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The unique attributes of Australian precious opal

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Abstract: Although the history of Australian opal begins in outback Australia as detailed below, the scientific contribution to opal research, and that of the Gemmological Association of Australia (GAA) should not be disregarded. By the time this article is published it will be essentially the fiftieth anniversary of the publishing of the first article on the colour of precious opal by John V. Sanders, in the journal "Nature" on the 19th of December 1964. John Sanders is a past president of the GAA, and in 1981 he signed off on the author's Diploma in Gemmology. It is hoped this article will follow in the footsteps of Australian opal research and GAA expertise by discussing the gemmological properties of precious opal. It is the intention of the author to provide brief information on just why opal from Australia is unique; unique in its appearance, its gemmological properties and its science and geology. Equally remarkable are those miners, lapidaries and traders who all express pride in being involved in what is a unique industry.

History of Australian Opal

The history of precious opal discoveries in the Australian outback is told in many texts written over the one hundred and sixty year period of Australian opal exploration, however certain texts provide us with a detailed experience of Australian opal.

In particular, two texts come to mind, one old and one new. The older text written by Tully Cornthwaite Wollaston and titled "Opal, Gem of the Never Never" details the first commercial expeditions to the boulder opal fields in western Queensland and his subsequent attempts to sell this unique opal in England. Wollaston's book contains his diary of events in the summer of 1888 (Wollaston, 1924).

The newer text is a series of four books entitled "A Journey with Colour" (Cram, 1998 - 2006) written and produced by the well-known opal author and local Lightning Ridge identity, Len Cram.

It is generally agreed that precious opal has been commercially mined in outback Australia since the late 1800's. The first discovery is attributed to a German mineralogist known as Johannes Menge who is reported to have discovered opal in the Flinders Ranges and also the Barossa Valley, South Australia in the 1840's. These early discoveries of opal have been eloquently documented in the first chapter of volume one of Len Cram's text (Cram, 1998, pp. 12-145).

Two wonderful quotes about precious opal are presented in the first two paragraphs of volume one of "A Journey with Colour" (Cram, 1998). These quotes encapsulate in many ways the romance behind Australian opal, and opal miners: *"Opal is like gold, once the fever is in your blood, you can never get it out!"* (p. 12), *and "Opal: 'Queen of Gems' – hid herself away like a delicate child playing hide and seek throughout the stark beauty of our timeless deserts"* (p. 12).

Right from the start opal from Australia was considered unique, especially the opal first introduced to the international market by Tully Wollaston on his first London trip. Wollaston (1924) wrote *"When I got to London, I found that opal was not on the market at all, for there was no supply"* (p. 76). Then referring to a small parcel of the new boulder opal he further states: *"It was undoubtedly opal, but not the pale Hungarian gem which the English people had been accustomed to get under the name of opal. If ours was superior as we said it was, they didn't know it, and such a new stone needs confident handling……"* (p. 76).

Figure 1. Opal Mine, White Cliffs. Plate XIX (Milne Curran, 1896).

Generally this new type of opal, Queensland boulder opal, was not well accepted at that time, so the market for opal did not grow thus resulting in opal prospecting back in Australia becoming very fragmented. Wollaston's persistence began to pay off however, with a chance new discovery of light opal, more like the Hungarian opal, at White Cliffs, New South Wales in 1890 (Figure 1). Wollaston returned to London with more samples of Australian opal and he writes: *"and we steadily made headway till within a year we had six (cutters) wholly engaged on Australian opal, and the cut product was selling as fast as they could turn it out!"* (Wollaston, 1924) (p. 91).

The Australian opal industry had begun and Australia was on track to become the major producer of precious opal in the world: *"Now that Australian opal – (that is Queensland and White Cliffs, for Black Opal was still hiding) – had won recognition and taken up an honourable position in the world's markets."* (Wollaston, 1924) (p. 94).

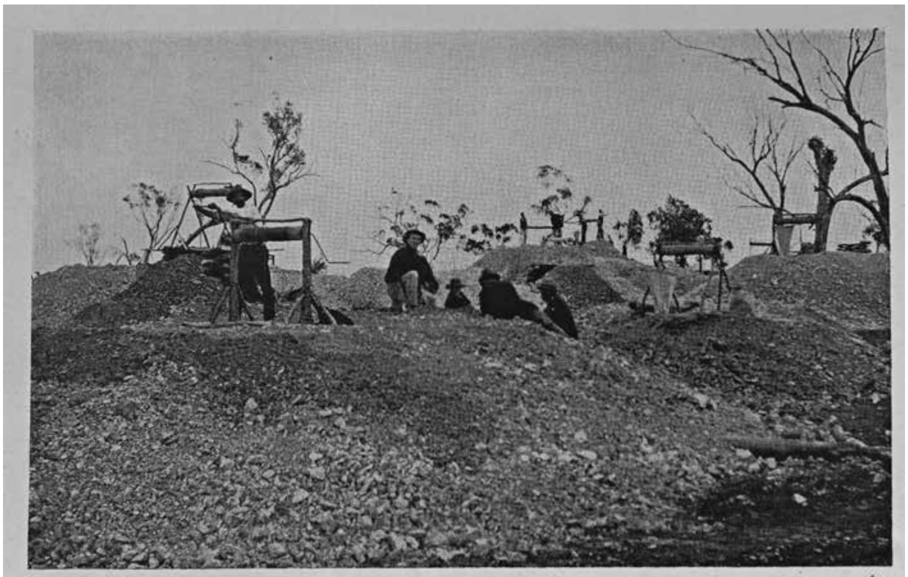
Then in the last decade of the 19th century an even more unique variety of opal was found at Lightning Ridge in northern New South Wales (Figure 2). This opal became known as Black opal as the vibrant play-of-colour (POC) was highlighted by a black to very dark grey background or body colour. Some examples of Australian Precious opal are shown in Figure 3.

The Australian opal industry – A unique industry

As can be seen from the discussion above, even a century ago the opal mining industry was growing quickly and was going to be dominated by small mining groups or individual miners. Prospecting, mining and processing of precious opal were local to the opal fields; over time these miners would band together and begin moving towards an industry of integrity. Australia now has a very well established National Opal Miners Association (NOMA) whose membership is made up of every opal miners' and opal wholesalers' association in Australia, providing the industry with longevity and integrity. The majority of opal mining and wholesaling is conducted by independent persons most of whom would be a member of at least one of the industry associations that make up NOMA.

NOMA oversees a National Opal Symposium usually held every two years. The symposium rotates around the three opal producing states of Australia with the next symposium proposed to be held at Coober Pedy, South Australia during Easter of 2015. International guests are very welcome. These symposiums provide a forum for the latest research into opal and an opportunity for the industry to come together and discuss the current issues of the day. Encouraging research into opal is very important for future exploration; the occurrence of opal cannot be predicted hence one of the reasons for its rarity. Research also leads to a better understanding of the gemmological properties of Australian opal and opal generally. Through mutual cooperation and working with government agencies, the industry has considerable integrity. In all locations throughout Australia where opal is mined, it is done ethically and is governed by strong occupational health, safety and environmental regulations.

Members of the Australian opal industry, be they miners, dealers, manufacturers or retailers, do everything they can to support and grow the integrity of the Australian opal industry, meaning that consumers can buy Australian opal with confidence. Australia does produce some unstable material, but the unique nature of the industry with its independent entities and number of wholesale levels means that it is rare that this material reaches the consumer, and if it does the industry standard is to replace the gemstone or refund the amount paid.



WORKINGS AT THE THREE-MILE, LIGHTNING RIDGE,
Where 60 feet of hard siliceous rock has to be pierced before the opal strata is met with.

Figure 2. Illustration from Wollaston's "Opal, Gem of the Never Never" (Wollaston, 1924).

Figure 3. Examples of Black Opal, Boulder Opal and Light Opal from Australia. Left: An oval Lightning Ridge black opal named "the Serpent" courtesy Frank Palmer displaying a vibrant green/orange multi-coloured play-of-colour in a large random pattern. Centre: A free-shaped Queensland ironstone black boulder opal showing a very bright strong red multi-coloured play-of-colour in a small random and slightly vertical bar-type pattern. Right: An oval Coober Pedy light opal showing a very bright red multi-coloured play-of-colour in a small and consistent pattern. Photos: A. Smallwood.

At present, only occasionally do international gem laboratories certify the country of origin of opal. Many of those involved in the Australian opal industry believe such certification can be achieved and become a standard practise just as has happened with some other types of gemstones.

Unique science and geology

It is fifty years now since Australian CSIRO scientists Peter Darragh, John Sanders, Arthur Gaskin and Ralph Segnit discovered the cause of the play-of-colour in precious opal publishing their results in the journal "Nature" (Jones, Sanders and Segnit, 1964). Further articles titled "The origin of colour in opal" (Darragh and Sanders, 1965) and "The nature and origin of opal" (Darragh and Gaskin, 1966) were published in The Australian Gemmologist (Figure 4). These original works included a discussion of diffraction of light caused by regular stacking of nanometer-sized silica spheres as the cause of the play-of-colour, these spheres being stacked in a similar way to the stacking of atoms in crystal structures. The researchers used an analog equivalent of information published by William Bragg from Adelaide University who had previously won a Nobel Prize for Physics for his work on X-Ray Diffraction in crystallography.

Where there is no regular stacking of the silica spheres or the opal is composed of disordered and misshapen silica spheres, then there is no play-of-colour. The name given in Australia to opal that does not show a play-of-colour is Potch opal or simply "Potch". Potch opal may occur in all shades from dark to light, most commonly occurring with a black, grey, brownish, cream, white, or colourless body colour.

It is not possible to have a discussion about Australian precious opal without considering its occurrence in relation to its Australian geological setting, as it is this that makes Australian precious opal unique by virtue of its gemmological attributes when compared to other worldwide precious opal occurrences.

The Great Australian Basin (GAB) is a sedimentary basin of large size, taking up one fifth of the continent and covering some 1.7 million square kilometres (Figure 5). It is the remnant of a large inland sea that gradually filled with sediments over years of geological time. The sediments date mainly from Jurassic to Cretaceous times. The opal deposits of Lightning Ridge, White Cliffs, Andamooka, and Coober Pedy are situated around the edge of the GAB, whilst the Boulder opal deposits in Queensland are spread throughout the sedimentary strata more towards the middle of the basin.

Figure 4. First pages of "The Origin of Colour in Opal" and "The Nature and Origin of Opal" as published in The Australian Gemmologist 1965 and 1966 respectively.

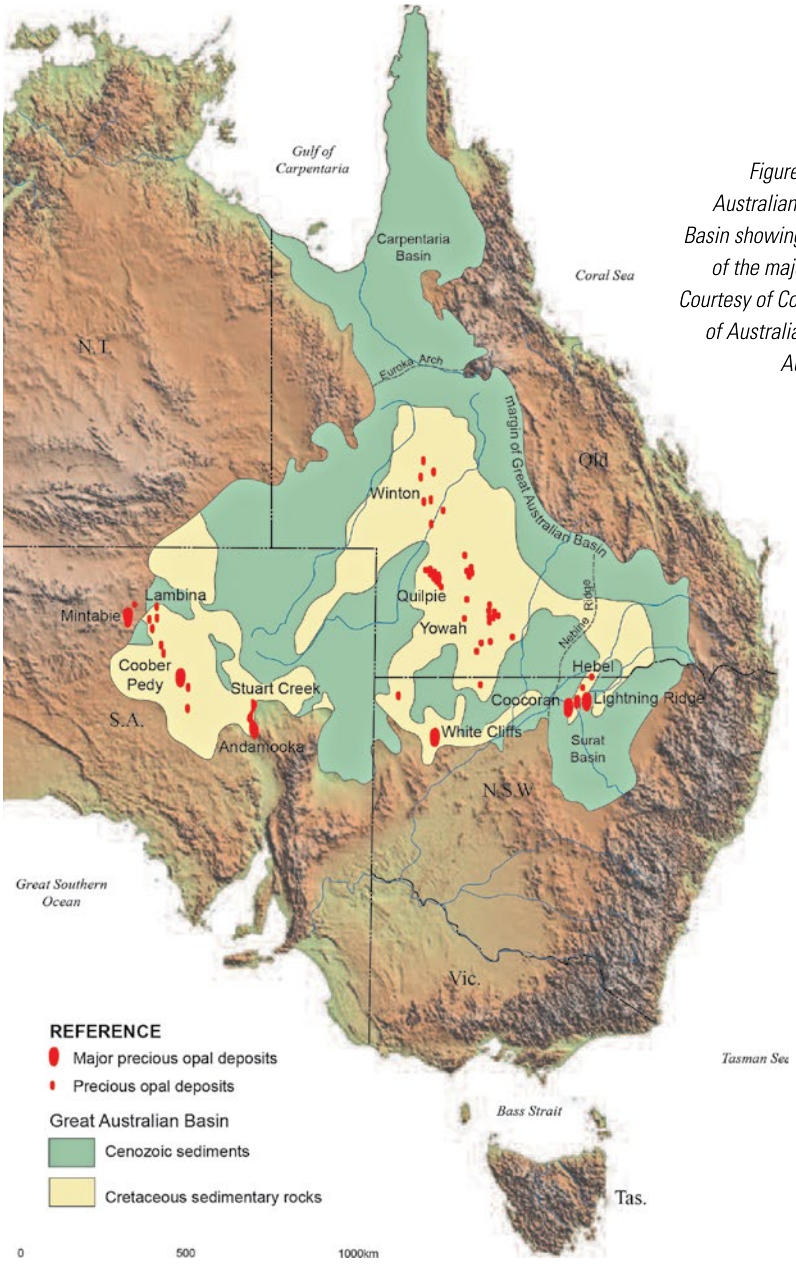


Figure 5. The Great Australian Sedimentary Basin showing the position of the major opal fields. Courtesy of Commonwealth of Australia, Geoscience Australia 2011.

Figure 6.
Left: The weathered profile at Lunatic Hill in Lightning Ridge in New South Wales. Photo: A. Smallwood.
Right: The weathered profile in a boulder opal field near Quilpie in Queensland. Photo: T. Coldham.

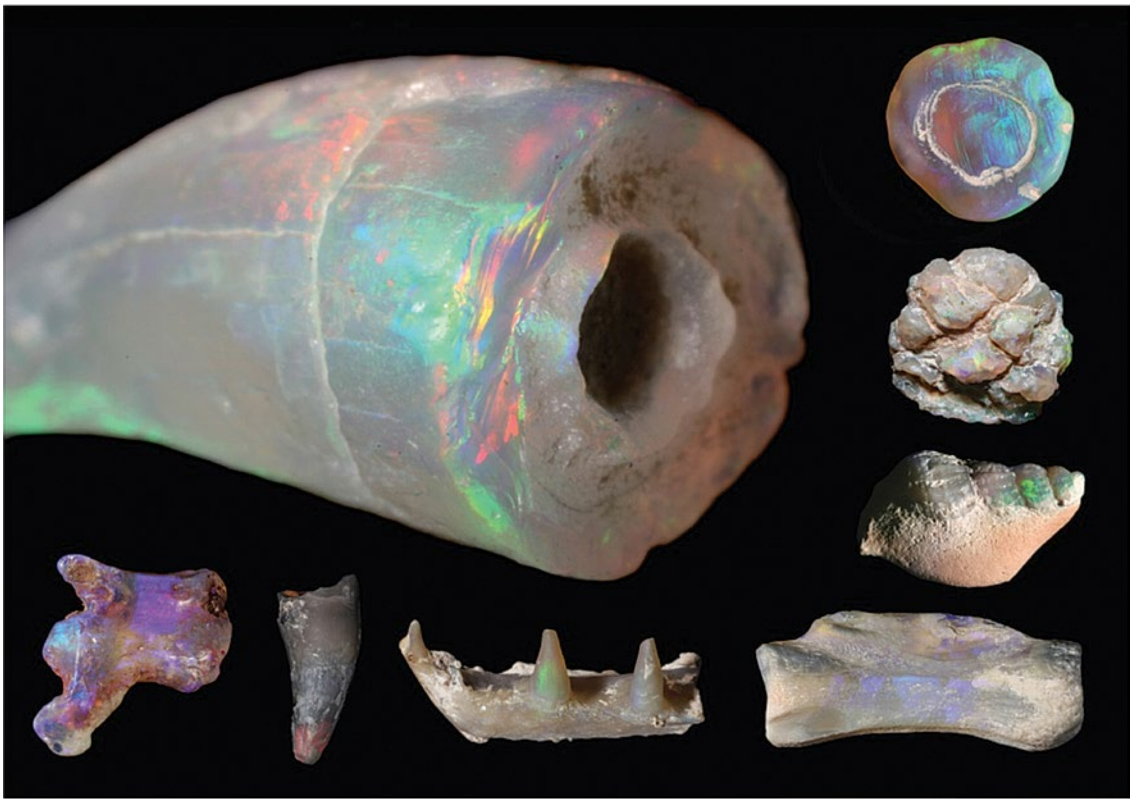


Figure 7. Early Cretaceous opalised fossils from Lightning Ridge. Clockwise from top left: dinosaur or bird tooth; crayfish gastrolith ('yabby button'), pinecone, whelk, dinosaur backbone, jawbone of freshwater fish, crocodile tooth, turtle tailbone. Collection of the Australian Opal Centre. Photos: R.A. Smith.

These major opal producing districts have their own special geological history and characteristics and whilst it is not the purpose of this article to discuss the geology in detail, it is however, worth noting that the sedimentary and weathering history of the rocks in the GAB are relevant to the type of precious opal found. For those interested, the details of the geology can be found in the literature provided by the individual reports of each of the Australian State Departments for Minerals and/or Natural Resources (Burton, 2011; Barnes et al., 1992; Connah, 1966; Brooks, 1967).

Common to all the Australian opal fields are sediments formed during the Jurassic and Cretaceous periods, when dinosaurs walked the Earth about 140 million years ago. The basin was a huge inland sea that accumulated large amounts of sediments washed into the basin from rivers and estuaries around its edge. These sediments consolidated and then were extensively weathered over long periods of geological history later hosting the suitable depositional sites for the formation of precious opal. Examples of weathered profiles can be seen in Figure 6.

In the Lightning Ridge precious stones field it is postulated the sediments were deposited in shallow water near the edge of the basin, probably in an estuary. The nature of this environment is reflected in the extraordinary opal fossils found at Lightning Ridge both from freshwater and marine environments (Burton, 2011). Opalised shells, wood, fish, bird, mammal and reptilian bones of the Cretaceous age are found in the opal mines of all of the fields in this area. These fossils are being preserved in the Australian Opal Centre (AOC) at Lightning Ridge, and have been well documented in books such as the definitive "Black Opal Fossils of Lightning Ridge" (Smith and Smith, 1999) and many papers published since. Opal fossils from the district are items of national heritage, and unusual in their abundance and variety (Figure 7.)

Whilst the sedimentary rocks of the South Australian opal fields of Coober Pedy and Andamooka may be correlated to those in New South Wales, the South Australian fossil assemblage is slightly different representing a marine environment with abundant fossil shells (bivalves and gastropods) crinoids, belemnites and marine reptiles such as plesiosaurs and ichthyosaurs (Figure 8).

The Queensland boulder opal fields are different again, although similar in that the rocks present can be correlated in type and geological time with those of New South Wales and South Australia. The presence of opal-bearing ironstone concretions provide an interesting difference from other Australian fields. Also in the Queensland opal fields there

Figure 8. Bi-valve shell fossils in light precious opal from Coober Pedy South Australia. Photos: A. Smallwood.

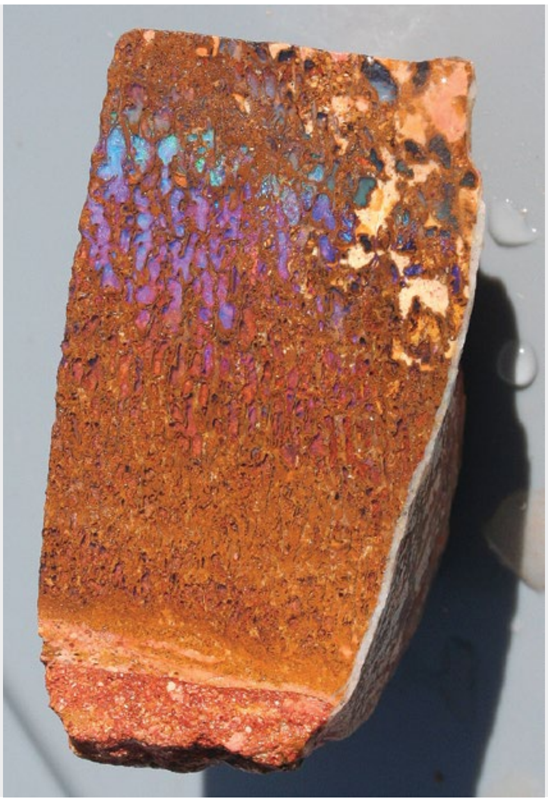


Figure 9. Evidence of dinosaurs on the Queensland opal fields. Left: Preserved dinosaur footprints "Dinosaur stampede" Lark Quarry near Winton, Queensland. Right: Matrix boulder opal believed to be fossil dinosaur bone. Photos: A Smallwood.

are indications of extreme geological weathering events, which can be related to both opal formation and opal abundance (Senior, 1977). Further, preserved in the Queensland sedimentary rocks are evidence of remains of sauropods and the preservation of indications of their existence. One of the most well known sites is the dinosaur stampede near Winton (Figure 9).

To date there appears to be no other recorded opal fossils derived from animal remains occurring anywhere else in the world. There are however a few opalised plant fossils, pine cones and petrified trees found at Virgin Valley, Nevada, USA (Weise, 2006), and possible occurrences of opalised wood are also reported from Brazil and plant fossils are found preserved within precious opal from Ethiopia (Rondeau et al., 2011).

A particularly important feature to be noted about the GAB is that it has remained relatively stable for a very long period of geological time, not being effected by strong tectonic processes, either heat or pressure or by any igneous intrusion or volcanic activity that could have caused metamorphism. There has only been small scale fracturing of the sandstones and small scale localised faulting of the strata. It is generally accepted that the silica available for the formation of precious opal has been released by a process of weathering of the available sediments present on all of the Australian opal fields (Rey, 2013).

By contrast, a search of literature indicates that almost all other precious opal occurrences found throughout the world have a much more significant relationship with "Volcanic" rocks.

In Mexico, the rock in the opal zones is predominantly extrusive (volcanic). The normal pattern is represented by a rhyolite of fluid texture and reddish colour with openings or holes, which is sometimes covered by rhyolitic tuff, layers of obsidian and basalt. This rhyolite is also intensively weathered to kaolinite (Mallory, 1969).

In Honduras, the opal is found near Erandique in the western Lampira district, and is covered by 1200 metres of volcanic basalt lava flows. The area where the opal is found is at a place the locals call the "Tablon" where there are many large blocks of dense volcanic rocks that are partially exposed and weathered on the surface (Dabdoud, 1985).

In Indonesia, opal is found in the Banten province in western Java and it is contained in a pumiceous layer of tuff that is fine-grained and deeply weathered to a clay rich soft rock of greenish grey colour (Sujatmiko, Einfalt and Henn, 2005).

In Slovakia, the opal is found in the Dubnik area and is found in weathered andesite within the extensively weathered Zlatobansky strato-volcano (Semrad, 2011).

In Brazil, the opal deposits at Pedro II are located in the north-eastern state of Piaui in a geological basin named Piaui-Maranhao and covering an area of 600,000 square kilometres. The western part of the basin is separated from the Amazonas basin by the Tocantins volcanic arc and in the north by the Ferrer arc, and the south by the Sao Francisco volcanic arc. This suggests the possibility of volcanic ash and tuffs having originally provided sediments suitable for weathering and opal formation that is not unlike the Great Australian Basin in Australia. However, the opal is found in claystones located in a contact zone near to a dolerite intrusion and appear to be associated with both contact metamorphism and weathering (Bartoli, 1990; Bittencourt Rosa, 1988).

In Ethiopia, there are two separate occurrences of opal. The opal found in Shewa province in Ethiopia occurs in a nodular formation, which is distinctive, if not unique. The opal nodules occur in a continuous layer of welded tuff which approaches obsidian in its character. The layer is approximately three metres thick and is situated between layers of decomposed and weathered rhyolite (Johnson et al., 1996). In the Wollo province in the district of Wegel Tena, the opal is found in a layer that is part of a sequence of volcanic tuff and ignimbrites. The opal-bearing layer is between one and two metres in thickness and this layer has been strongly weathered into clays (Rondeau et al., 2011).

Australia also has opal associated with volcanic rocks. The only commercial precious opal occurrence which occurs in a volcanic environment is in northern New South Wales near the township of Tintenbar. The opal is found within the junction of two basalt lava flows associated with the Mount Warning volcanic province. The precious opal occurs as loose nodules in the soil and as amygdales in weathered and decomposed vesicular basalt (MacNevin and Holmes, 1979). It is a useful convention in the discussion of precious opal formation and identification to simply discuss opal occurrences by relating the opal type to the rocks in which the opal has been found. This leads to the use of terms such as “sedimentary” opal or “volcanic” opal which will be used in our discussions throughout this article.

There are however some reservations as to the appropriateness of these terms in light of recent opal research. An examination of literature suggests that during the Lower Cretaceous history of the formation of the GAB, the sediments washed into and deposited in the early “inland sea” show characteristics of being derived from volcaniclastic material transported from volcanism associated with the of Rockhampton volcanic province on the east coast of Australia. This extensive volcanism on the continental margin occurred over several millions of years from 132 to 95 Ma and resulted in a substantial amount of eroded sediments and debris being washed as alluvium into the inland sea, that is the GAB (Figure 10) (Rey, 2013; Veevers, 1984).

It is apparent that all precious opal occurrences, whether in a sedimentary environment or in a volcanic environment have several things in common. Worldwide it appears that the constituents of rock types associated with precious opal formation are of a silica-rich nature likely derived from volcanic ash, volcaniclastic tuff or similar. It is also apparent that in each of the precious opal occurrences we have discussed, there has been a substantial amount of weathering, which has released silica from these rocks. It is generally agreed that this silica is the source material for the formation of precious opal.

What is sometimes missing in discussions on the formation of precious opal, is a method in nature to produce a silica solution from which it is possible to form a colloidal suspension of mono-disperse silica spheres and then provide a suitable mechanism to precipitate these spheres in a way that they can be arranged in an ordered array suitable to produce a play-of-colour and hence form precious opal. The science of sphere formation is reasonably well understood; what is not so clear is how the sphere formation takes place in the ground within the geological environment to form precious opal as we know it.

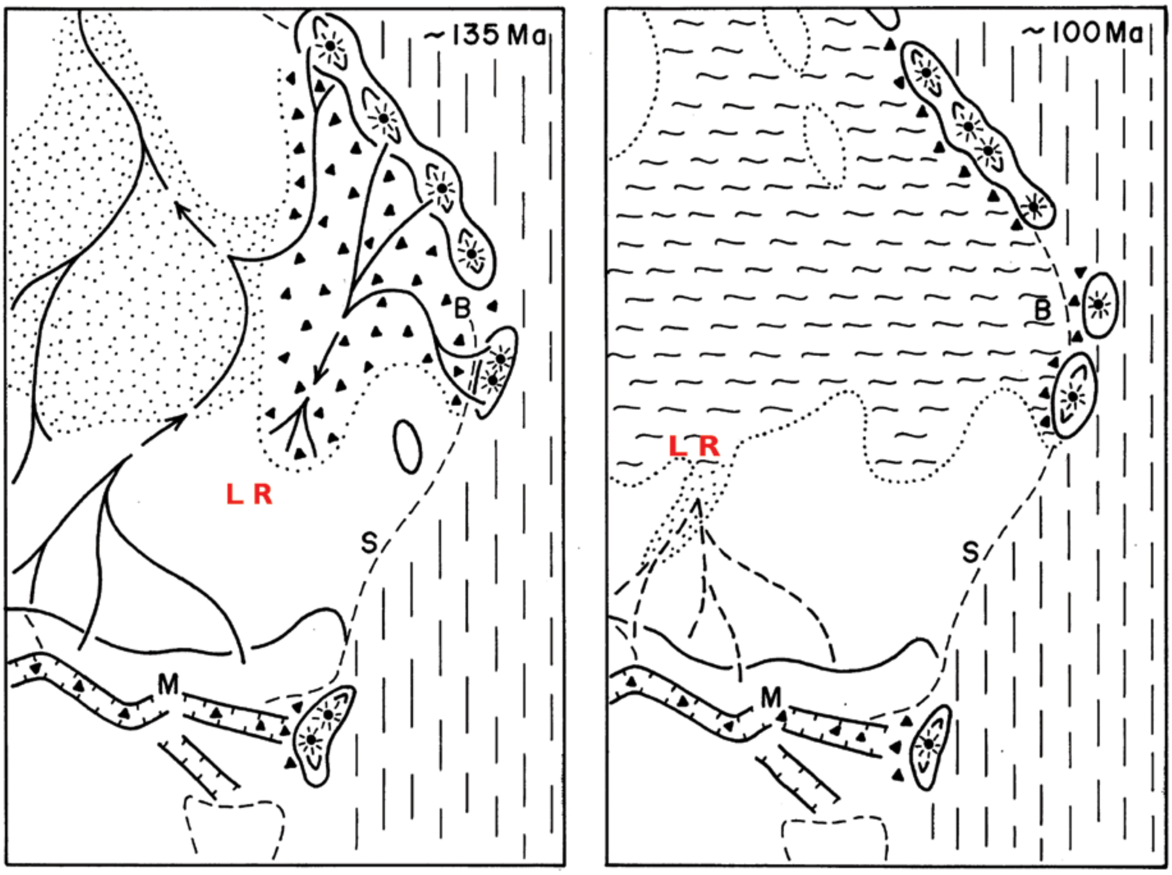


Figure 10. Diagrams after Veevers showing the suggested position of the Rockhampton volcanic province (top right corner and drainage patterns into the GAB during the Cretaceous) (Veevers, 1984).

Left: Approximately 135 Ma. The drainage pattern (represented by lines and triangles) forming the GAB. Right: Approximately 110 Ma. The GAB inundated with water (represented with waves).

"LR", "B" and "S" mark the approximate positions of Lightning Ridge, Brisbane and Sydney respectively.

Figure 11. Notice the banding or layering of precious opal in each of these specimens especially note the curved meniscus at the edge of each indicating formation at or near standard temperature and pressure (STP). Left: A light banded opal from the volcanic environment Idaho, USA. Centre: Light banded boulder opal from Queensland. Right: Dark opal in sandstone from Lightning Ridge, New South Wales. Photos: A. Smallwood.

The actual process of precious opal formation is apparently extremely complex. It first involves the chemical weathering of the silica rich minerals provided in the lithology of the local environment; there are several theories published supporting this (Rey, 2013). Once the silica is released into solution, it is then polymerised and precipitated in suitably ordered arrays of spheres to give play-of-colour. This is followed by a mechanism to cement the opal spheres together as a solid. It is the opinion of the author that the process may be controlled by the pH of the opaline silica solutions present. There is evidence also of cyclical or episodic solution and dissolution of silica spheres as evidenced in banding or layering of opal observed in both the macro range, and nanometre range (Figures 11 and 12) as well as a generational growth of the silica spheres as can be seen in the growth patterns in the electron micrographs (Figures 13, 14 and 15).

Figure 12. A sample of seam opal from Mintabie, South Australia. Note the original band of white and grey opal has fractured and has been subsequently "healed" by a further generation of yellow potch opal. Photo: A. Smallwood.

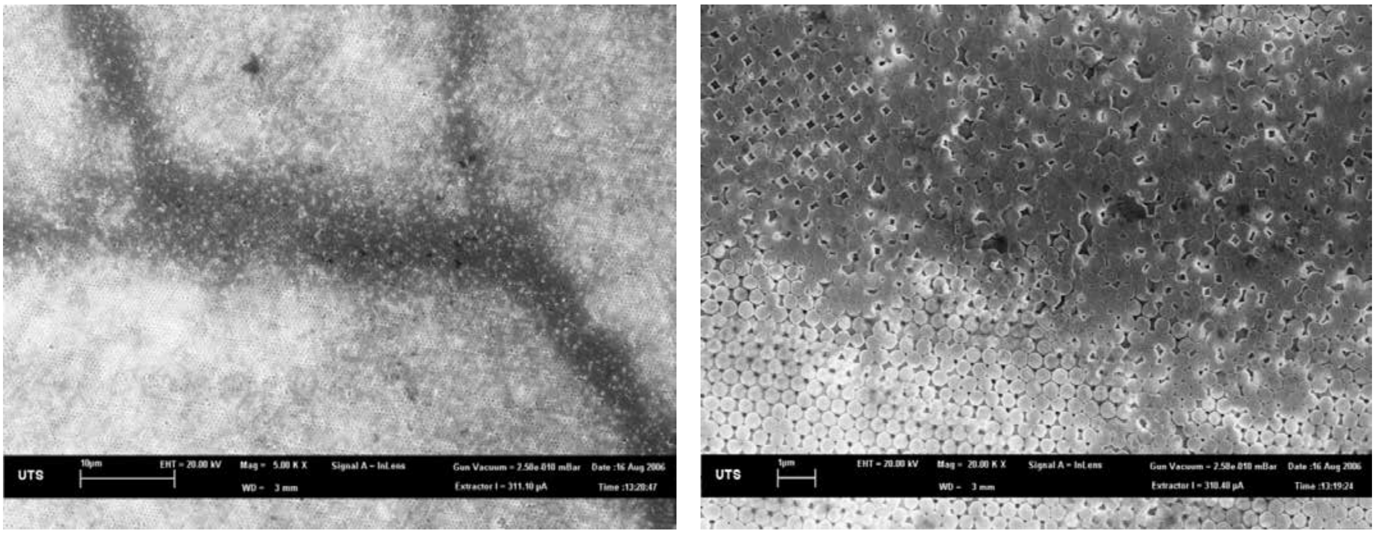


Figure 13. Left: Photomicrograph showing a dark "fracture" in a precious opal from Coober Pedy, South Australia, 5,000x. Right: Photomicrograph showing that the dark area is in fact an in-filling of "potch" opal with no ordered array of spheres that may have filled and healed the original fracture as a second generation of opal, 20,000x. Photos: A. Smallwood.

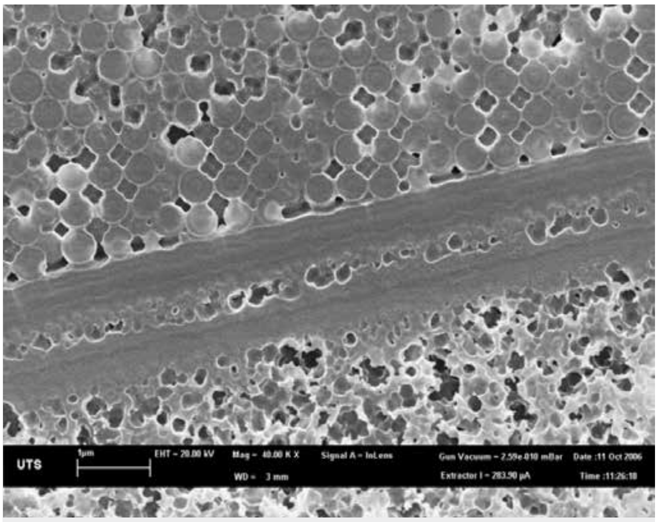


Figure 14. A sample of the Idaho precious opal as shown in Figure 11 examined by SEM. Note the nanostructure layering of this opal showing precious opal (with an ordered array) where it appears the "cement" has been etched from around the spheres and is separated by two thin layers of other silica, with a 'honeycomb"-like section where it appears the silica spheres have been etched away. 40,000x. Photo: A. Smallwood.

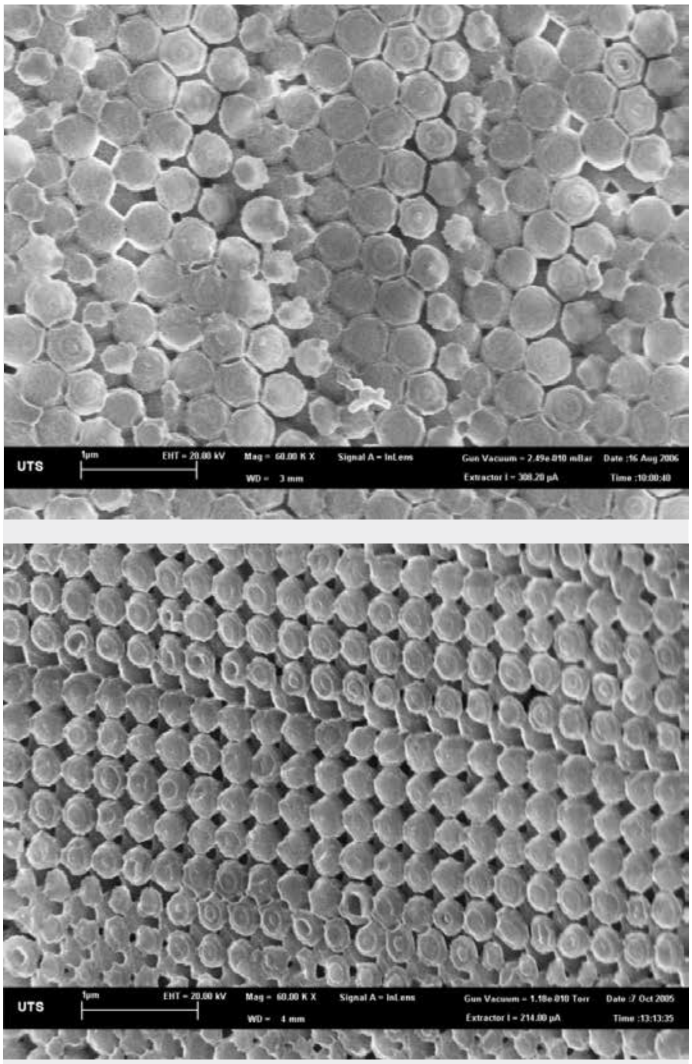


Figure 15. Two samples of Coober Pedy Precious opal. Top: A lightly etched sample, note the concentric ring structure of the opal spheres suggesting a generational growth process for the spheres. Below: An oblique aspect; the opal has been more strongly etched. This has provided a greater contrast to the sphere structure. Both micrographs are at 60,000x. Photos: A. Smallwood.

The unique varieties of Australian Precious Opal

Two varieties of precious opal are unique to Australia, Precious Black Opal from Lightning Ridge in New South Wales and Precious Ironstone Boulder Opal from Queensland, each of which can be readily identified as being of Australian origin. Precious Light opal including Precious Crystal opal (transparent opal) is not unique to Australia and represents a greater challenge to the gemmologist when separating it from precious opal originating from occurrences outside Australia.

Australian Precious Black Opal

Precious Black opal consists of a layer of precious opal (i.e. opal that has play-of-colour) on a very dark grey to black potch opal. The gemstone is still entirely opal and has formed naturally as a single solid piece. Black opal is a family of opal that grades from black tones through to very dark grey tones and is produced almost exclusively at Lightning Ridge from mines in sedimentary environments.

All shades or tones of dark opal (from medium dark grey to medium light grey) and light opal (from light grey tones through to white opal) form part of the range of opal produced in Lightning Ridge. Black opal occurs as seam opal and nobby opal from fields in the Lightning Ridge district in New South Wales including Grawin, Glengarry and Sheepyard (Figures 17 and 18). Some limited production also comes from Mintabie and Allan's Rise in South Australia. However, apart from these occurrences, this variety of sedimentary black precious opal is not found at any other occurrence in the world.

	SEDIMENTARY OPAL	VOLCANIC OPAL
Refractive Index usual range:	1.42 -1.45	1.40 – 1.42
Specific Gravity usual range:	2.10 -2.15	2.00 – 2.10
Luminescence		
Fluorescence	Light opal strong bluish white	Usually inert
Phosphorescence	Light opal Prolonged Black opal medium to subdued	If fluorescence no phosphorescence

Box 1. Gemmological Properties of Australian Precious Opal with comparisons between Sedimentary and Volcanic opal.

Figure 16. A selection of fine Lightning Ridge Black Opals. Left: Photo: R. Webber. Centre: Photo Courtsy Cody Opal. Right: Photo: Len Cram.

Figures 17. Examples of Lightning Ridge Precious Black opal occurring as "in situ" seams in the cretaceous sediments. Photos: T. Coldham.

Figure 18. Top: A parcel of Lightning Ridge "seam opal" from the Grawin field. Bottom Left: A parcel of Lightning Ridge "seam opal" from the Grawin field. Bottom right: "Nobbys" Photos: T. Coldham.

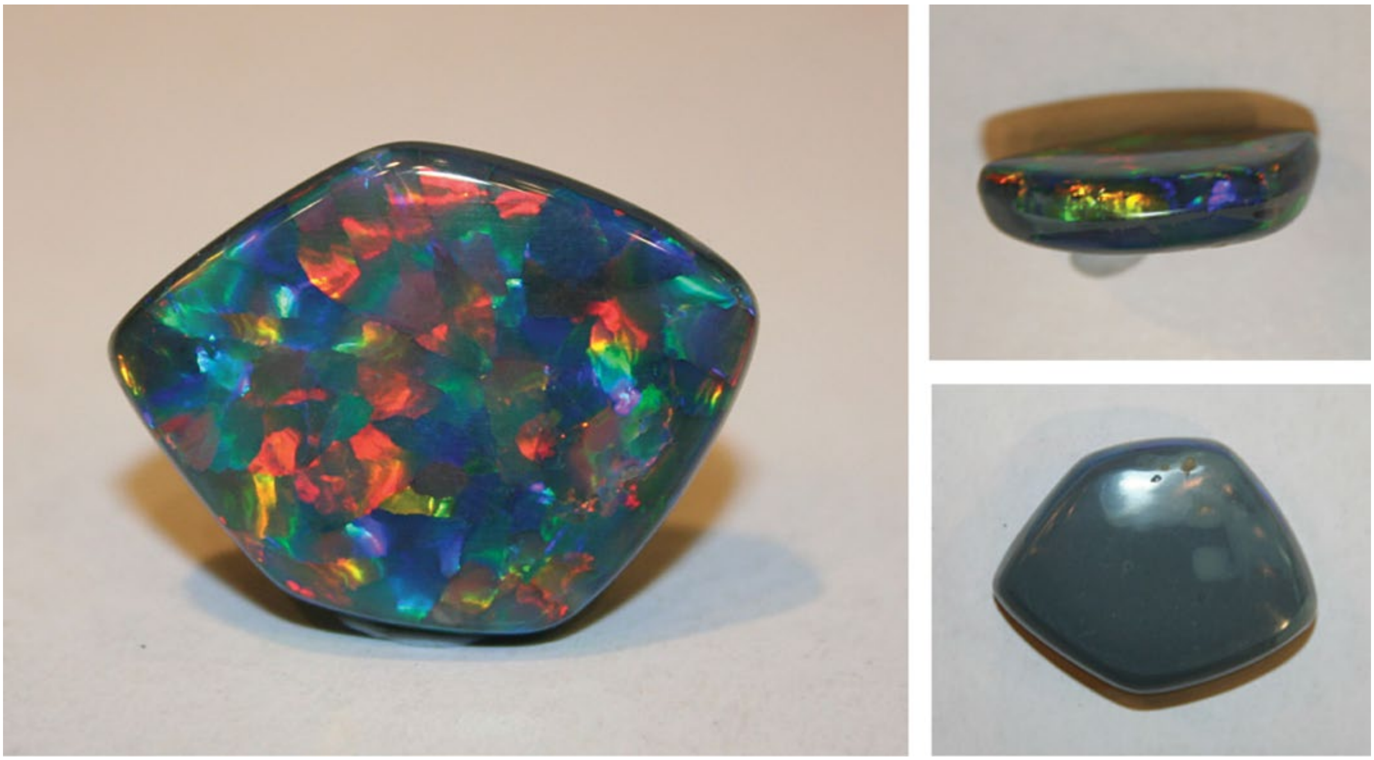


Figure 19. One distinctive feature of a black opal is a layer of precious opal occurring on a layer of black potch. Left: The face up view of an exceptional example of a vivid red multi-coloured precious Black opal, known as "the artist's palette". Top right: The side-on view. Bottom right: The back of the same stone. Note the band of precious opal with play-of-colour intimately joined with the black potch layer below. Opal courtesy Cody Opal. Photos: A Smallwood.

Figure 20. A light opal bead in a strand of mixed dark and light opal bead displays strong fluorescence under UV light and weak phosphorescence once the UV source is turned off. Left: normal lighting. Centre: Under UV light. Right: Immediately after the UV light is extinguished. Photos: T. Coldham.

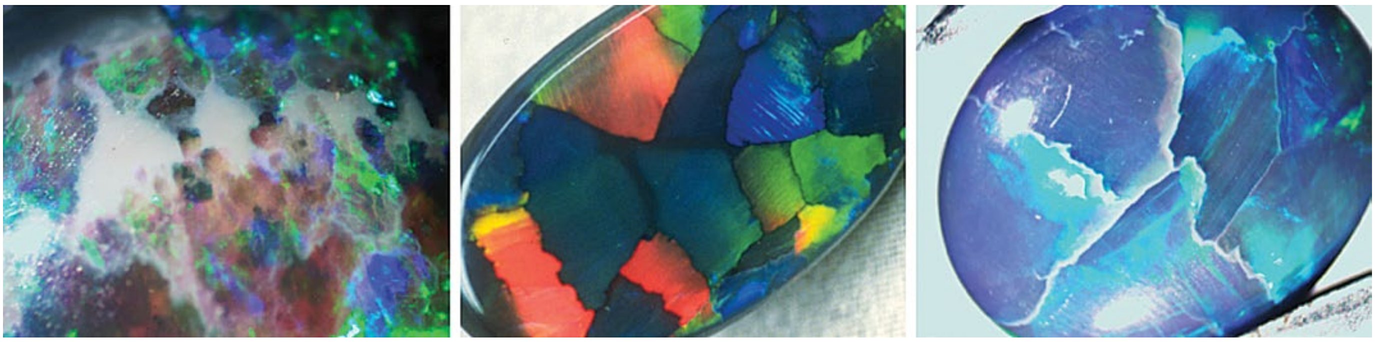


Figure 21. Left: Light irregular shaped "potch" inclusions in the face of a Lightning Ridge black opal. Centre: Black potch lines between the colour grains in a Lightning Ridge black opal. Right: White "potch" or "matrix" lines between the colour grains. Photos: A. Smallwood.

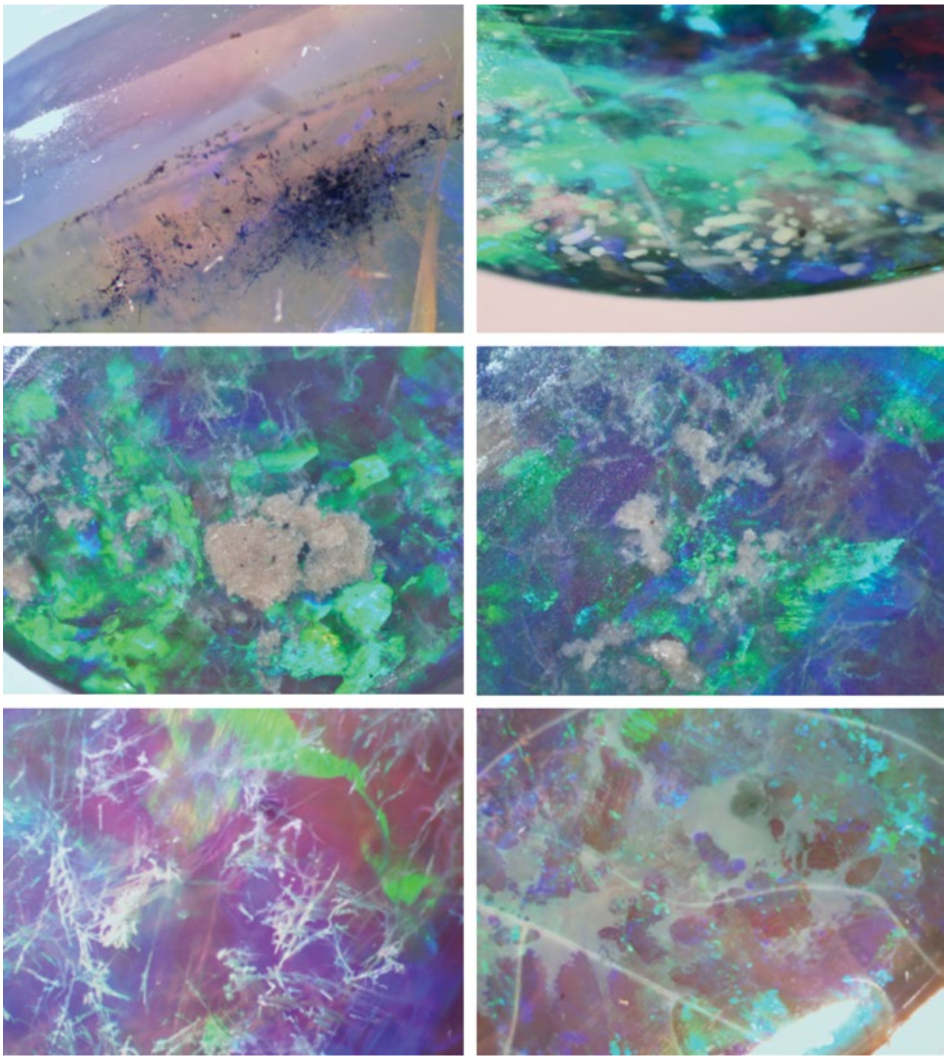
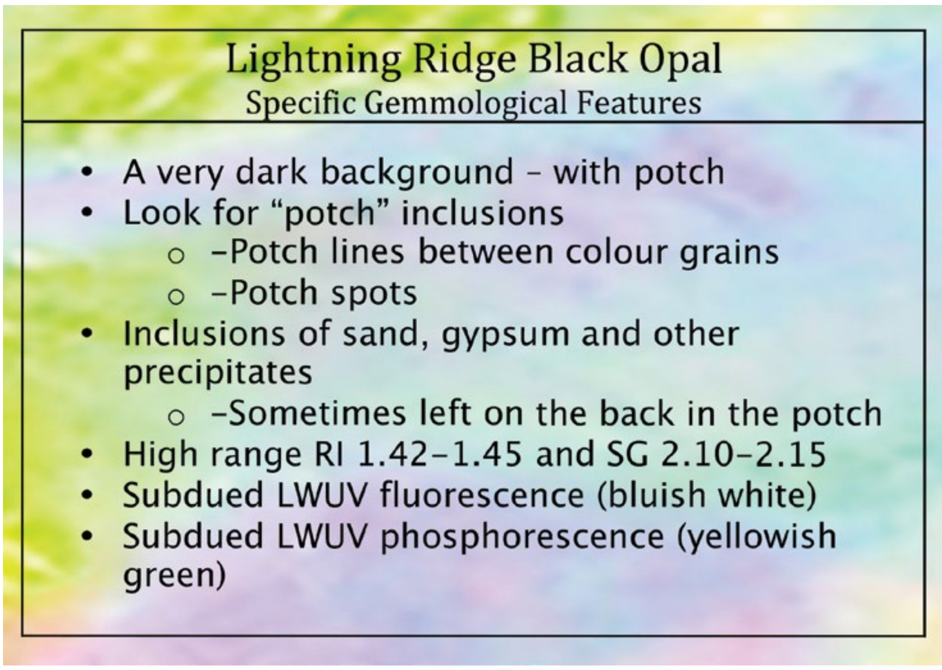


Figure 22. Top left: Irregularly shaped "black" potch spots distributed through a Lightning Ridge black opal. Top right: Irregularly shaped "white" potch spots distributed through a Lightning Ridge black opal. Centre left: A series of sand inclusions in the face of a dark opal from Lightning Ridge. Centre right: A lower magnification showing numerous sand inclusions. Bottom left: Potch "whisp" inclusions. Bottom right: Potch "webbing" in the face of a Lightning Ridge dark opal. Photos: A. Smallwood.



Australian black opal from Lightning Ridge typically has a refractive index (RI) higher on the range of readings as provided by the lists of constants such as those of the GAA, and is usually between 1.42 and 1.45; with a spot or distant vision RI often averaging close to 1.45. Also the Specific Gravity (SG) is usually in the higher range for opal being between 2.10 and 2.15, often closer to 2.15 (Smallwood, 2003).

Fluorescence and particularly phosphorescence of Black Opal is usually subdued and often variable and may be difficult to assess or view with normal gemmological instrumentation. The usual observation is that black opal and dark opal will fluoresce a very weak bluish white to both Long Wave (LW) and Short Wave (SW) ultraviolet (UV) radiation. When the UV light is extinguished the opal will phosphoresce yellowish green for a prolonged period of time (Figure 20). As the fluorescence is usually moderately weak, the corresponding phosphorescence is also weak and may not always be visually detected, however, both the fluorescence and the phosphorescence have been detected instrumentally (Smallwood, unpublished thesis).

Microscopic examination of cut and polished Precious Black Opal commonly reveals an association of black potch (or non-precious opal) with POC opal. The potch can be seen as surrounding the borders of colour grains, or occurring as spots and patches both around the side of a cut opal as well as in the face of the POC (Figure 21). Often observed are inclusions called "sand" by miners and traders. Sand is simply small remnants of the "sandstone" or country rock in which the opal was formed left in the surface of a finished stone. On the back of cut stones it usually appears as remnants of white sandstone in a black background, whilst on the face of a cut opal it is seen as clusters of particles having a granular appearance. Other inclusions found in Black opal are inclusions of a wispy or fibrous appearance occurring within the POC. It has been postulated that this material may be simply either potch, a fibrous form of gypsum or barite (Figure 22). A report on detailed examination of these inclusions is the subject of a paper currently being finalised by the author.

Figure 23. A series of ironstone concretions or "boulders" in the wall of a boulder opal mine in southwest Queensland, Photo: T. Coldham. Insert: An example of a "boulder" with precious opal and measuring approximately 90cm x 15cm. Photo: A. Smallwood.

Figure 24. Left: A sample of boulder opal where the precious opal has in-filled shrinkage cracks. Photo: A Smallwood. Centre: Boulder Matrix opal from Koroit, Photo: A. Smallwood. Right: A fine example of a "Yowah Nut" showing gem quality light opal in the centre, Photo: T. Coldham.

Queensland Ironstone and sandstone Boulder opal

This variety of precious opal is usually cut as "opal and rock" (Smallwood, 1997). The opal is integral to and deposited directly onto or into an ironstone rock. Precious boulder opal of this type is unique to the Queensland opal fields and not known to occur anywhere else in the world. The ironstone may vary from a very fine grained very dark haematite-rich material with an almost metallic lustre through to a fine-grained dark brown, chocolate brown or yellowish brown coloured iron rich sandstone. These ironstone rich sedimentary rocks result from the deposition of iron oxides in the sandstones over geological time. Quite often the ironstone occurs as concretions within the cretaceous sandstones that have the appearance of boulders hence the name boulder opal (Figure 23).

The opal occurs as infillings in shrinkage cracks and other cavities in the ironstone. The ironstone is often characterised by concentric banding seen as differences in shades of colour and hardness. When the opal in-fills small voids as spots and single colour grains it is known as boulder matrix opal. In a particular named variety of boulder matrix opal, the nodules are known as "Yowah" nuts after the opal field in Queensland where the occurrence of this opal type is predominant (Figure 24).

Precious Boulder opal when cut and polished as a full-faced opal may occur either as Black Opal or Light opal and it is usual that the opal layer is a relatively thin veneer on the top of the ironstone.

Figure 25. Left: A piece of rough boulder opal prior to polishing. Photo: T. Coldham.
Centre: A polished example of "light" Boulder opal. Photo: A. Smallwood.
Right: An exquisite example of vibrant Green on blue, "black" Boulder opal. Photo: A. Smallwood.

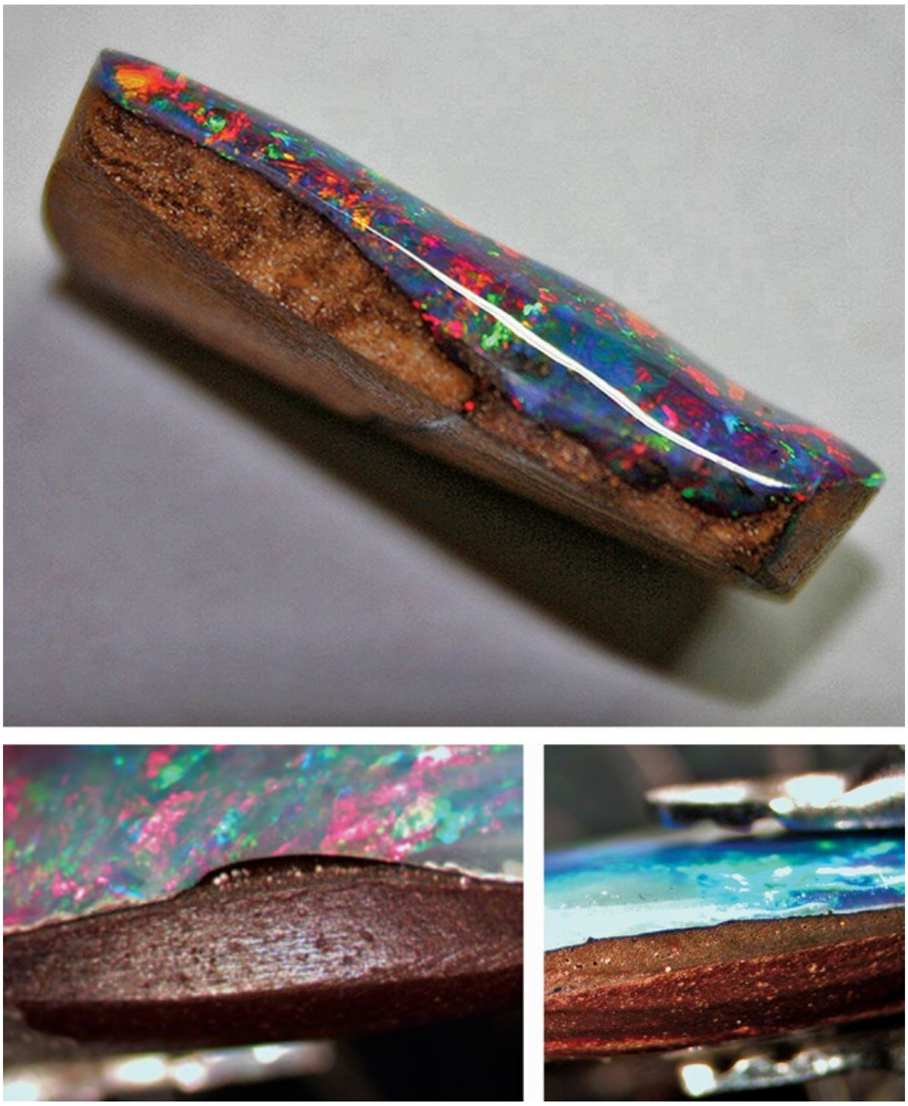
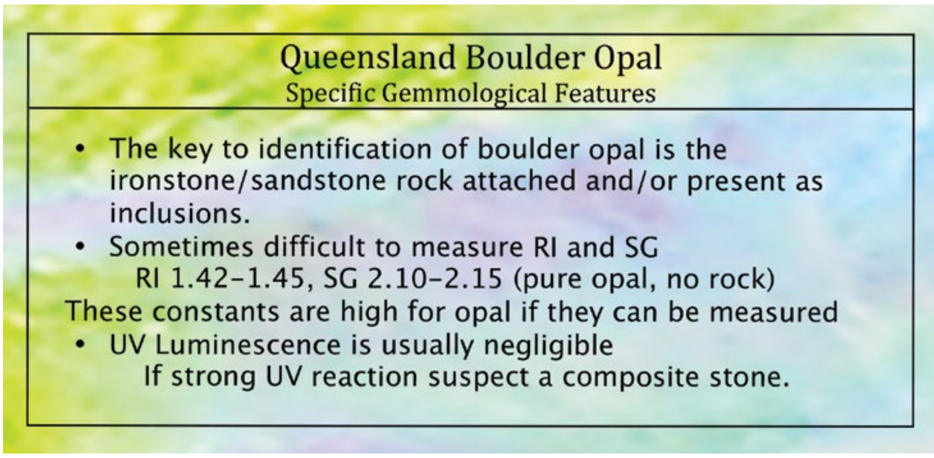


Figure 26. Above: The Boulder opal shown in Figure 3 (centre) photographed from the side. Note the undulating nature of both the polish and the connection with the ironstone host rock. Below right and left: The junction of precious opal and backing material of composite stones. Note the bubbles, hollows and variation in grain sizes at the junctions and the layer of brown coloured "glue" especially evident in the right hand photo. Photos: A Smallwood.

According to the opal nomenclature these gemstones should more correctly be described as "Black Boulder Opal" and "Light Boulder Opal" (Smallwood, 1997) as illustrated in Figure 25. There are several different types of ironstone and sandstone that allow distinctions to be made by local miners for various types of boulder opal. Given the association of opal and rock it may be possible to expand the current opal nomenclature to include more information regarding the description of the rock that the precious opal is deposited on. This forms a part of ongoing research by the author.

The identification of Precious Boulder opal is most often done visually as the opal with POC is intimately attached to the ironstone and, in most instances requires no other process of identification. However care must be taken to make sure the stone being examined is not a composite stone or doublet with a manufactured backing.

It is often difficult to obtain a RI reading on many "Boulder" opals as the opal face is often undulating following the contours of the thin opal veneer making it difficult to place the opal surface on a refractometer. Where a boulder opal is cut with a flat or sufficient domed face to measure the RI, it is usually found to be at the higher end of RI scales quoted for opal. Obtaining a suitable reading for specific gravity (SG) is usually impossible as it will be distorted due to the presence of the ironstone rock. Rarely the thickness of the actual opal with POC is sufficient to be cut and polished separate from any ironstone, in such stones the SG is usually in the higher range of that quoted for opal.



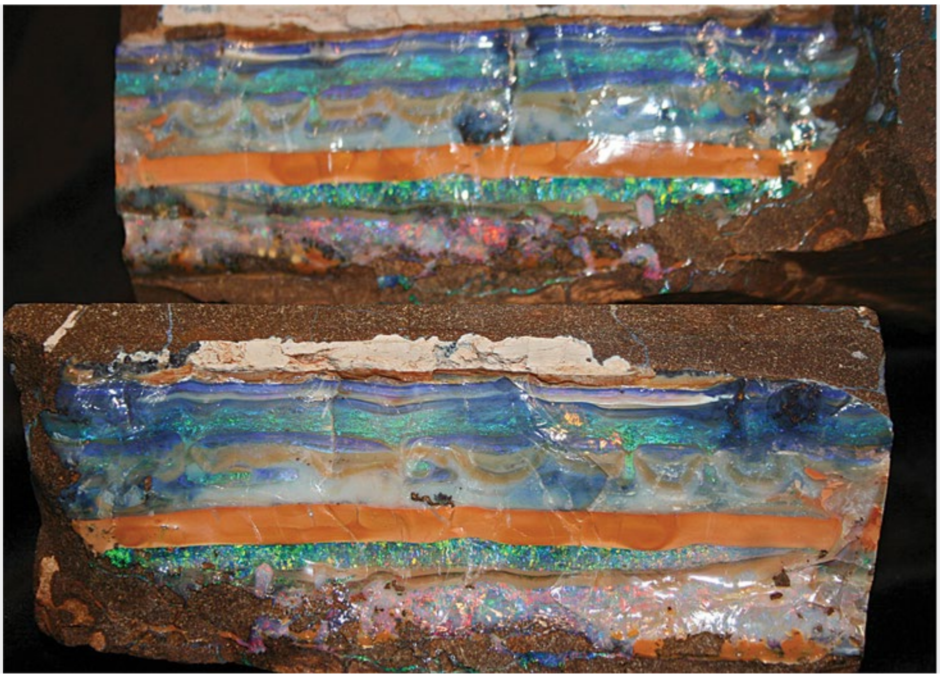


Figure 27. Left: A pair of matching faces of boulder opal resulting from a thin vein of precious opal in the original boulder being split open, specimen courtesy of Eric Steltzer. Right: A separate gem quality pair of polished boulder splits. Sample courtesy of Mark Hodges, Sunrise opals Quilpie. Photos: A. Smallwood.

Photoluminescence of the Australian ironstone boulder opal is also of interest. For most boulder opal the fluorescence is very, very weak if visible at all and phosphorescence is not present. For all general identification purposes it can be considered to be inert to both LW and SW. Should a piece of boulder opal be found to exhibit a strong UV reaction (strong fluorescence and strong and prolonged phosphorescence) then a doublet or composite opal should be suspected.

The inclusions observed in precious boulder opal are to a great extent mostly related to the ironstone rock. A distinctive feature of boulder opal is that the opal face is often very well polished but has an undulating or uneven surface. As boulder opal often usually occurs as extremely thin "veins" when it is deposited in the host ironstone, and lapidaries have very little precious opal to work with to produce a cut gemstone. It is interesting to note with much boulder opal when seen in the rough it is often difficult to visualise how a lapidary can produce a

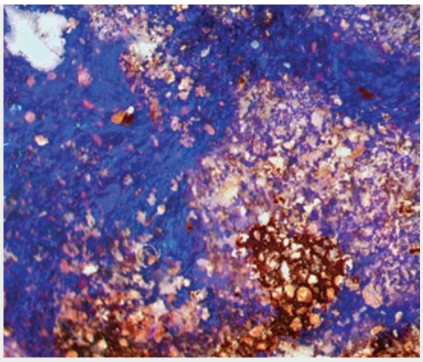
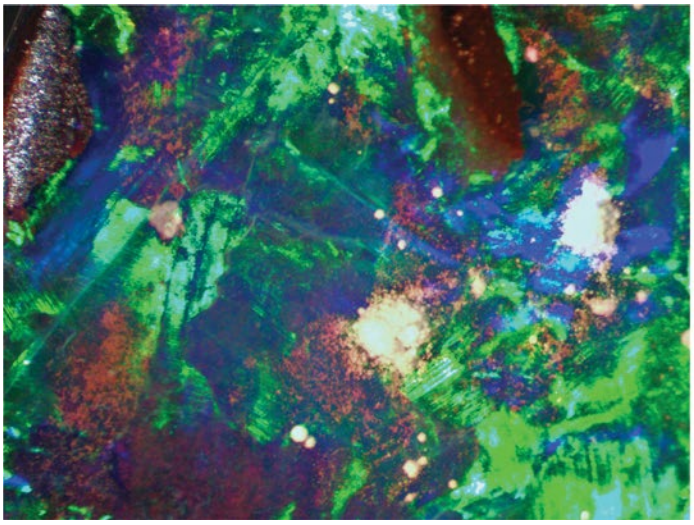


Figure 28. Queensland Boulder opal, left, a specimen of bright blue/green opal with ironstone in the face. Right, a close up showing ironstone breaking the face, and the ironstone under the opal with POC.



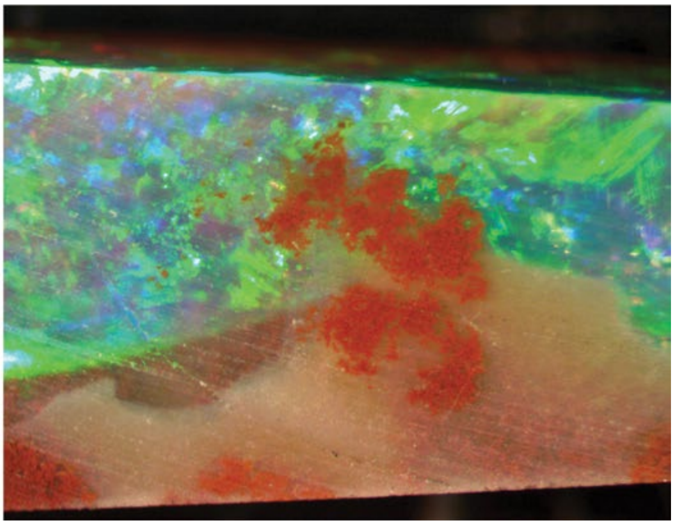


Figure 29. Left: Photomicrograph showing the underlying ironstone under the POC .
Right: Photograph showing the uneven nature of the ironstone backing.
Photos: A. Smallwood.

Figure 30. Example of a "painted lady" from Andamooka opal fields in South Australia. Photo: A. Smallwood.

stunning gemstone. Careful cutting allows the opal to be "split" into two almost identical pieces as illustrated in Figure 27.

As a consequence, more often than not, some part of the ironstone rock will protrude through the opal veneer and is left in the face of the stone and is a suitable inclusion for identification. If the ironstone does not present itself in the face, then microscopic observation will often show as growth hillocks and granular inclusions just "under" the surface. It is often helpful to examine such opals under the microscope using a fibre optic light source to reveal these structures. This is also a good technique to use to confirm a doublet opal. If no hillocks or ironstone structure are observed in the flat plain between the POC and the backing, a doublet opal can be suspected (Figure 28).

Accepting that the proper interpretation of the opal nomenclature is that boulder opal is "opal and rock" then there exists some other varieties of opal that can be properly labelled as boulder opal. Examples from other opal producing districts include precious opal on the face of quartzite from Andamooka (colloquially known as "painted ladies" (Figure 30.)), opal cameos cut from andesite with an opal veneer on top from Slovakia, and from Mexico, "fire" opal cut and polished with the host rhyolite remaining as a part of the gemstone (Figure 25).

Figure 31. Left: An abstract carving of light precious opal from Coober Pedy, South Australia. Photo: T. Coldham.
Centre: Light crystal opal from Lambina, South Australia. Photo: A. Smallwood.
Right: Crystal opalised shell probably from Coober Pedy. Photo courtesy Cody Opal.

Precious Light opal and Precious light crystal opal

Production of Light precious opal and precious crystal opal (transparent precious opal) is much more prolific worldwide, coming from many different localities. However, Australian sedimentary occurrences of this variety of opal have certain uniquely different attributes to those from other worldwide opal occurrences (Figure 31).

The identification of Australian light precious opal and its separation from opal from other occurrences, including those from volcanic environments may become a little more difficult for the gemmologist; however the presence of strong and distinctive luminescence will be found to be of great assistance.

Measurement of the RI as a part of the identification of precious light opal is useful. As stated before, Australian precious opal has a statistically higher RI when compared to that of opal from volcanic environments. There is notably an overlap in the range of refractive indices when comparing them with overseas occurrences such as precious opal from Brazil. In these instances the RI is not a conclusive property that can be used for the separation precious opal from different origins. However, if the RI is in the higher range for opal then it may well be of assistance in the separation of Australian precious opal from opal of other origins.

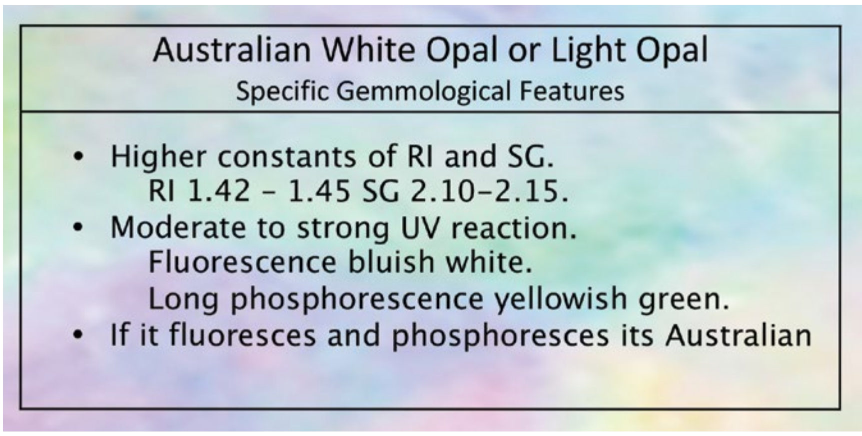
Specific gravity determinations may also provide a strong indication as to the origin of light precious opal. Most Australian light and crystal precious opals have a SG that is considered high for opal, in the range of 2.15, whereas light and crystal precious opal from overseas occurrences are distinctly lower in the range of 2.00 to 2.10.

In the identification of light precious opal varieties photoluminescence is important. Photoluminescence in opal of Australian origin may be considered both distinctive and conclusive at the present time. The fluorescence of light opal from Australia is distinctively moderately strong to very strong bluish white. Opal from the volcanic environments both from Australian and overseas locations is usually completely inert. An exception is certain light precious opal from Honduras that shows a degree of white fluorescence (author's observation) and from some older historical opal specimens from Slovakia that has been reported (Rondeau et al., 2004).

However, the observation of phosphorescence in the modern production of Australian sedimentary light precious opal remains conclusive. Light and crystal precious opal from the Australian sources of White Cliffs in New South Wales, and Andamooka, Coober Pedy, Lambina, Mintabie in South Australia all display distinctive and prolonged phosphorescence. Although it is described in most gemmological literature as being sustained for 10 to 12 seconds duration and is a yellowish green colour, the duration of the phosphorescence can vary from a few seconds to 10 seconds or longer.

For the purpose of determining the origin of precious light opal, it can be stated, if the gemstone gives test results indicate a high refractive index for opal, and a high specific gravity for opal as well as displaying a bluish white fluorescence and yellowish greenish white phosphorescence, then the opal is of Australian origin.

The inclusions observed in Australian light precious opal are similar to those discussed previously with Black opal. Light and white potch is often seen as an inclusion in the form of lines, spots and irregular shapes. In some instances crystals of gypsum and other precipitates such as barite are seen as fibrous wisps. Sand spots, and fibrous clusters are also indicative at least of natural origin (Figure 32).



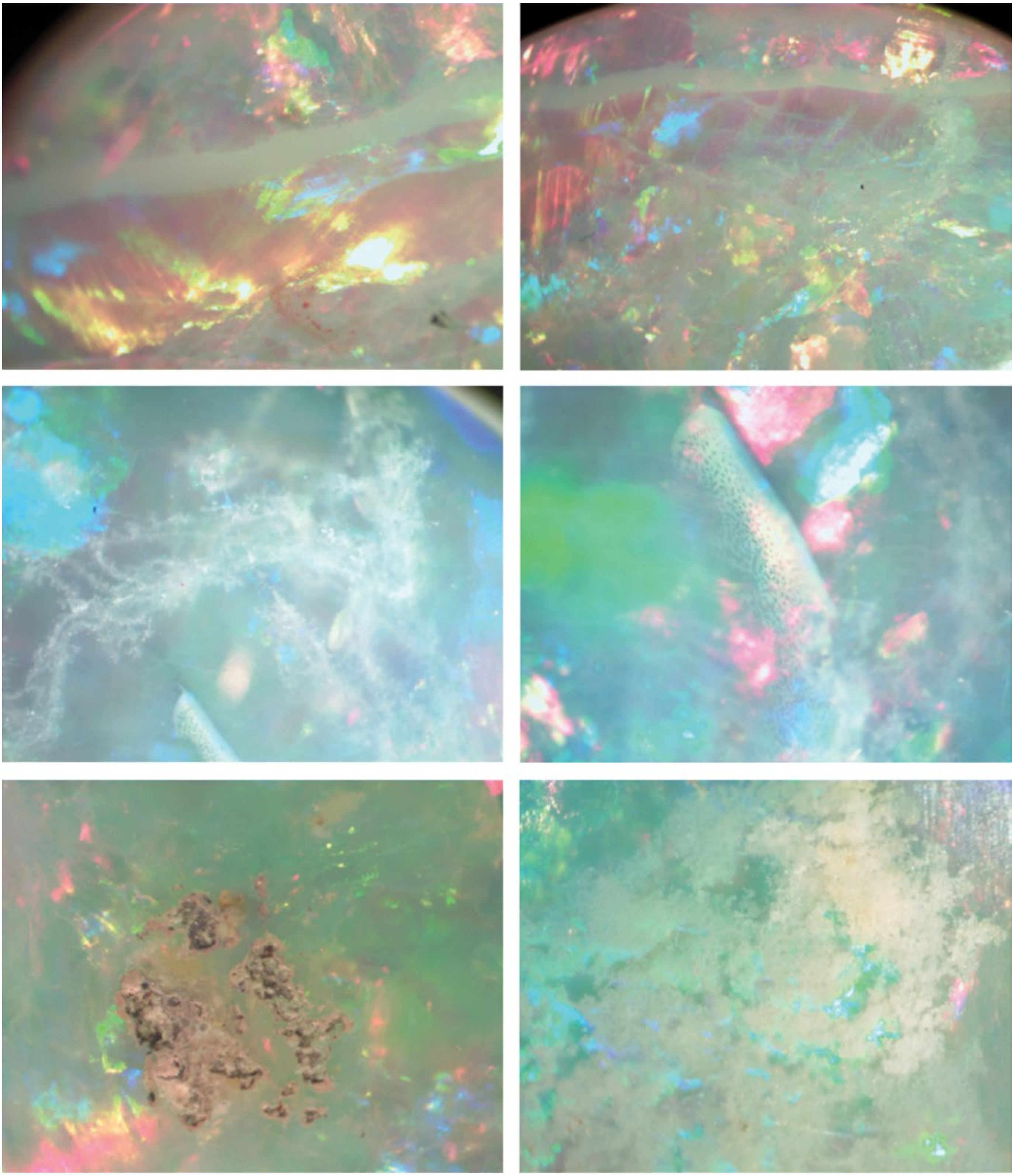


Figure 32. Inclusions seen in precious light opal. Top left: A line of light "potch" in the face of a light Coober Pedy opal. Top Right: The same photo at a lower magnification showing the potch line and other light potch "wisps" in the centre of the photo. Centre left: Potch "wisps" throughout a light opal from Coober Pedy. Centre right: A natural fracture showing infilling with white sand. Bottom left: Prominent "sand" left in the face of a light crystal opal from Andamooka. Bottom right: Sand inclusions pervading a light opal from Coober Pedy.

Matrix opal

The distinctive attribute of matrix opal is that it is described as "opal in rock". The definition of matrix opal in the nomenclature states "the opal is intimately diffused as infillings of pores or holes or between grains of the host rock in which it was formed." (Smallwood, 1997). The key to the identification of matrix opal resides around the identification of the host rock. Because of the intimate mixture of opal and particles within the rock the determination of normal gemmological constants such as refractive index and specific gravity are not of assistance. Differentiation from other opal types and other gemstones relies on visual characteristics. Australian precious matrix opal (matrix opal with POC) is found predominantly at Andamooka where there occurs a light variety, a natural black variety and a yellow variety. The light or white variety is a matrix opal that is often treated by a sugar and acid treatment (Figure 33).

Apart from the boulder matrix discussed above, another variety of sandstone matrix opal occurs on a number of fields in Queensland where precious opal infills the spaces between sand grains, often as the cement (Figure 34).

This sandstone opal is also often treated by soaking in oil (either vegetable or automobile) and then carbonised by heating in an oven. This material is often cut into beads (Figure 35).

Examples of locations of precious matrix opal outside Australia are a natural black variety from Honduras, a light variety from Mexico, and a sandstone matrix from Louisiana in the USA.

Figure 33. Left: Section through a piece of Andamooka treated by the normal process of acid and sugar carbonisation. Note the carbonisation and therefore strong play of colour is only a few millimetres deep. Right: The outside treated surface of the same specimen. Photos: A. Smallwood.

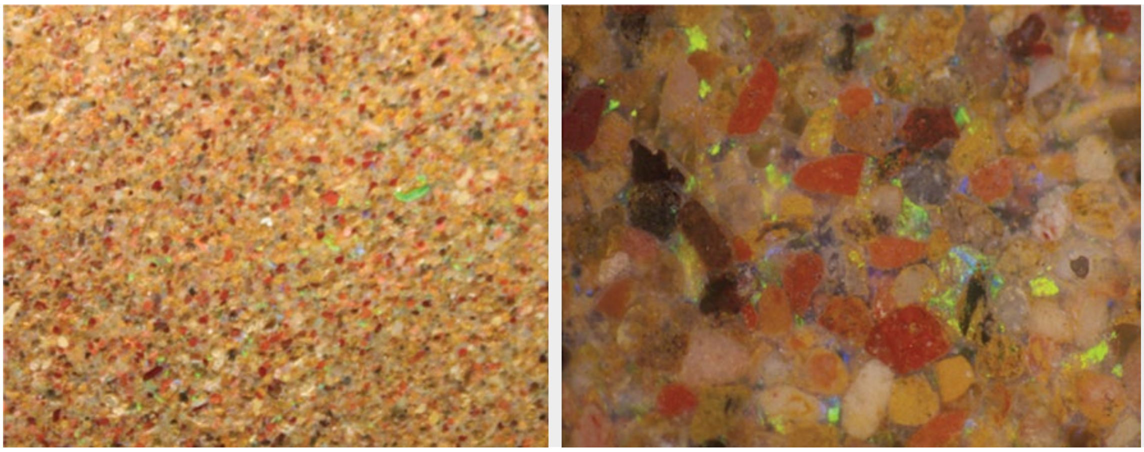


Figure 34. Sandstone matrix opal untreated. Left: The sandstone matrix at normal magnification. Right: The same matrix opal at 40x. Note that the precious opal in-fills the spaces between the sand grains. Photos: A. Smallwood.

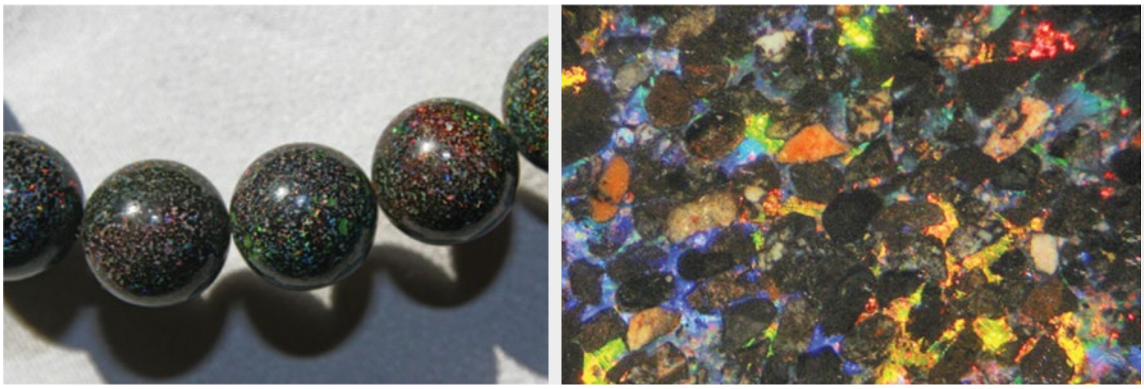


Figure 35. "Fairy opal" beads. Left: A partial strand of 12mm treated boulder sandstone matrix beads. Photo: A. Smallwood. Right: A section of the treated sandstone matrix beads at approximately 40x. Photo: G. Pearson.

Scientific experimental analyses of Australian Precious Opal

Historically Australian scientists have been at the fore-front of opal science. The original discovery of the internal structure of opal and the reason for "Play-of-colour" being present in precious opal was made by Ralph Segnit, Peter Darragh, John Sanders and Arthur Gaskin in the 1960's. Using newly available technology in the form of, the electron microscope at the CSIRO in Melbourne this group revealed for the first time the regular stacking of minute nanometre sized silica spheres (Jones, Sanders and Segnit, 1964; Darragh and Sanders, 1965).

More recently a substantial amount of research has been undertaken into Australian precious opal and its formation. Since 1999 bi-annual scientific symposiums have been organised in Australia where invited researchers and miners have gathered to elucidate postulations and theories of opal formation and enhance mining exploration with the purpose of advancing opal production and a greater understanding of Australian

precious opal. With advances in analytical techniques, precious opal has now been the subject of investigation in Australia by modern instrumentation including X-Ray Diffraction analysis, advanced electron microscopy, thermal analyses and trace element analysis by Neutron Activation Analysis (NAA) and many other available techniques.

An overview of these scientific techniques and results follow with suitable references for those readers who want to delve further into the science of opal.

X-Ray Diffraction – (XRD)

XRD has for a long time been used to separate silica polymorphs as well as opal polymorphs. The original powder XRD analyses undertaken by Darragh and Sanders and published by the Geological Society of Australia remain the definitive work on this subject (Jones and Segnit, 1971). This reference defines three opal types Opal-A, Opal-CT and Opal-C. The basic results have a bearing on comparisons of opal from a sedimentary environment (Opal-A) to opal from a volcanic environment (Opal-CT). At this point it must be acknowledged that there is now considerable literature published on opal types and therefore only a selected few papers are listed (Langer and Flörke, 1974).

Precious Opal-A is opal that is amorphous when examined by XRD analytical technique. Essentially it means that the silica in this type of opal shows no silica network structure. This is represented by the broad peak in the graph in Figure 36. Precious Opal-CT is opal that is slightly more crystalline (however still amorphous) when examined by this technique, and this is illustrated by a narrow peak in Figure 36. Essentially it means that the silica is more ordered and the results show a combination of the silica polymorphs of cristobalite (C) and tridymite (T) within their structure. From a gemmological point of view this material (Opal-CT) will still appear amorphous when examined by a polariscope. Nevertheless there is a slightly higher degree of order in the structure of this material. The main point of the discussion is that Australian precious opals from sedimentary environments are all Opal-A. Almost all opal from volcanic environments is Opal-CT.

Scanning Electron Microscopy (SEM)

The original Scanning Electron Microscope (SEM) observations were the subject of publications in *The Australian Gemmologist* in the 1960's and as mentioned above were interpreted as giving evidence for the reason for POC seen in precious opal (Darragh and Sanders, 1965).

In the original publications (Jones, Sanders and Segnit, 1964; Darragh and Sanders, 1965), a distinction was made between ordered arrays of nanometre sized silica spheres of a particular size and arranged in a regular three-dimensional array, which provides a suitable structure to result in the diffraction of light and produce POC, and disordered or irregular spheres of varying size and shape in opal potch which resulted in no POC in this material.

In understanding SEM micrographs it is important to understand the method of preparation of the specimens. In order to reveal the structure of the opal in the specimen to be scanned, the normal procedure is to etch a freshly fractured opal surface with Hydrofluoric Acid (HF) (Figure 37). This etching is both variable and destructive as it dissolves a portion of the silica present on the surface of the opal revealing the sphere structure. It is also usual to coat the material with an electrically conductive material such as carbon, or platinum.

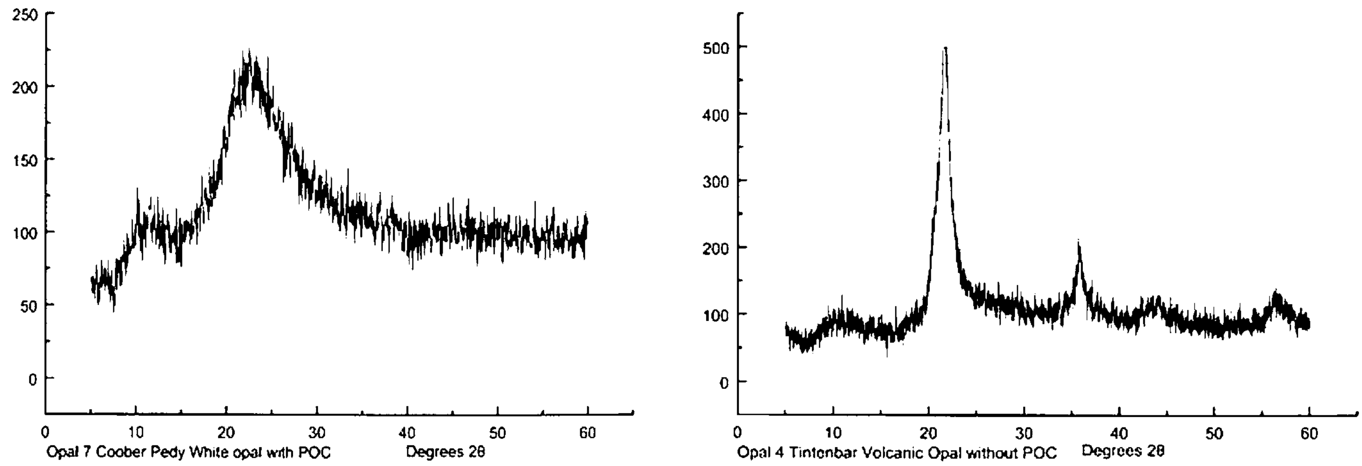


Figure 36. Left: The typical XRD results for opal-A which is indicative of opal from a sedimentary environment. Right: The XRD results for opal-CT which is indicative of opal from the volcanic environment (Smallwood, 2007).

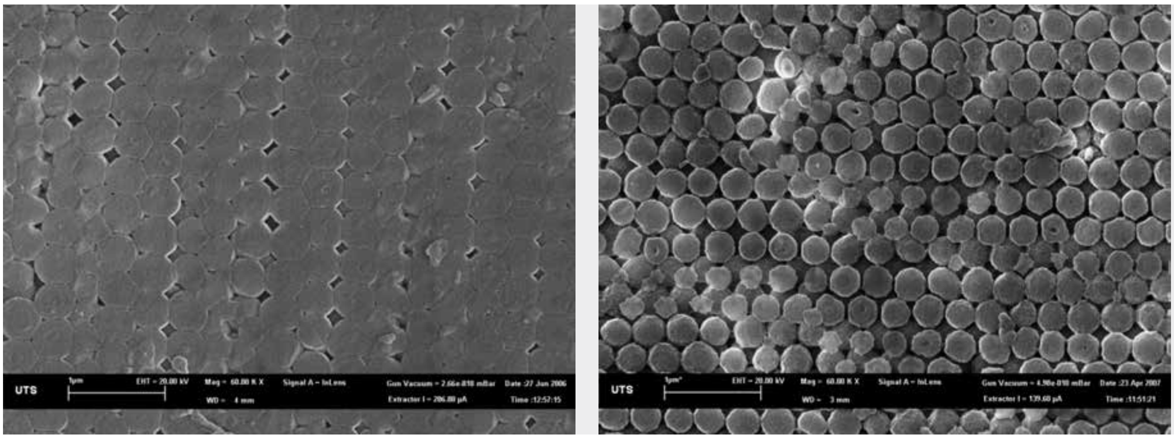


Figure 37. Coober Pedy light precious opal samples showing varying degrees of HF etching. Left: After a light etching. Right: After a more strongly etched sample. Photos: A. Smallwood.

Interpretation of these micrographs is that precious opal from the sedimentary environments shows an ordered array of evenly sized spherical silica spheres with the other silica binding or cementing the spheres being preferentially etched away. Further examination of electron micrographs of the sphere structure of Australian precious opal reveals that the internal structure of the individual opal spheres show a concentric and generational growth or ring structure.

In the SEM micrographs of precious opal from the volcanic environment, in this case from Tintenbar, New South Wales (Figure 38), and Brazil (Figure 39), the interpretation is that the silica spheres have been etched away leaving the cementing material behind which shows evidence of a nanometre-sized crystal structure. This may also be seen in Mexican type precious opal (Gaillou et al., 2008; Fritsch et al., 2002). In some instances of precious opal, the electron micrographs will reveal so called "lepispheres" (Figure 40), in a sample of Leopard opal from Mexico (Coenraads and Zenil, 2006). In this way scanning electron microscopy allows a unique differentiation between Australian sedimentary precious opal and other precious opal occurrences. Substantial investigations continue in the field of electron microscopy as the equipment continues to improve and offer new techniques and better resolution as is highlighted in some more recent publications (Smallwood, Thomas and Ray, 2008).

Thermal analyses

The primary role that thermal analysis has played in the characterisation of opal has been predominantly in the characterisation of the water in opal. The most common technique applied is thermogravimetric analysis (TG) which measures the mass of a sample as a function of temperature. As the temperature increases, the water contained in the opal is evaporated and the mass of the sample drops. The temperature at which the water is evaporated gives an idea of how well bound the water is in the opal. A good example of the types of differences that can be observed is in the loss of water from opal that is derived from a sedimentary environment or from a volcanic

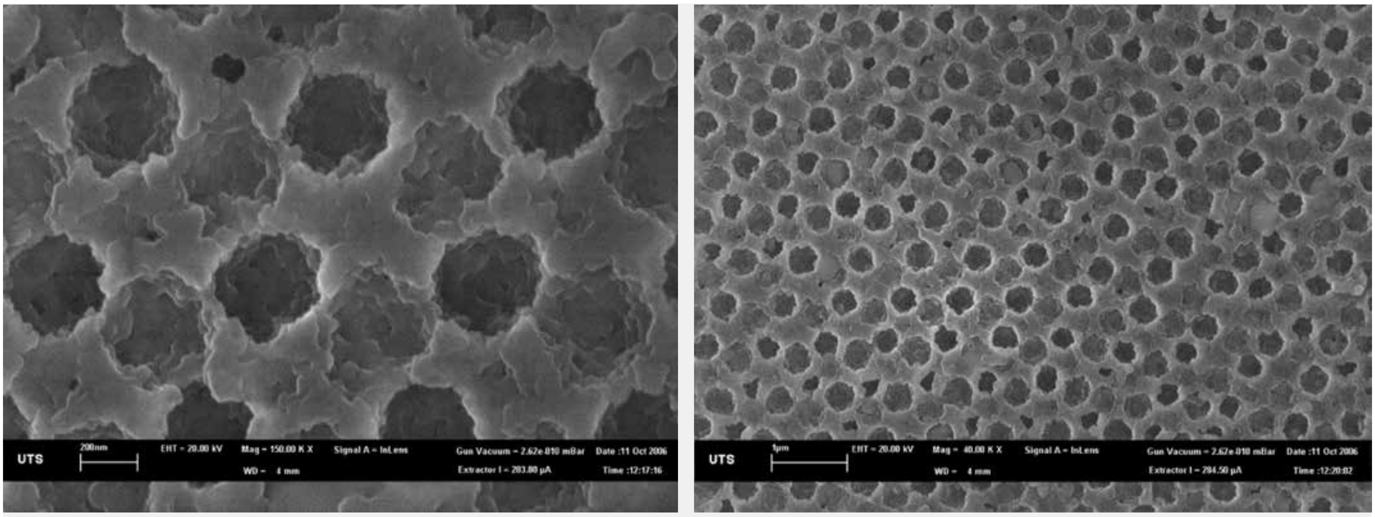


Figure 38. Tintenbar precious opal from a volcanic environment showing the structure in which it appears the "spheres' have been etched away leaving the cementing material behind, note that there appears to be a nano-structure of crystallites evident in this material. Left: Photograph at 150,000x Right: Photograph at 40,000x. Photos: A. Smallwood.

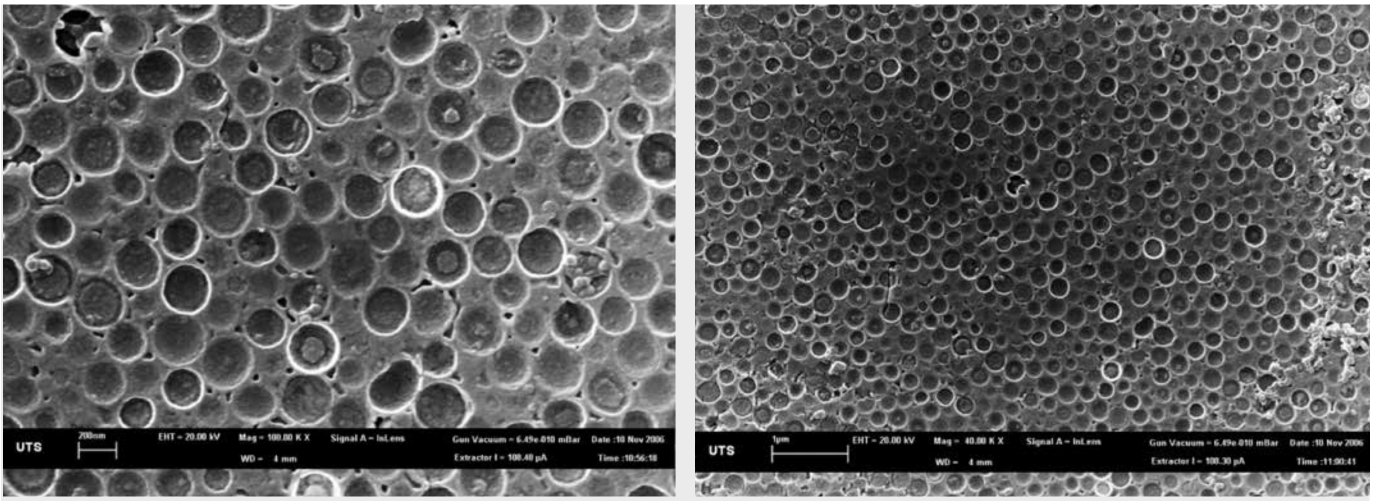
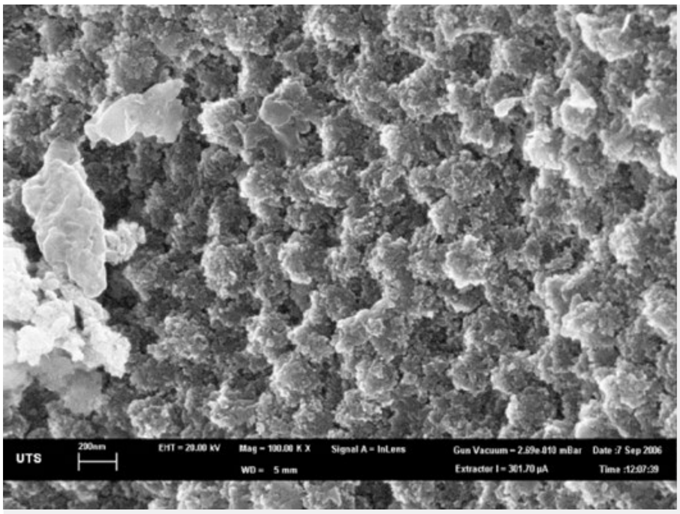
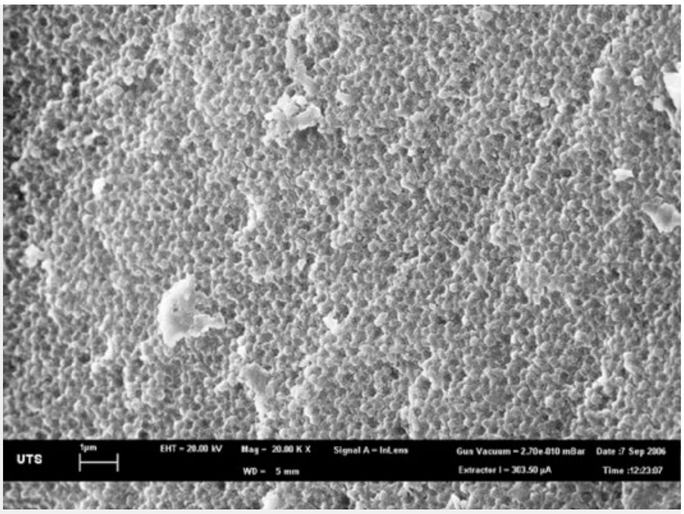


Figure 39. Brazil precious opal showing the structure of the precious opal in which it appears the "spheres" have been etched away leaving the cementing material behind, note that there does not appear to be a nanostructure of small crystallites in this material. Left: Photo at 100,000x. Right: Photo at 40,000x. Photos: A. Smallwood.





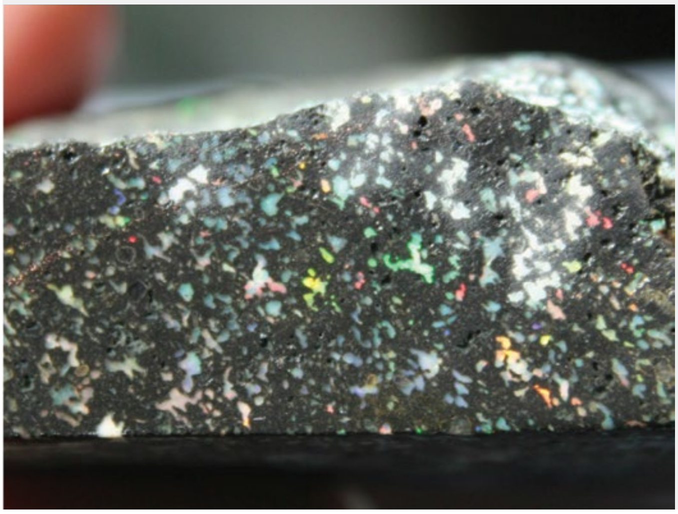


Figure 40. Leopard opal that has been strongly etched in HF and shows small cluster like "lepispheres". Top left: The image does not appear to show a suitable structure for POC at 100,000x, whilst the top right image at 40,000x does show a degree of order suitable for POC. Bottom left: The original Leopard opal sample from which the electron micrographs were obtained. Photos: A. Smallwood.

environment (Smallwood, Thomas and Ray, 2007, 2008). The TG curves are plotted below (Figure 41) for POC opals sourced from Lightning Ridge and from Tintenbar in New South Wales.

The mass loss data shown above clearly show the differences between a Lightning Ridge specimen of POC opal and a POC opal derived from Tintenbar. The first significant difference is the total amount of water contained in the opal. The total mass loss associated with Lightning Ridge opal is 5.7 +/- 0.2% and for the Tintenbar opal is 9.8 +/- 0.2%. A second significant difference is the shape of the curves. This can be better seen if the derivative (or slope) of the gravimetric curve is plotted as a function of temperature (Figure 42).

The derivative or DTG curve shows a peak at temperatures where mass is lost. It should be noted that the shape (geometry) and size of the sample is very important in determining the position of the peak. As mass loss is only observed when water is lost from the sample, the size of the sample very much affects the way the mass is lost. This effect can be easily seen in the Lightning Ridge dehydration data which shows that the peak shifts to lower temperature if a hand ground sample is used in place of pieces of opal. The shape of the peak does change a little in that there is less tailing from the powdered sample. This indicates that the opal is essentially homogeneous silica where the silica of the spheres is very similar to the silica that has subsequently filled the spaces between the spheres (i.e. the silica cement holding the spheres together). It should be noted at this stage that the chemical environment of the water is not specified. The water could be contained as bound silanol water or as molecular water trapped in silica cages, contained in capillary pores or in unfilled voids between the spheres or even in inclusions in the opal. TG data only provides evidence of mass loss as a function of temperature. The origins of the mass loss are interpretive.

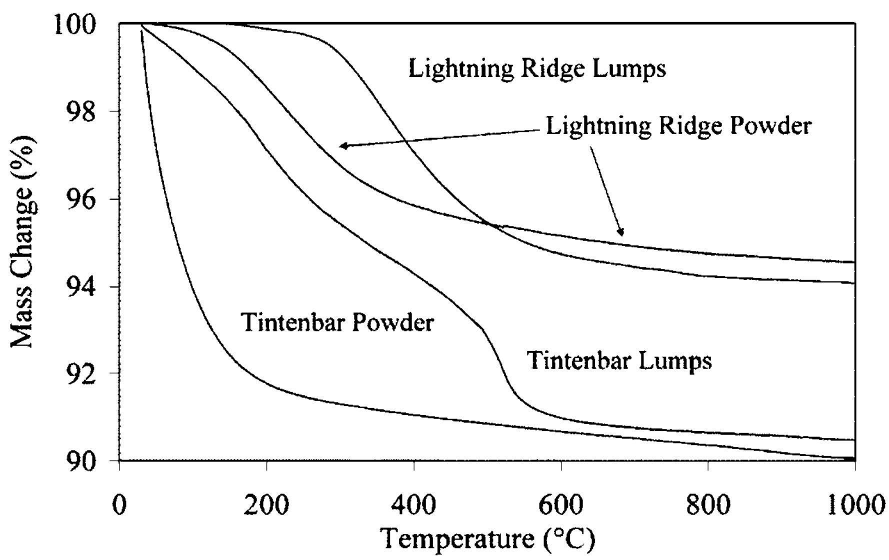


Figure 41. Thermogravimetric (TG) curves for precious opals from Lightning Ridge and a sedimentary environment and Tintenbar from a volcanic environment. (Smallwood, Thomas and Ray, 2008).

Inspection of the set of Tintenbar DTG curves, however, shows a much more complex dehydration process than the Lightning Ridge opal. When pieces or lumps of Tintenbar opal are used, two prominent peaks are observed suggesting that there are at least two types of distinct environment in which the water is contained. This is suggestive of significantly different types of silica present for the spheres and the cement. It has already been noted above that for the collection of SEM micrographs, the sphere silica is commonly etched when preparing samples for SEM imaging. This is indicative of a different character of the sphere silica in volcanic opal and in particular in Tintenbar opal. What is also notable is that the Tintenbar opal in the powdered state has a significantly different dehydration profile. In this case the dehydration occurs very rapidly. This suggests that the grinding process exposes what will be identified as the sphere silica here especially given its propensity to etch more rapidly, allowing rapid loss of water. The data indicate that Tintenbar opal is much more porous than Lightning Ridge opal and it is the sphere silica in particular which is the more porous material. Spectroscopic evidence using a technique called cross-polarisation nuclear magnetic resonance spectroscopy (NMR) (Brown, Ray and Thomas, 2003) has demonstrated that chemically volcanic opal is a more open molecular structure. A complementary technique to gravimetric analysis is differential scanning calorimetry (DSC), which is a technique where the heat flow required to evaporate a liquid or melt a crystalline solid can be measured. The measurement is carried out in a similar manner to TG in that a sample is heated and the heat flow into or out of the sample is measured as a function of the rising temperature.

It turns out that the temperature at which the solid water ('ice') melts is a function of the diameter of the pore in which it is contained. The melting temperature is depressed and can be observed as low as -40°C. This effect is only observed for capillary pores, pores of diameters between 2 and 10 nm (the size of a sphere in opal is of the order of 300 nm). In larger pores the water melts in a similar manner to bulk water specimens. Data for the melting of water in a range of sedimentary and volcanic opals is shown in Figure 43 (Thomas, Guerbois and Smallwood, 2013).

It is clear from this data that melting of water in volcanic opal is characteristically different from that of sedimentary opal. As the onset of melting in the sedimentary opal occurs at about or slightly below 0°C, this indicates that the crystallisable water present in opal is contained in pores greater than 10 nm in diameter. Images of voids in opal suggest that there are typically voids of circa 50 nm present in opal. It is likely that the water is contained in these voids.

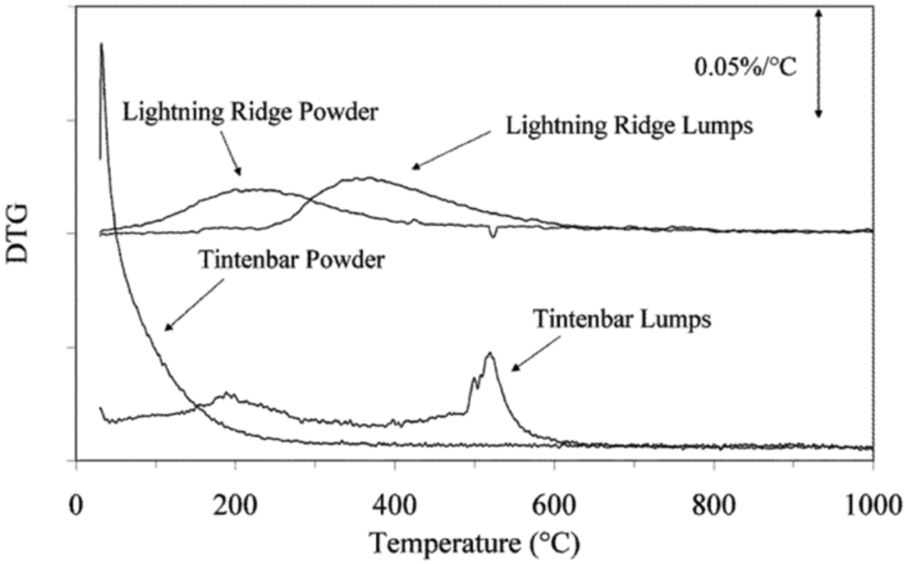


Figure 42. The derivative of the thermogravimetric curves (DTG) for precious opals from Lightning Ridge and a sedimentary environment and Tintenbar from a volcanic environment (Smallwood, Thomas and Ray, 2008).

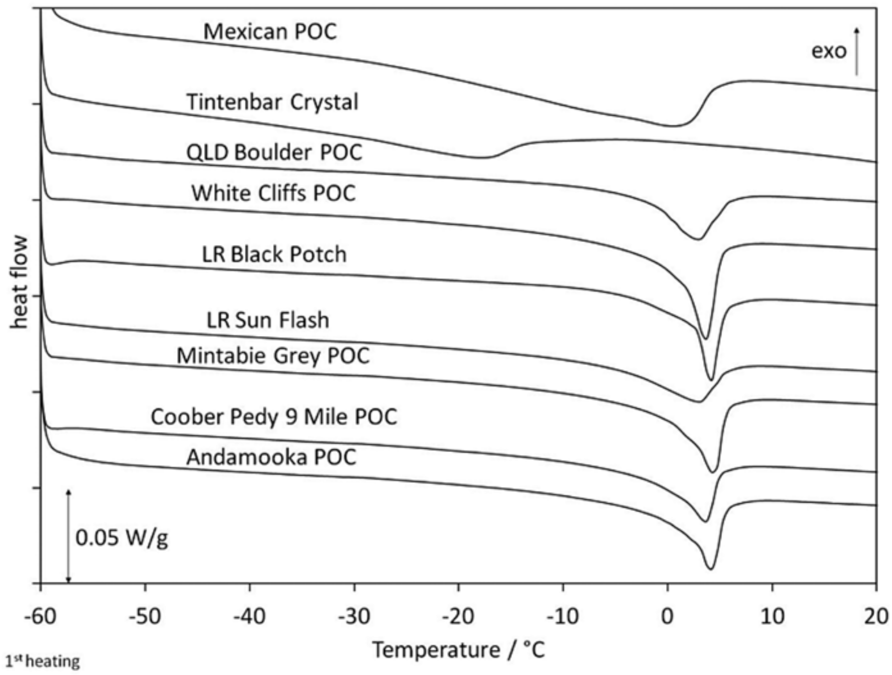


Figure 43. Graphs showing the melting water range of opals from both the sedimentary environment and the volcanic environment (Thomas, Guerbois, and Smallwood, 2013).

Sample	Mass loss at 1000°C / %	% crystallisable molecular water
Andamooka POC (SA)	6.7	8.9
Coober Pedy (CP) 9 Mile POC (SA)	7.2	9.8
Mintabie Grey POC (SA)	6.3	6.3
Queensland (QLD) Boulder POC	6.5	8.2
Lightning Ridge (LR) Black Potch (NSW)	6.1	10.4
Lightning Ridge (LR) Sun Flash POC (NSW)	8	7.0
White Cliffs POC (NSW)	6.6	13.8
Tintenbar Crystal (NSW)	9.1	9.8
Mexican Fire Opal	8.8	22.2

Table 1. Crystallisable water in precious opal (Thomas, Guerbois, and Smallwood, 2013).

Although the DSC profiles for the Tintenbar and Mexican opal differ, both of these opals have melting onset temperatures significantly below room temperature indicating that there is crystallisable water contained in pores which are of capillary size (2 to 10 nm). These pores are slightly smaller for Tintenbar opal as the onset is at a lower temperature. A notable difference between these opals is that the Mexican opal has a peak near zero indicating that there is crystallisable void water. The Tintenbar opal does not appear to contain any void type water as no melting occurs near 0°C. From the size of the peak it is possible to estimate the amount of crystallisable water (Table 1).

It is interesting to note that the total amount of crystallisable water present in opal is only 10% of the total amount of water present as measured by dehydration experiments using TG. This means that 90% of the water present is not present as crystallisable water. Typically water contained in opal is separated into two groups; bound (silanol – surface and bulk) and molecular (void, pore and cage water). NMR experiments suggest that only 10% of water in sedimentary opal is bound (silanol) water suggesting that 90% of the water in sedimentary opal is molecular. Of the molecular water only 10% is in voids and capillary pores. This suggests that the remaining water (80%) is contained as molecular water trapped in silica cages.

Conclusion

As can been seen from this discussion, Australian precious opal is a unique gemstone and a unique opal type. It is found and mined in a unique geological environment and it has suitably differing gemmological characteristics to allow its separation from precious opal presently mined from other sources external to Australia.

It is hoped that these differences in character and gemmological properties will make possible accurate and repetitive determinations on the origin of individual fashioned pieces of precious opal, especially the identification of Australian precious opal of all types.

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Information Box

TYPE OF NATURAL OPAL	REFRACTIVE INDEX	SPECIFIC GRAVITY
Australian varieties		
Lightning Ridge black	1.440 – 1.453	2.09 – 2.13
Lightning Ridge potch	1.450 – 1.457	2.09 – 2.10
White Cliffs light	1.450 – 1.460	2.08 – 2.10
Coober Pedy light	1.442 – 1.455	2.05 – 2.11
Andamooka Light opal	1.440 – 1.460	2.11 – 2.13
Mintabie opal	1.450 – 1.456	2.11 – 2.13
Lambina	1.445 – 1.458	2.12 – 2.13
Boulder opal	1.457 – 1.458	2.11 – 2.13*
Treated Andamooka matrix	1.42 – 1.43 spot	2.11 – 2.12
Tintenbar	1.422 – 1.440	1.98 – 2.02
Overseas Varieties		
Slovakian	1.439 – 1.442	2.09 – 2.11
Virgin Valley (USA)	1.360 – 1.445	1.90 – 2.00
Mexican Fire	1.438 – 1.444	1.99 – 2.02
Indonesian	1.440 – 1.458	1.98 – 2.12
Brazilian	1.465 – 1.472	1.97 – 2.00
Ethiopian	1.439 – 1.438	1.98 – 2.03
Peru	1.425 – 1.450	2.05 – 2.09
Cat's-eye (various)	1.420 – 1.450	1.94 – 2.11

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2017 Lightning Ridge Fossil Dig participants at First Shaft lookout, 6 Mile opal field, Lightning Ridge. Photo: K. Robinson-Griffiths.

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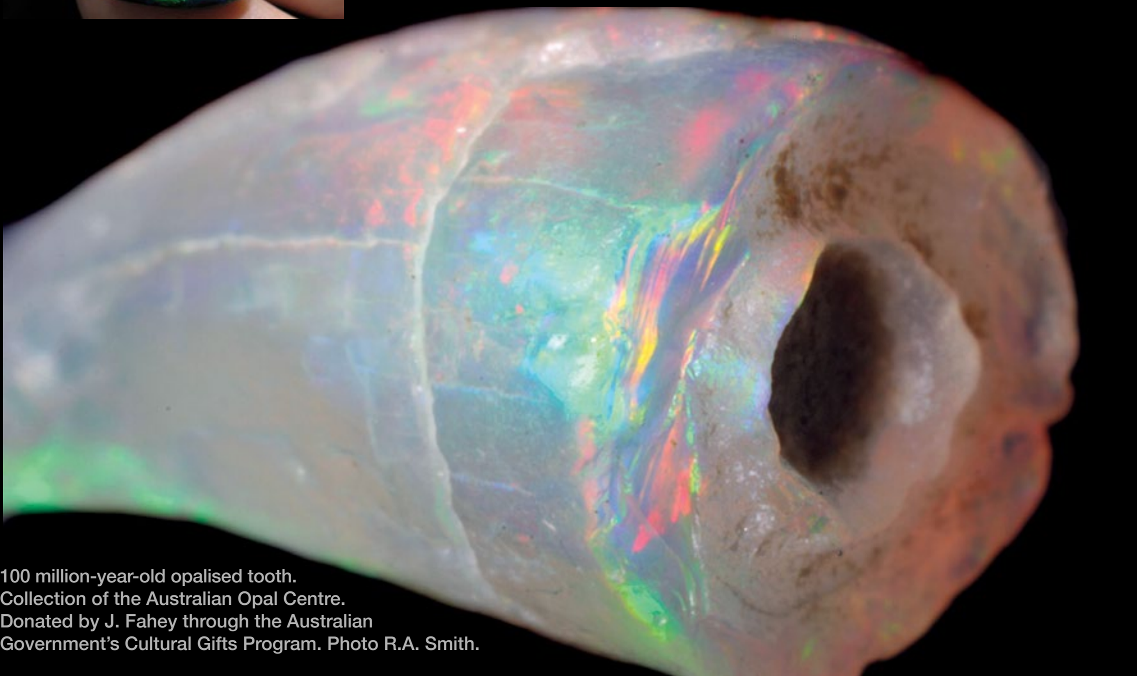

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