THE ORIGIN OF PRECIOUS OPAL
A new model

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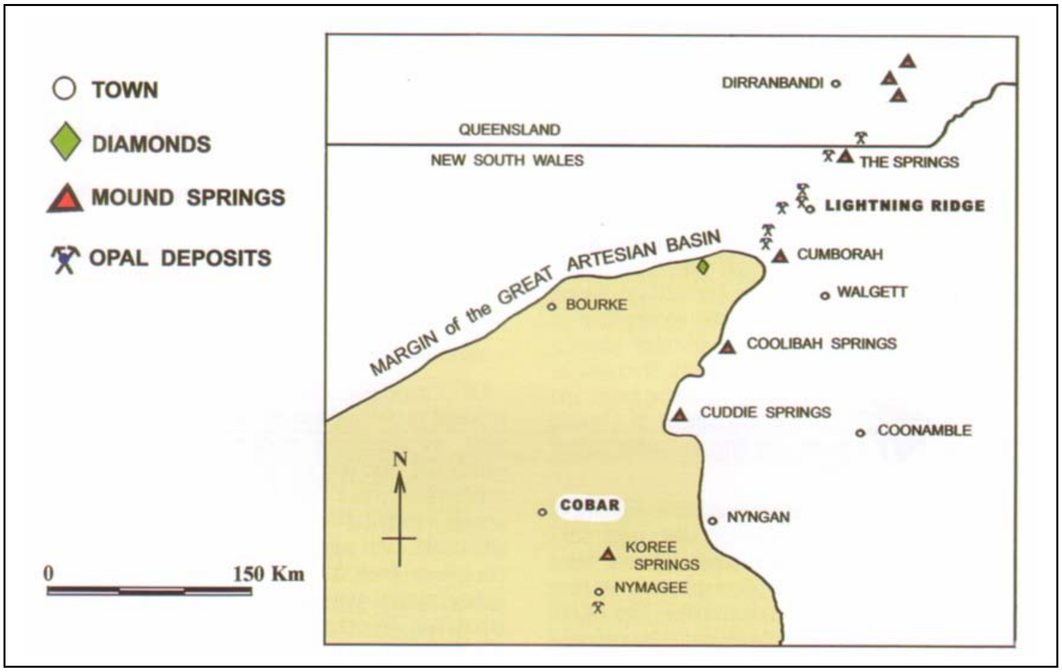
ABSTRACT

A new model for the formation of precious and potch opal is proposed. The essential components of this model are mound spring waters of appropriate chemistry; a mechanism whereby the physico-chemical properties of this water are changed so that suitable silica spheres, and then linear chains of these spheres, are formed; and suitable voids that are lined with clay that can act as a semi-permeable membranes to concentrate and purify the silica sol by ultra filtration and dialysis.

MOUND SPRINGS AND OPAL: AN ASSOCIATION

The Lightning Ridge opal field lies on a line of natural artesian springs, called mound springs, running at 20 degrees magnetic for over 300 km from Coolibah Springs in the south to the springs around Dirranbandi in Queensland (See map 1). The mound springs to the south are extinct (the fossil megafauna site at Cuddie Springs is dated at about 30,000 years before the present time), while the Cumborah spring is nearly extinct, and the springs to the north are active. The distance is increased to over 400 km if the Corea (Koree) group of mound springs 30 km north of Nymagee is included—although this group of springs lies outside the margins of the Great Artesian Basin (GAB).



Map 1 Location of mound springs in relation to the Lightning Ridge opal field.

The strike of this line of mound springs (20 degrees magnetic) is the same as the basement structural features underlying the Lightning Ridge opal fields, as interpreted from magnetic data by Hartman and reported by Watkins. It was also noted by Watkins that Cretaceous ridges in the Lightning Ridge district trend sub-parallel to these basement structural features, which he interprets as basement contacts between different lithologies or faults.

Active and extinct mound springs are found in general proximity of several sedimentary opal fields and opal occurrences in NSW, South Australia and Queensland: namely Lightning Ridge, Mehi, Lila Springs, Nymagee, White Cliffs, Andamooka, Coober Pedy, and the Eulo/Yowah district. This proximity, coupled with the demonstration below that opal could be generated from mound spring waters, and other evidence, provides a strong case for the involvement of mound springs in the formation of opal.

A plot of the sedimentary opal fields shows that in NSW and South Australia they are all located near or on the intersection of continental scale lineaments, or a short distance along significant splays from these linear features.

FORMATION OF SUITABLE SILICA SPHERES

It is generally known that precious opal consists of amorphous silica spheres of uniform size in the range 0.14 to 0.30 microns (μ) diameter, usually arranged in a primitive cubic configuration. Silica spheres of sufficient chemical purity, and approximately 40 per cent of the minimum required size for the formation of precious opal, have been made from geothermal water (alkaline water of pH 8.7, nearly saturated with silica) simply by means of cooling and a decrease in pH, followed by ultrafiltration and dialysis. This process was applied in New Zealand in a pilot plant at the Wairakei geothermal power station (Brown and Bacon 2000). The silica spheres and the process used to obtain them are described at the web site:
http://www.geothermie.de/egec-geothernet/ci_prof/australia_ozean/new_zealand/manufacture.pdf

The simplicity of the process, and the presence of artesian mound springs in the general vicinity of several opal fields, suggest that precious opal is formed from the mound spring waters by the same process of silica hydrosol (an aqueous suspension of colloidal silica spheres) formation followed by natural concentration by ultra-filtration and removal of impurities by dialysis.

Silica hydrosol (sol) containing monodisperse silica spheres could form by slow cooling, or decrease in pH of silica rich alkaline mound spring water. The size of the silica spheres would be determined by various physico-chemical parameters such as the cooling rate, pH change, and other factors such as the presence of pre-existing nuclei. It is important to note that a colloidal suspension of silica spheres (sol) is only stable above pH 7 (the neutral pH) and in solutions of low ionic strength (low dissolved salt), and silica gel, which is composed of tangled strands of silica spheres rather than discrete silica spheres, is formed if the pH falls below pH 7 (see figure 1) or if the ionic strength of the solution becomes excessive. For further detail see Iler pages 174 and 225.

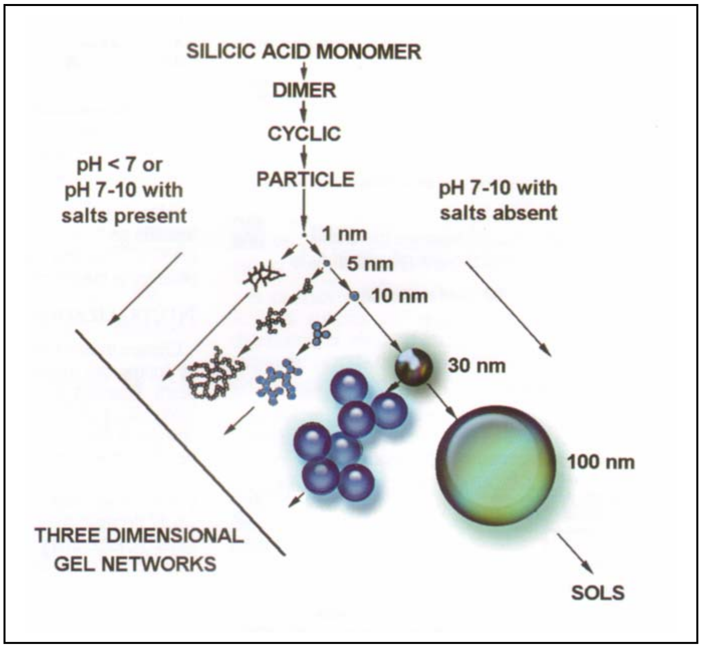


Fig. 1 Formation of silica spheres, after Iler (1979).

A notable feature of precious opal is that the silica spheres are very uniform in size (apparently within 2-3 per cent of the mean size), and any model has to explain this homogeneity. The homogeneity points to a batch process of formation of the silica spheres rather than a continuous process.

The silica spheres prepared from the Wairakei geothermal water are not as uniform in size as the spheres that form precious opal. But, the Wairakei spheres were formed within a few hours. If the process was slowed down, by reducing the cooling rate or slowing down the rate of change of other physico-chemical parameters such as the pH, it could be expected that the silica spheres would be larger and more uniform in size. The mechanism of Ostwald Ripening [transformation of an unstable phase into a stable phase through successive intermediate stages that require lower activation energy] would operate over time to further reduce any size inhomogeneity.

It is known that silica spheres in some samples of opal have an onion skin structure (Iler, page 401), suggesting the layers might have different trace element chemistry, and the silica spheres may have precipitated around pre-existing nuclei. This would explain the presence of a central core covered by a single layer, and additional layers could reflect the input of solutions with a different trace element composition. This points to a batch process rather than a continuous process that is required by the weathering fluids theory of opal formation.

The presence, in the water, of any pre-formed colloidal nuclei of opposite charge to silica would lead to the formation of more uniform sized silica spheres. Such nucleating effects are well known and are widely used in industrial processes to obtain uniform sized crystals.

Parameters that will influence the final size and the uniformity of size of the opal spheres include:

- initial concentration of silica
- starting and finishing pH
- starting and finishing temperature
- concentration of any silica complexing agents
- ionic strength
- initial concentration of pre-existing nuclei
- the charge on the nuclei, as positively charged nuclei will attract silica (which is negatively charged).
- hydrosol stabilizing agents, including surfactants.

A consideration of the trace element composition of precious opal, and the concentration of the trace elements, points to zirconium hydroxide or zirconium phosphate as possible nucleating agents. The reasons for this conclusion are:

- relatively high concentration of zirconium in opal.
- zirconium hydroxide is oppositely charged to silica sol, and the silica will be attracted to the zirconium hydroxide nuclei, and ,
- at the concentrations indicated by the analyses, zirconium hydroxide would precipitate before silica.

Other trace elements in opal that may form suitable colloidal nuclei, particularly with opposite charge to silica, are aluminium, titanium and thorium—all of which are present in opal at anomalously high concentrations (see Gallacher and see McOrist). It is of note that zirconium phosphate is extremely insoluble, and could form suitable nuclei. No data concerning phosphate levels in opal are available, but mound spring waters generally carry significant levels of phosphate. Zirconium phosphate is known to strongly absorb cerium, thorium and titanium, all of which are present in opal in anomalous amounts.

TRACE ELEMENTS IN SILICA SOL MANUFACTURED FROM GEOTHERMAL WATER COMPARED WITH THE TRACE ELEMENT CONCENTRATIONS IN BLACK OPAL

Only a few elements were assayed in the silica sol prepared from the Wairakei geothermal water, but it is of note that the trace element levels are similar to those seen in precious opal.

Table 1 shows an analysis of trace elements in Wairakei geothermal water, the concentrated silica sol prepared from this water, and trace element ranges observed in black opal from Lightning Ridge

	Raw Geothermal Water	**Silica sol**	**Lightning Ridge Black Opal**
SiO_2	490	250,000	-

Na	960	1,960	700-1,800
K	144	900	920-4,000
Ca	15	1,050	1,300-2,700
Rb	1.8	20	8-20
Cs	2	40	2.4-3.0
As	4.5	3	2-26
Sb	0.1	80	0.4-6.6
Al	0.3	550	5,900-10,200
Mg	0.005	10	170-320

Table 1 Adapted from Brown and Bacon (Wairakei geothermal water and the silica sol prepared from this water) and from G.D. McOrist et al. (Lightning Ridge black opal).
All values expressed in parts per million w/v and w/w

NEUTRALIZATION

Changes in any of the physico-chemical properties of an appropriate mound spring water (high pH water nearly saturated with silica) could bring about the formation of silica spheres. However, the most likely changes in the environment of a mound spring would be pH, temperature and ionic strength. Mixing warm, alkaline mound spring water with cool, slightly acid ground water with low total dissolved salt content would decrease the pH, lower the temperature, and lower the ionic strength of the mound spring water. All three changes facilitate the formation of silica spheres.

ROLE OF MONTMORILLONITE

It is a feature of the Lightning Ridge opal fields that opal is generally found in or adjacent to *opal dirt*, a claystone that contains significant swelling clay that is generally considered to be montmorillonite[1]. This association with montmorillonite is weaker on other Australian opal fields.

Perhaps sufficient quantities of acidic ground water were not available at Lightning Ridge, and the only neutralizing mechanism that was operational was reaction with the hydrogen (proton) form of montmorillonite which had formed previously by ion exchange with acidic ground water over an extended period of time.

Montmorillonite has several favourable physico-chemical properties that facilitate both the formation of the silica spheres and the ultra-filtration and dialysis of the water carrying silica spheres, for it:

- can act as a semi-permeable membrane (particularly lining cracks);
- is a strong cation exchange material that could absorb impurities from the water. Exchanging impurities for ions such as sodium and potassium; and,
- in the proton form can neutralize the alkaline mound spring water.

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[1] Montmorillonite, $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2.nH_2O$ is a member of the smectite group of monoclinic clay minerals (silicates) that possess swelling properties and high cation-exchange capacities

It should be noted that other clays can function as semi-permeable membranes and have some ion exchange capability, but montmorillonite is superior.

Another possible role for montmorillonite, and any other swelling minerals, is the pressurization of fluids containing silica spheres by the absorption of water or the exchange of cations. This pressurization could act as the driving force for the ultra-filtration of the fluid, and also cause explosive rupturing of rock units and the formation of *blows*. Published accounts refer to pressures of 50 psi (3.45 bar) generated in relatively open systems (around building foundations) by the absorption of water by montmorillonite.

THE ARRANGEMENT OF SILICA SPHERES

The forces and processes involved in the aggregation of colloidal particles are not entirely understood, but the following discussion employs well established aspects of theory.

The major forces that determine in what configuration the silica spheres aggregate are the long range electrostatic repulsion force (the repulsive force between similarly charged objects), and the short range van der Waal's forces which are a force of attraction.

In solutions of low salt content, and pH greater than 7, silica spheres are mutually repelled by the distribution of electrical charge on them, and the magnitude of this charge is determined mainly by the pH and ionic strength of the surrounding fluid..

As the pH of a suspension of silica spheres is lowered, the overall electrical charge on the spheres is reduced and the spheres can more closely approach each other. Also, as a suspension of silica spheres was concentrated, by whatever process, the spheres will be crowded together. At some point the equilibrium distance between the silica spheres would become less than the distance at which the van der Waal's forces (attractive forces) start to become significant. At some point the silica spheres will bond together by the action of van der Waal's forces. The electrical charge on the spheres will favour end on bonding because the electrical repulsion is least at the ends of a linear chain. This mechanism will ensure that linear chains of silica spheres are produced, rather than tangled and cross-linked chains as happens when the pH drops below about pH 7 and the electrical charge on the silica spheres becomes too weak to prevent random bonding at other sites on the chain. As the suspension becomes further concentrated the individual chains would tend to align themselves into linear bundles (rods) because this configuration would minimize the repulsive electrical effects between them.

As the suspension is concentrated still further, van der Waal's forces would dominate and the chains would cross-link. The cross-linking brought about by a relatively gradual change in physico-chemical properties would produce a primitive cubic packing arrangement (simple cubic) rather than a closest packing arrangement, because the electric repulsion effect is lessened with cubic primitive packing. A rapid change in physico-chemical properties would usually lead to random cross linking and the disorder that characterizes potch opal.

Electron micrograph images of precious opal confirm that the silica spheres are often in a cubic primitive packing arrangement; but cubic close packing and hexagonal close packing also occur and still lead to the formation of precious opal.

The colour in precious opal is often seen to be arranged in vague ‘fibres’ or ‘rods’, and this is more evident in some types of artificial (man-made) opal. These ‘rods’ can be explained by the formation of bundles of linear chains of silica spheres and the individual ‘colour’ of the ‘rods’ can be explained by the association of particular sized spheres. Spheres of exactly the same size would tend to associate and form rods (and hence have one colour).

TRACE ELEMENTS IN OPAL

The trace element components in opal suggest that the silica is sourced from an alkaline solution. Also, during the formation and aggregation of the silica spheres, the pH of the solution does not drop below pH 7 because below this pH silica spheres irreversibly aggregate into tangled chains rather than into the regular packing arrangement that is required for precious opal (see Iler pages 174, 225). It is likely that the tangling would be irreversible, and these tangled chains could not later be re-arranged into the regular arrangement of spheres that is required for precious opal.

It has been pointed out by a number of workers that the weathering model has deficiencies. In particular, the weathering model does not explain why opal is restricted in occurrence; and it implies that opal formation is a very slow process, whereas evidence points to opal being emplaced rapidly. But, it is the trace element composition of opal which is perhaps the strongest evidence against the weathering model.

A notable feature of the trace element assemblage in opal is the presence of significant concentrations of very unreactive and immobile elements such as zirconium, hafnium, niobium, tantalum, thorium and titanium, coupled with the low levels of other, more common and more reactive and geochemically mobile elements.

The unusual assemblage of trace elements is very difficult to account for if the source of the silica were solely weathering fluids. Mound spring water, with a component of water derived from exotic intrusives such as carbonatites or natrocarbonatites, can plausibly account for the observed trace element assemblage seen in opal.

The presence and absence of various elements in precious opal can be accounted for by alkaline hydrothermal leaching to obtain the source water (or part of the source water), followed by partial pH neutralization to precipitate silica spheres, followed by removal of soluble impurities by dialysis.

At first sight the relatively low concentration of aluminium in precious opal appears to contradict an alkaline fluid provenance; but this can be explained by removal of the aluminium by initial co-precipitation of aluminium hydroxide with some of the silica spheres as the pH lowers. If the initial solution contains more silica than aluminium, then the co-precipitation (silica and aluminium are oppositely charged and form a flocculant precipitate – a process that is often used in water treatment plants) will remove nearly all the aluminium and a number of other cations and anions. The remaining fluid would then be sufficiently pure to yield suitable silica spheres.

The trace elements in opal are those that would be expected from a highly alkaline leachate, because only those elements that form species - generally oxy-anions that are significantly soluble in highly alkaline solution, and that would precipitate with the silica spheres, or co-precipitate in the silica spheres - are present in precious opal. Various other unusual trace elements such as silver, gold and platinum can occur in precious opal, and their presence can be explained because these metals can form colloidal solutions that will co-precipitate with the silica spheres.

SEMI-PERMEABLE MEMBRANE PROPERTIES OF CLAYS

Various clays, and montmorillonite in particular, can function as semi-permeable membranes. Semi-permeable membranes can concentrate and purify dilute suspensions of silica sols (silica spheres), as has been described above. This property offers an explanation for the observed link between montmorillonite and opal at Lightning Ridge. However, it should be noted that other clays also can act as semi permeable membranes, so the presence of montmorillonite is not essential, although it is favoured: because it has the most favourable characteristics, including ion exchange capability, and can have alkali neutralizing capacity.

Clays are universally present in the sedimentary opal environment, and it should be noted that bulk clay is not required. A thin layer of clay, or perhaps silica gel, lining a crack could function as a semi-permeable membrane.

Commercial silica sol preparations reach concentrations of 50% w/v, and these are relatively non-viscous and are available commercially for various Hi-tech applications. It is not known how concentrated a silica sol can be made, while retaining fluidity, but, on theoretical grounds a case can be made that concentrations of more than 75% w/v are possible. A 75% w/v sol would give the structural features observed in seam and nobby opal, such as meniscus features and shrinkage cracks forming when the sol dehydrates, and suspended fragments of rock.

It is proposed that pockets of silica sol (silica spheres and chains of spheres) are intermittently injected by hydraulic pumping caused by seismic or other events - such as geyser activity or mud volcano activity - into a system of localized cracks and voids. The voids are generally formed by previous leaching of fossils and evaporite minerals in the sediments, or may be formed during hydraulic fracturing.

It is suggested that this process is likely to operate at relatively shallow depth (less than 100 meters) because of the requirement for the open space *cul-de-sacs* within the sediments.

Another process that could pressurize the suspension of silica spheres includes pressure caused by the swelling of smectitic clays when they either absorb water or when they absorb cations such as sodium ions. Mound springs in the Eulo area are described by Read as oozing blue green mud, a feature that is reminiscent of some mud volcanoes where the driving force is thought to be natural gas.

CONCENTRATION AND PURIFICATION OF SILICA SPHERES

The purification, by dialysis, of a suspension of silica spheres requires either the input of energy or a counter current of water of lower ionic strength. Simple pressurization (the energy source applied in commercial reverse osmosis plants) is sufficient and could be generated by a mound spring, particularly in its waning phase where channel ways are presumably blocking up. The intermittent violent eruption of some mound springs is evidence that water in mound springs can become highly pressurized.

A counter current of purer water on the other side of the semi-permeable membrane is another mechanism whereby impurities can be removed, but the silica sol is not concentrated in this process and an additional step where the silica sol is concentrated (by the removal of water) is then required.

It should be noted that a carat of opal could be obtained from as little as ten litres of mound spring water by means of the proposed mechanism. So, the opal forming events are minor affairs.

‘EXPLODING’ MOUND SPRINGS AND THE ORIGIN OF *BLOWS*

A notable feature of Lightning Ridge opal is its common association with breccia pipes, known as *blows*. Breccia is also noted on other opal fields. It is known that artesian springs in other parts of the world can form breccia pipes, although the mechanism of their formation is not clear. There is both anecdotal and field evidence that some Australian mound springs occasionally erupt explosively, ejecting gravel and boulders 600 mm in diameter from rock derived from a formation 150 metres below (e.g. mound springs near Malpas, Queensland (see Grimes) and mound springs in the Eulo-Yowah district). Mound springs in the Eulo area are reported by Read (2002) to occasionally explode and then ooze a blue mud which changes to green in contact with air, and then dries to a brown colour.

Further evidence of intermittent explosive activity of mound springs is found in the general form of many of the nearly extinct springs in NSW. Often, these (e.g. Tooloomi, Mascot, and Native Dog mounds springs) have the form of shallow craters surrounded by gravel and boulders, while there is paucity of such material in the general vicinity, and the springs are occasionally surrounded by broken silcrete boulders reminiscent of the surface expression of blows on the Lightning Ridge opal fields (see Pickard 1991).

Pebbles and boulders of exotic rock have been noted on many of the opal fields. These have been dismissed as glacial erratics. However, it is probable that many, perhaps all, of these pebbles and boulders are unconsolidated GAB basement gravels that have been mobilized by the intermittent explosive activity of mound springs. Boulders of basement rock containing Devonian fossils were reported by Kenny (1934) to be common in one locality at White Cliffs (Lenas Hill). These have been interpreted in the past as glacial erratics, although Cretaceous glaciation in the area is problematic. Boulders of granite and granite breccia have been reported by L. Keith-Ward (1921) around mound springs located SW of Coober Pedy, and basement (the same granite and granite breccia) is at 1,000 meters plus depth at this locality.

ASSOCIATION OF DIAMOND WITH OPAL

There is a strong spatial connection between deep sourced intrusions and the opal fields of New South Wales and South Australia. Microdiamonds have been found in intrusives in the general vicinity of Lightning Ridge (see CRA), and parakimberlites occur in the White Cliffs district (see Barrows). ‘Volcanic’ opal, that is precious opal found in various Tertiary volcanic rocks, is found in NSW in proximity to alluvial diamond occurrences, alkaline rocks, and plutonic driven springs such as those in the Nandewar mountains.

The geophysical data suggest that the Lightning Ridge opal fields are located on splays from the Darling River Lineament which is associated with diamond occurrences in NSW and South Australia. White Cliffs is located close to the Koonenberry Fault, a mantle tapping structure that hosts parakimberlitic pipes such as at Kayrunnera. The South Australian opal fields are all located adjacent to the G2 gravity linear that is strongly associated with diamond occurrences in South Australia (see map in Wills page 114).

It has been noted by Townsend (2003) that opal is often associated with sandstone paleochannels. It is to be expected that paleochannels would follow faults, mound springs would access these faults and the mound spring waters would move along the paleochannels which generally contain permeable sandstone.

COMPATIBILITY WITH EXISTING MODELS

There are three accepted models of sedimentary opal formation: the microbial model, the weathering model, and the syntectonic model.

The model presented here is an extension of the syntectonic model proposed by Pecover (2003), and it includes a role for bacteria and weathering fluids. Dowell *et al.* (2003) have reported very recent Carbon-14 ages (a few thousand years) for Lightning Ridge black opal nobbies. The present author has found evidence of mound spring activity and associated breccia pipes in the Lightning Ridge district that are geologically recent, so the recent carbon-14 ages are not incompatible with the proposed model.

Fossilized bacteria have been reported in samples of opal by K. Dowell and J. Mavrogenes. This finding is consistent with the present model because it is possible, even likely, that bacteria could live in the semi-stagnant waters in a waning mound spring structure. It is of note that some mound spring waters carry significant amounts of nutrients (ammonia, nitrate and phosphate), and could carry sufficient organic material leached from the underlying GAB sediments to support bacterial growth. Silicified bacteria have been noted by various authors in siliceous sinter formed by geothermal springs (see McKenzie et al. 2001).

Bacteria can excrete organic compounds with surface active properties. One area where such bacteria are used is in the *in situ* viscosity reduction of oil in oil wells. Surface-active compounds are well known for modifying the growth and stability of colloidal particles, so it is not unlikely that bacteria growing in mound spring water would exert some effect on the growth and stability of the silica spheres.

It should be noted that a small amount (5 ppm) of a proprietary surface-active material (Acumer 5000™, Rohm & Haas) was used in the New Zealand experiments to stabilize the suspension of silica spheres.

Bacteria were also implicated in the abnormal growth of silica scale in earlier experiments conducted by Brown and Dunstall (2000) on the Wairakei geothermal water.

It is of note that algal growth was observed in the separated silica sol prepared from the Wairakei geothermal water (Brown and Bacon p. 536). and silica gel has been used as a culture medium for bacteria.

BOULDER OPAL AND VOLCANIC PRECIOUS OPAL

The main features of this proposed model - growth of suitable silica spheres, the arrangement of these spheres into chains and bundles of chains, and filtration and dialysis under pressure - could occur in both the boulder opal and volcanic opal environment.

Boulder opal seems to occur in paleochannels and, as is the case elsewhere, these could be expected to be the focus of, and channels for, mound spring waters. Active mound springs occur near some of the boulder opal deposits (e.g. Lila Springs). *Blows* do not appear to be a common feature of boulder opal fields, so perhaps the filtration mechanism that operated was driven by a sustained pressure from the mound spring water, rather than rapid high pressure events that appears to be a feature of Lightning Ridge opal

Silica spheres, and linear chains of these spheres, would naturally anchor themselves to ironstone surfaces within voids in ironstone boulders; because hydrated iron oxides are generally oppositely charged to the silica spheres.

Emission of hydrothermal fluids is a general feature of waning volcanic systems. The composition of the fluids depends on many things and varies considerably. However, only under exceptional circumstances would the fluids be suitable for the formation of precious opal. Generally volcanic hydrothermal fluids contain too much material that would prevent the formation of opal.

WHY IS OPAL LOCALIZED?

According to the proposed model there are many factors that determine if and where opal may form. The most important factors are:

- mound springs, with three thousand being known within the GAB;
- mound spring water of appropriate chemistry, that is alkaline water with a high silica content and a low concentrations of some elements. Only a few of the present mound springs have alkaline, silica rich water;
- a contribution of alkaline hydrothermal fluids from carbonatites or natrocarbonatites, or similar rocks;
- some mechanism that will lead to the formation of silica spheres, such as mixing with acid ground water or contact with buffering materials such as the proton form of montmorillonite;
- ultra filtration and dialysis of the water containing silica spheres in clay lined open spaces (cracks and voids); and,
- the water has to be pressurized to drive the ultra filtration process.

The most restrictive factors are the first three that predicate mound springs and water of appropriate chemistry. Mixing with acidic ground water would be a common event. There is evidence that pressurization of mound springs occurs and is not uncommon, so this factor is probably less restrictive that the first three.

ERRATICS

Patches of gravel, occasionally up to 10 m thick, occur in the near surface materials covering the Cretaceous opal sequence in the Lightning Ridge district. These are generally described as Tertiary river gravels. The gravels are mainly (80%+) comprised of well rounded quartz pebbles of 2-40 mm diameter, with lesser amounts of quartzite, jasper and silicified wood, generally mixed with quartz sand. These gravels are similar to the ‘Cumborah Gravels’ that have been described as Tertiary river gravels. But the author has found evidence that some, and probably most of the gravels on the Lightning Ridge opal fields, have originated from unconsolidated gravel at the base of the Great Artesian Basin (GAB) that have been brought to the surface by the long term action of mound springs. It is proposed that a combination of lithostatic pressure, and a flow of water from the basement, periodically moves these gravels along long-lived fractures associated with continental scale linears. Hydraulic pumping by seismic events possibly also help to move the gravels.

There seems to have been insufficient erosion since the GAB sediments were laid down to support the suggestion that rivers would carry such gravels, and there are no sources of quartz within 100 km of Lightning Ridge. The gravels in the Lightning Ridge district contain water worn and occasional unworn topaz crystals, implying but slight water transport. The nearest exposed source of topaz is the granites in the New England district, but, even if suitable rivers existed, topaz is relatively brittle and would not survive this length of transport.

Occasional fine flakes of gold are present in the cemented gravels (silcrete) of the Angledool area. Indeed, richer patches were worked by the Chinese in the 19th Century. Gold, in flakes and small nuggets, is a notable feature of the unconsolidated GAB basement gravels at Tibooburra, and gold could be expected in any gravels derived from the Lachlan Geosyncline sediments—particularly those from the Gilmore Suture corridor which appears to continue under cover in the basement of the GAB near Lightning Ridge.

The Gilmore Suture corridor is a tin, tungsten, gold mineralization belt (see Cullen Resources 2003), and the gravels derived from these rocks would be expected to contain topaz which is a common accessory mineral with tin mineralization.

The opal and the surrounding sediments at Redfire Resources NL's Hebel prospect are reported by Gallacher (2001) to contain anomalous amounts of tungsten, silver, platinum, and gold, and Lightning Ridge opal is reported by McOrist *et al.* (1994) to contain anomalous amounts of gold.

The presence of erratic pebbles in the Cretaceous rocks, notably in opal workings, is generally ascribed to the pebbles falling from the surface into open 'blows' (breccia pipes). But, the author has seen pebbles exposed in opal workings that are unlikely to have reached their present position from the surface.

Pebbles in the Cretaceous rocks of opal workings have been observed by the author to occur within what appears to be an 'injection mélange' which often does not break through the silicified sandstone *roof* , and is often deflected along the interface between the *roof* and the underlying claystone (*opal dirt*)—dying out as bifurcating 'fingers' within the claystone.

IMPLICATIONS OF THE MODEL IN OTHER AREAS

The material presented in this paper is suggestive that at least part of the artesian water (the water that drives the mound springs, and the water that is involved in the formation of opal) is sourced from the basement rocks beneath the GAB. This would explain a number of puzzling features that are not adequately explained by the conventional artesian basin model. Foremost amongst these features, at least to the author, is the often rapid change in the chemistry of the GAB artesian waters over short lateral distances. Other evidence that points to a plutonic basement source rather than an artesian source for the water is discussed in Professor Gregory's book, and in Professor L.A. Endersbee's internet papers.

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