Common gem opal: An investigation of micro- to nano-structure

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ABSTRACT

The microstructure of nearly 200 common gem opal-A and opal-CT samples from worldwide localities was investigated using scanning electron microscopy (SEM). These opals do not show play-of-color, but are valued in the gem market for their intrinsic body color. Common opal-AG and opal-CT are primarily built from nanograins that average ~25 nm in diameter. Only opal-AN has a texture similar to that of glass. In opal-AG, nanograins arrange into spheres that have successive concentric layers, or in some cases, radial structures. Common opal does not diffract light because its spheres exhibit a range of sizes, are imperfectly shaped, are too large or too small, or are not well ordered. Opal-AG spheres are typically cemented by non-ordered nanograins, which likely result from late stage fluid deposition. In opal-CT, nanograins have different degrees of ordering, ranging from none (aggregation of individual nanograins), to an intermediate stage in which they form tablets or platelets, to the formation of lepispheres. When the structure is built of lepispheres, they are generally cemented by non-ordered nanograins. The degree of nanograin ordering may depend on the growth or deposition rate imposed by the properties of the gel from which opal settles, presumably, fast for non-ordered nanograin structures in opal-CT to slow for the concentric arrangement of nanograins in the spheres of opal-AG.

Keywords: Opal-A, opal-CT, common opal, structure, SEM, nanograin

INTRODUCTION

Opals are natural hydrous silica with either amorphous (opal-A) or disordered cristobalite/tridymite structures (opal-CT). Gem opal is best known for the highly prized variety showing diffraction of visible light, called play-of-color opal. Yet, the most widespread gem varieties, so-called common opals, do not show play-of-color but are valued in the gem trade for their attractive body colors. The only detailed studies of common opals reported to date are for Australian potch opals (Bayliss and Males 1965; Barnes et al. 1992) and biogenic opals (e.g., Kastner et al. 1977; Botz and Bohrmann 1991; Graetsch 1994; Elsass et al. 2000). The picture emerging from the previous studies is that opal-A consists of regular spheres and opal-CT of spherical aggregates of plate-like cristobalite crystallites, called lepispheres. In this study, we characterized a large number of common gem opals from a wide variety of geologic settings and localities to provide a more complete understanding of the structure of these materials and to determine if they are consistent with this model. We do not consider here biogenic opals, which are not used as gems.

BACKGROUND

There are three recognized opal varieties: opal-A (amorphous); opal-CT (cristobalite-tridymite, which consists of disordered α-cristobalite with tridymitic stacking), and opal-C (which

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the proportion of cristobalite much greater than that of tridymite; we did not encounter this type in our study). The basic types are typically identified using X-ray diffraction (XRD) (e.g., Jones and Segnit 1971; Elzea and Rice 1996), but opal-A can also be distinguished from opal-C and -CT on the basis of Raman scattering spectroscopy (Ostrovoumov et al. 1999).

Langer and Flörke (1974) subdivided opal-A into two groups on the basis of features observed in small angle X-ray and neutron-scattering experiments: (1) opal-AN (network), or “hyalite,” which shows only diffuse scattering of X-rays or neutrons at small angles, suggesting that it has a glass-like structure; and (2) opal-AG (gel), which is the most widespread variety. In small-angle X-ray or neutron patterns, it exhibits obvious intensity maxima superimposed upon the diffuse scattering, indicating a structure consisting of packed silica spheres. The term opal-AG typically is synonymous with opal-AG.

Structure of opal-AG

The first scanning electron microscopy (SEM) study of the structure of opal was published by Jones et al. (1964) for an Australian play-of-color opal-AG. They demonstrated that it is constructed of a near-perfect 3-D stacking of monodisperse silica spheres, which diffracts visible light if the spheres have diameters ranging from ~150 to 300 nm (Sanders 1964). Common opal-AG, named potch opal by Australian miners, appears to be made of the same type of spheres (Darragh and Gaskin 1966; Rau and Amaral 1969; Sanders and Darragh 1971). The absence of visible