptable as U–Pb and U-series standards, at least in the interim. The data obtained in this study can be used to guide further search for a better opal standard.

Keywords: Silica; Opal; Chalcedony; U–Pb; U-series disequilibrium; XRD

1. Introduction

Uranium–lead method is widely used for dating processes that fractionate U from Pb. Four groups of processes are well known to effectively fractionate these elements: magma crystallization (fractionation depends on compatibility of U and Pb in minerals), evaporation and condensation (fractionation due to higher volatility of Pb), dissolution and precipitation (fractionation due to higher solubility of oxidized U in water), and sub-solidus mineral growth during metamorphism. Successful application of U–Pb geochronometer depends on finding appropriate minerals that concentrate U and exclude Pb during their formation, but preserve radiogenic Pb and other decay products of uranium formed during the lifespan of the mineral. Crystallization of magma is successfully dated using a variety of igneous minerals enriched in U and depleted in Pb: zircon, baddeleyite, monazite and others. Volatility-related Pb–U fractionation makes it possible to date refractory meteorite components: chondrules and Ca–Al rich inclusions, as well as bulk meteorites depleted in volatile elements. Low mobility of Pb compared to mobility of U in oxidizing near-neutral pH water (Gaillardet et al., 2003) facilitates high U/Pb ratios in hydrogenic (water-laid) minerals such as calcite and amorphous silica.

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Table 1
Sample descriptions and X-ray diffraction data

Sample	Common or precious opal	Origin	Appearance	UV fluorescence	Material analyzed for X-ray diffraction (XRD)	XRD patterns	Classification based on XRD
E1989	Common	Kamloops Lake, British Columbia	Thin (<10 mm) layer of clear, colourless, optically homogeneous amorphous silica with botryoidal texture.	Brightness is relatively low and slightly variable at millimetre scale.	Two colourless transparent fragments with slight opalescence	Both fragments are basically X-ray amorphous. One of the films gave a hint of one very weak line at approximately 4 Å (identified visually), consistent with the opal-CT or opal-C.	Opal-A, with a possible small addition of opal-CT or opal-C
M21006	Common	Leo, Wyoming	Massive white translucent opal intersected by veins of clear opal. The thickness of the veins varies from 2–3 mm to less than 0.1 mm.	Both translucent matrix and clear veins are brightly fluorescent. Brightness is variable but does not correlate with veining	Four fragments: two colourless transparent (vein), and and two translucent (matrix)	All four films suggested relatively low degree of crystallinity (Fig. 2a,b) and matched the data for opal-CT of Graetsch (1994). Translucent variety shows slightly higher degree of crystallinity.	Opal-CT
M21277	Common	Humboldt County, Nevada	Massive yellowish opal, with no macroscopic heterogeneity visible in plain light. Microscopic netlike structure, clearly visible in thin shards of this opal in transmitted light, may suggest possible diatomite origin.	Relatively homogeneous bright fluorescence with some variation in brightness between broad (ca. 5–20 mm), approximately parallel zones.	Two visually identical milky translucent fragments	Very weak and diffuse diffraction patterns.	Opal-CT
BZ-VV	Common	Virgin Valley, Nevada	Similar to M21277. Previously studied by Zielinski (1982).	Similar to M21277	Not analyzed	Not analyzed	Not analyzed
HV-1	Common	Harper Valley, Nevada	Mostly massive translucent silica, which locally, grades into cloudy and opaque white varieties. Visually most heterogeneous sample among the studied common opals.	Relatively bright but variable.	Four fragments: (1) Translucent, slightly cloudy. (2) Colourless transparent. (3) Colourless, translucent to milky. (4) White, translucent.	(1) Well crystallized quartz pattern. (2) X-ray amorphous with no discernable lines. (3) Mixed pattern of well crystallized quartz with a weaker, more diffuse pattern of moganite. (4) Mixed pattern of crystalline quartz and cristobalite.	(1) Quartz (2) Opal-A (3) Quartz + moganite (4) Quartz + cristobalite
Assorted	Precious	Unknown	Green-red opalescence in plain light. Visually homogeneous.	None	Not analyzed	Not analyzed	Not analyzed
Bone	Precious	Unknown	Green-red opalescence in plain light. Shadow structure suggesting that it was formed by silicification of a bone.	None	One opalescent fragment	Very weak and diffuse diffraction patterns	Opal-CT
M42001	Precious	Australia	Green-red opalescence in plain light. Visually homogeneous.	None	One opalescent fragment	X-ray amorphous	Opal-A