BRECCIA PIPES – FLUID PATHWAYS OF THE OPAL GODS

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Introduction

One of the most defining geological features of all the opal producing areas in the Great Australian Basin (GAB) is the ubiquitous, pervasive and widespread brecciation of the Cretaceous sedimentary rocks hosting deposits of precious opal.

Zones of brecciation associated with faulting and fracturing in the opal fields occurs over distances ranging from millimetres to tens of metres, and affects both sandstones and claystones. The zones of brecciation may be horizontal (concordant to bedding) through to vertical (discordant to bedding), and are commonly highly irregular in shape.

While some forms of brecciation appear to be syndepositional in nature, resulting from erosional episodes that punctuated periods of deposition (forming layers comprising jumbled mixtures of rip-up clasts concordant to bedding), the formation of breccia bodies that are syntectonic and associated with faults and fractures are of most significance to understanding the formation of opal deposits in the GAB. Today, Lightning Ridge provides one of the best locations in Australia to study these fault and fracture hosted tectonic breccias and their genetic relationships to juxtaposed veins of potch and precious opal (Pecover 1996, 1999 & 2003).

Textural Characteristics of Breccias at Lightning Ridge

Texturally, the breccias at Lightning Ridge range from net vein fracturing to more open framework breccias. Internal fabrics may be clast-supported through to matrix-supported. Breccias showing jigsaw-fit textures are common, as are breccias showing well developed clast rotation. They commonly contain fills of angular to subrounded fragments showing abrasion, some autogenous milling, striations, scratches and slickensides, mixed with a compositionally corresponding gouge, or with a gouge mixed with light-grey low-crystallinity kaolinite (Keller 1976) and amorphous silica. There is rarely any sorting, but the fault-fill may be zoned, having larger more angular and proximal wallrock blocks along the walls, and a subrounded, matrix-rich dragged breccia in the centre. Straight or anastomosing slickensided planes of slip, and/or kaolin-rich gouge-coated stockworks are common within the fill, as well as on and along the walls of brecciated zones (Pecover 1996, 1999 & 2003).

Breccia Pipes at Lightning Ridge

At Lightning Ridge, pipe-like breccia bodies known locally as "Blows" (also known as "verticals" on some other opal fields), form some of the most important types of breccia bodies associated with deposits of precious opal. These breccia pipes occur as subvertical to vertical cylindrical, cone, wedge or anastomosing contoured shaped structures that are typically highly irregular, and may pinch and swell abruptly.
The breccia pipes at Lightning Ridge are typically discordant to bedding, and may cut across several layers of sandstone and claystone, or may be restricted to a single layer of either facies. They range in diameter from several centimetres to several metres, and can be several tens of metres in length, commonly breaking through to the surface. Where “blows” penetrate to the surface, they may be filled with deposits of sand and gravel derived from surface draping Tertiary sediments that have washed into the pipe. Angular fragments of silicified sediments derived from lithologies occurring above the opal-producing "level" may also occur within the pipe, suggesting foundering of these materials into the pipe. However, pipes that have not penetrated to the surface do not generally contain clasts derived from near-surface lithologies, but rather tend to contain clasts that are compositionally similar or identical to lithologies bounding the sides of the pipe. Figure 1A-D illustrates some of the features described above.

Some pipes display tulip-shaped morphologies (seen by the author at Lightning Ridge as well as at a number of other opal producing areas in the GAB) that show a vertical transition from basal non-brecciated fracture plane surfaces (the stem), to straight or contorted cylindrical zones of crushed and broken rock (the tulip) (Figure 2A & B). In cross-section, some of these pipes are remarkable similar to breccia pipes occurring in volcanic environments (Figure 2C, E & F), and may also resemble the morphology of volcanic diatreme-like structures.

Relationship of Breccia Pipes to Tectonic Structures at Lightning Ridge

The breccia pipes at Lightning Ridge are commonly associated with vertical fractures, related to nearby areas of well developed extensional and thrust faulting. In all the opal fields around Lightning Ridge studied by the author, extensive vertical fracturing of both the sandstones and claystones was found to be pervasive and widespread. These vertical fracture arrays can be clearly seen in the walls of many opencut mines, such as the Three Mile Opencut at Lightning Ridge (Figure 3 A-H).

These vertical fracture arrays consist of close-spaced parallel to sub-parallel joints and fractures that comprise extensive fault/fracture meshes that have formed on the hanging wall and footwall sides of both thrust and extensional faults.

Breccia pipe development at all scales is typically associated with discreet fractures within these fault/fracture meshes, which demonstrates that breccia pipes at Lightning Ridge are most probably syngenetic with the tectonically formed fault/fracture meshes that host them.

Relationship of Breccia Pipes to Opal Veins

Breccia pipes at Lightning Ridge are commonly juxtaposed to areas of opal mineralization. Many of the breccia pipes examined by the author were found to be heavily silicified and hardened by opaline silica and commonly intermixed with low crystallinity kaolinite. A number of the breccia pipes studied, were also found to contain broken fragments of vein opal, and were commonly intersected by veins of opal that cut across the clastic fabric of the pipe. Horizontal to near vertical veins of potch and precious opal associated with bedding-plane-parallel fractures in the
surrounding claystones and clay-rich fine-grained sandstones were found to occur adjacent to and transitional with the pipes examined.

The opal veins occurring adjacent to the breccia pipes studied, appear to have developed along layer-parallel slip surfaces in areas where undulation of bedding contacts between sandstones and claystones had produced opal-filled voids at the sites of dilational jogs and hydraulic extension fractures. These areas of opal concentration surrounding the breccia pipes were also found to consist of a complex horizontal to sub-horizontal layering and intermixing of bedding-parallel fracturing, cataclastic brecciation, fault gouge and networks of opal veins that collectively defined the opal horizon in those areas (Pecover 1996, 1999 & 2003).

**Possible Sedimentary/Tectonic Analogue to Lightning Ridge Geology**

The fault/fracture meshes hosting the breccia pipes at Lightning Ridge show many of the features of Hill-type fault/fracture meshes (Figure 3E & F), described by Sibson (1994 - after Hill 1977), that occur in the horizontally bedded sandstones and claystones of the Miocene Monterey Formation in California (Figure 3 A-H).

In studying the Monterey Formation, Sibson (1994) proposed that fault/fracture meshes provide important conduits for basinal fluid migration during earthquake rupturing events. He suggested that fluid flow in the Monterey Formation was likely to have occurred initially preferentially within extension fractures parallel to bedding, while fluid flow across bedding was likely to have occurred along the near vertical Hill-type extension fractures, with fault slip along connecting shear fractures providing a mechanism for continually re-opening extension fractures that may otherwise seal up due to mineral precipitation.

The fault/fracture meshes of the Monterey Formation also demonstrate that permeability and fluid flow in such a system is likely to be highly anisotropic, with flow occurring along both bedding-parallel detachment horizons and vertical fault/fracture meshes linked to large nearby cross-bedding faults, whose roots tap basinal fluids at depth.

As such, the tectonic regime and mineralizing environment of the Monterey Formation may provide an appropriate analogue for the geological and tectonic features evident at Lightning Ridge.

**Formation of Breccia Pipes at Lightning Ridge**

The textural features displayed by the breccia pipes studied at Lightning Ridge, reveal extreme shattering of host rock lithologies along dilational zones. Furthermore, their association with vertical to subvertical fault/fracture meshes is considered indicative of a co-genetic relationship with the tectonic brittle-fracture deformation of the Cretaceous sandstones and claystones that has occurred at Lightning Ridge (Figure 3 G & H).

The close association of breccia pipes to juxtaposed and cross-cutting opal vein arrays, and the intense opaline silicification and kaolinisation of many of these breccia pipes, strongly indicates a genetic link between breccia formation, fault and fracture.
development, and significant fluid flow coupled with the deposition of potch and precious opal at Lightning Ridge.

Therefore, considering the geological similarities with the Monterey Formation, it is highly probable that the fault/fracture mesh-hosted breccia pipes at Lightning Ridge have also acted as conduits for large volumes of basinal fluids that have traveled towards the surface under pressure.

Also, these structures are highly likely to have delivered silica-laden waters to sites of opal deposition within juxtaposed interconnected hydraulic extension fractures located along bedding plane detachment surfaces at the interface between sandstones and claystones.

In those areas where breccia pipes have intersected the surface, it is also probable that they have acted as tectonic valves and major fluid expulsion structures, allowing silica-laden basinal fluids to escape the confines of the sedimentary pile, and to saturate sufficial deposits of sands and gravels, leading to widespread silica induration on the surface.

**Exploration Value of Breccia Pipes at Lightning Ridge**

Assuming that the above genetic model is correct, then breccia pipes occurring in the opal fields must be considered as very important opal exploration targets. This is because, these pipes are likely to be one of the principle fluid pathway structures favored by the “Opal Gods” for the delivery of silica-laden waters to juxtaposed sites of opal vein array formation, that are located within bedding plane-parallel hydraulic extension fractures along layer-parallel slip detachment surfaces.

**Bibliography**


Figure 1. Breccia pipes cross-cutting thinly bedded sandstones and sandy claystones at the Coochran Opal Fields, Lightning Ridge. 

A. Shows a stockwork of breccia-filled vertical fractures. 
B. Shows pinching and swelling of the pipe, with jig-saw-fit textures evident along wall-rock boundaries. 
C. Shows tulip-shaped pipe with well developed clast rotation towards the centre of the pipe. 
D. Shows large irregular wedge-shaped pipe displaying pinching and swelling, with jig-saw-fit textures along the walls and extensive clast rotation in the centre. Grey low-crystallinity kaolinite comprises most of the matrix in these structures.

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Figure 2. Comparison between tectonic breccia pipes cross-cutting Cretaceous GAB sediments and Tertiary volcanic breccia pipes cross-cutting Devonian meta-sedimentary rocks. A. Shows a tulip-shaped tectonic breccia pipe in Cretaceous sediments near Quilpie, Queensland. B. Shows a tulip-shaped tectonic breccia pipe in Cretaceous sediments near Coober Pedy, South Australia. C. Shows volcanic breccia pipe filled with a red basaltic volcaniclastic matrix supporting Devonian meta-sediment clasts near Inverell, NSW. D. Shows tectonic breccias infilling fracture meshes at Coober Pedy. E. Shows basaltic volcanic breccia infilling fracture mesh at Inverell. F. Shows close-up of volcanic breccia pipe and bounding wall rocks with textures very similar to those shown in Figure 1A-D.
Figure 3. Fault/fracture meshes in sedimentary rocks of the Cretaceous GAB and the Miocene Monterey Formation, California

A. Shows fault/fracture meshes in sandstone above a claystone opal-bearing level in the 3 Mile opencut.

B. Shows fault/fracture meshes hosting breccia pipes in sandstone (one penetrating the surface) in the 3 Mile opencut.

C. Shows fault/fracture meshes in sandstone near Hebel, Queensland.

D. Shows fault/fracture meshes in sandstone near Coober Pedy, South Australia.

E & F. Shows fault/fracture meshes in thinly-bedded sandstones and claystones in the Monterey Formation.

G & H. Shows fault/fracture meshes hosting breccia pipes in thinly-bedded clayey sandstones, in Frank Palmer’s opal claim, Coochran Opal Fields.

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