ORIGIN AND TIMING OF FORMATION OF PRECIOUS BLACK OPAL NOBBIES AT LIGHTNING RIDGE

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Black opal, the most unique and economically important opal in the world, is only found at Lightning Ridge in northern New South Wales. Only a handful of studies have been published on black opal, all of which suggest that black opal formed in the Cretaceous and Early Tertiary (Darragh *et al.* 1965, Watkins 1984, Pecover 1996, Behr 2001, Behr *et al.* 2000, Townsend 2001). Determining the origin of black opal is important for our understanding of sedimentation and regolith evolution, silica transport pathways and to improve the value of the mineral resource economy of New South Wales. This study aims to determine the age and origin of Lightning Ridge black opal.

All of the significant opal deposits in Australia occur within sedimentary deposits above or near the Great Artesian Basin. Vegetation, soil and geological environments are similar for all opal deposits. North of Lightning Ridge at Hebal, precious boulder opal is mined and, as the name suggests, it is found on the surface of Quaternary gravels. The mining area of Lightning Ridge is extremely flat with slight ridges consisting of outcropping Cretaceous sediments. It is below these ridges that the precious black opal is mined. The town is 150 m above sea level with the mining area ranging from 137 m to 162 m above sea level. The area is structurally undeformed with little outcrop

Several conceptual models have been suggested to explain black opal formation: 1. weathering; 2. syntectonic; and 3. Cretaceous microbes. We have established an alternative model for black opal formation based on the use of stable isotopes (^{13}C, deuterium and ^{18}O), major and trace elements in sediments, ground water analysis and radiocarbon dating.

METHODS

Fieldwork was conducted during two one-week trips in March and June 2002. 13 mines were visited and sampled to study the similarities or differences of the opal in mines of the Lightning Ridge area. Ironstone, silcrete, sandstone, claystone, potch and opal (where possible) were sampled. Ground-water samples were collected from 4 sites; pH, alkalinity, electrical conductivity and dissolved oxygen were measured on site, and anions, cations ^{13}C, deuterium and ^{18}O were analysed in appropriate laboratories.

Opal and sediment thin-sections were analysed for biological evidence and mineralogical compositions. The thin-sections were analysed using transmitted, reflected and scanning electron microscopy. X-Ray Fluorescence was used to determine the bulk major element composition of the Lightning Ridge sediments. Opal and sediment stable isotopes of ^{13}C, ^{18}O and deuterium were analysed by mass spectrometry. Trace elements were analysed *in situ* using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at the Research School of Earth Sciences (RSES) at the Australian National University. The opals were ^{13}C dated using the mass spectrometer at Research School of Physics (RSPhys), Australian National University.

RESULTS

Thin-section analysis and XRF bulk rock geochemistry provides information to classify the rock types. The stratigraphic sequence of Lightning Ridge is similar throughout the area. From surface to opal level the sedimentary sequence consists of rudites, silcrete, arenites and the argillite (opal host). Opal is always found in the argillite, which occurs between 6 m and 25 m below the surface. The opal thin-sections helped to identify microbacterial evidence and microstructures within the precious opal.

Using deuterium, ^{18}O and ^{13}C (the heavy stable isotopes), the fluid source can be determined (^{18}O & D) and evidence of biological activity assessed (C^{13}), thus the origin of the silica for the precious opals and the carbon making up the black nobbie can be inferred. The $\delta^{13}C$ and $\delta^{18}O$ stable isotopes indicate that the carbon within the opal is organic (Figure 1). The deuterium stable isotopes (Figure 2) indicate that the opals are not water dominated but have a low water/rock ratio. It is evident that the opals are not derived from hydrothermal fluids.

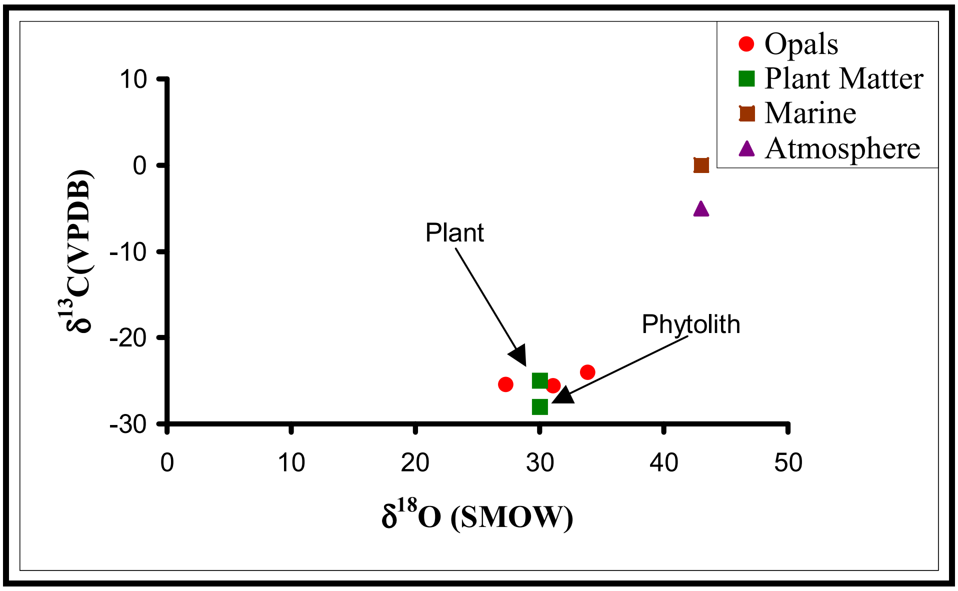

Figure 1: ^{18}O versus ^{13}C stable isotopes. Plant and phytolith data values are from Webb & Longstaffe (2000). The marine and atmosphere values are put in for contrast and the values are from Ehleringer & Cerling (2002).

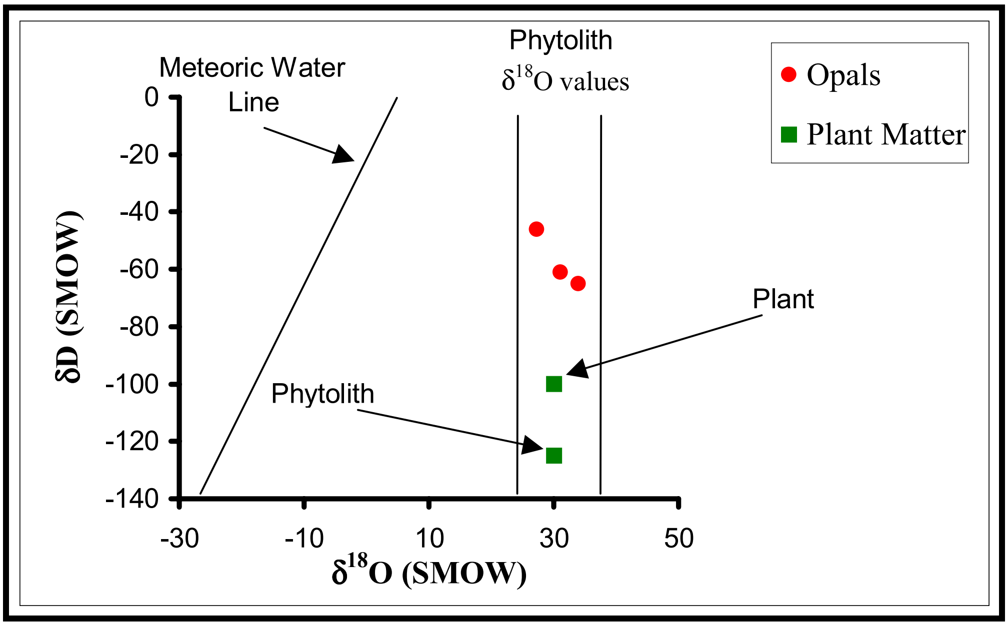

Figure 2: Deuterium versus ^{18}O. The vertical lines represent $\delta^{18}O$ values for phytoliths (Webb & Longstaffe 2000). Individual plant and phytolith points are also plotted from values published by Webb & Longstaffe (2000). Meteoric water line is plotted from the equation $\delta D = 8\ \delta^{18}O + 10$ (Craig 1961).

Trace element compositions indicate that the black potch has higher concentrations than clear potch. The trace element patterns also indicate that the sandstone and the claystone at Lightning Ridge are geochemically the same. Trace element patterns between the opal and host sediment are similar in some cases but not in others.

The radiocarbon dating was conducted because microbacteria were discovered within the thin-sectioned opal. Radiocarbon dating determines the age of carbon since it was either no longer in equilibrium with the atmosphere or since death. Accurate dating using this technique is only possible if there is carbon in the opal and if the organic material within the opal was deposited within the last 40,000 years (Gillespie 1986). The carbon within the black opal nobbies is organic and is younger than previously published, dating to between 1,000 and 7,000 BP (calibrated years).

CONCLUSION

Lightning Ridge opals are biogenic and contain organic carbon within them that is 1,000–7,000 years old. The results of this study make all previous models for Lightning Ridge black opal formation untenable.

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Acknowledgments: KD thanks the NSW Department of Mineral Resources and CRC LEME for financial support.