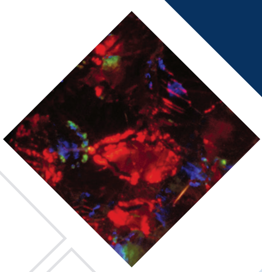
Mintabie opal resource evaluation: Current value of opal resources and projected value of undiscovered resources

2nd edition

Report Book 2020/00001

L Katona and C Krapf



energymining.sa.gov.au

SOUTH AUSTRALIA

Government of South Australia
Department for Energy and Mining

Mintabie opal resource evaluation: Current value of opal resources and projected value of undiscovered resources, 2nd edition

Laszlo F Katona and Carmen BE Krapf

Geological Survey of South Australia
Department for Energy and Mining

January 2020

Report Book 2020/00001

Department for Energy and Mining
Level 4, 11 Waymouth Street, Adelaide
GPO Box 320, Adelaide SA 5001
Phone +61 8 8463 3000
Email dem.minerals@sa.gov.au
dem.petroleum@sa.gov.au
www.energymining.sa.gov.au

South Australian Resources Information Gateway (SARIG)
SARIG provides up-to-date views of mineral, petroleum and geothermal tenements and other geoscientific data. You can search, view and download information relating to minerals and mining in South Australia including tenement details, mines and mineral deposits, geological and geophysical data, publications and reports (including company reports).
map.sarig.sa.gov.au

Preferred way to cite this publication
Katona LF and Krapf CBE 2020. *Mintabie opal resource evaluation: Current value of opal resources and projected value of undiscovered resources*, 2nd edition, Report Book 2020/00001. Department for Energy and Mining, South Australia, Adelaide.

Cover photos
Precious opal in situ, Mintabie Opalfield. (Photo T015072)
Red fire opal, Mintabie. (Photo 038452)

CONTENTS

TABLES

FIGURES

Mintabie opal resource evaluation: Current value of opal resources and projected value of undiscovered resources

Laszlo F Katona and Carmen BE Krapf

ABSTRACT

The Mintabie Precious Stones Field (MPSF) has, since the early 1920s, produced some of the finest quality opal in the world. This report book provides a review for understanding the remaining opal resources. A detailed spatial analysis shows that after approximately 40 years of mining in the MPSF, an area totalling less than 2 km^2 has been intensively mined. A conservative estimate of the area of greatest prospectivity within the MPSF is 20 km^2. Within this region of high prospectivity, assuming a similar deposit density to the intensively mined areas to date, the MPSF will support mining for ~400 years at the levels already experienced in its lifetime. Complimentary analysis published in 2002 reveals further prospective regions within the MPSF totalling 44 km^2. The total value of the opal mined at Mintabie up to 2016 has been estimated by the South Australian Government to be $412M (unadjusted value of rough opal). An area-based analysis concludes that this is less than 10% of the total contained opal at Mintabie. The opal resource in the MPSF, including the opal already found, is therefore estimated to have an unadjusted raw opal value of over $4B.

SCOPE, CONTEXT AND METHODOLOGY

The aim of this review is to provide an informed view with a level of precision suitable for understanding the tenor of remaining opal resources at the Mintabie Precious Stones Field (MPSF). The natural distribution of opal within their host formations is very irregular (i.e. extreme nugget effect) and therefore renders the application of conventional (predictive) resource assessment methodologies inappropriate. Accordingly, an empirical approach has been applied in this review, which recognises the production history of the MPSF to date inclusive of mining methods and production output as well as Laz Katona's extensive personal history as an opal miner and prospector at Mintabie (15 years, from 1985 to 2000) with over 30 years' experience in opal processing and manufacturing at wholesale and retail levels, together with his experience as a geoscientist, specifically in the area of resource potential mapping using Geographic Information Systems (Gum and Katona 2010; Cowley et. al. 2009). This assessment also benefits from the availability and use of present day high resolution remotely sensed data that previous studies have not benefitted from. References to the dollar value of opal production are based upon statutory publications. Previous technical publications by the former Department of Mines, South Australia, are also considered in this evaluation.

INTRODUCTION

Opal at Mintabie is said to have been discovered in the early 1920s, with the first official record reported in 1929 by the Queensland Government Mining Journal (Barnes and Townsend 1992). In 1931, The Mining Review (Adelaide) stated "*A new occurrence of opal has been found at a place 15 miles southwest of Mount Johns… similar to, but of a darker shade than that found at Coober Pedy*" (Barnes and Townsend1992). This darker shade of opal has become globally recognised as Mintabie semi-black opal. Mintabie also produces fine quality crystal, light and black opal, all of which have become highly regarded around the world for its fine quality and internal stability. In 1992, Barnes and Townsend (1992) indicated that from 1985 to 1989 Mintabie was the largest producer of opal in Australia in terms of value, even though a greater volume of opal was produced by Coober Pedy. This statement underlines what is well known throughout the wider opal community – opal produced at Mintabie stands among some of the finest quality opal in the world.

Since its heyday in the late 1980s, Mintabie has continued to sustain various levels of opal mining operations, gradually diminishing, mainly due to cost pressures and an ageing opal mining demographic. This review considers the potential for the remaining undiscovered opal resource at Mintabie, focusing on the areas shown in Figure 1. These areas are either known, or are inferred to be opal-bearing and have been defined through mining, drilling programs and current interpretations of the geological controls on opal formation at Mintabie.

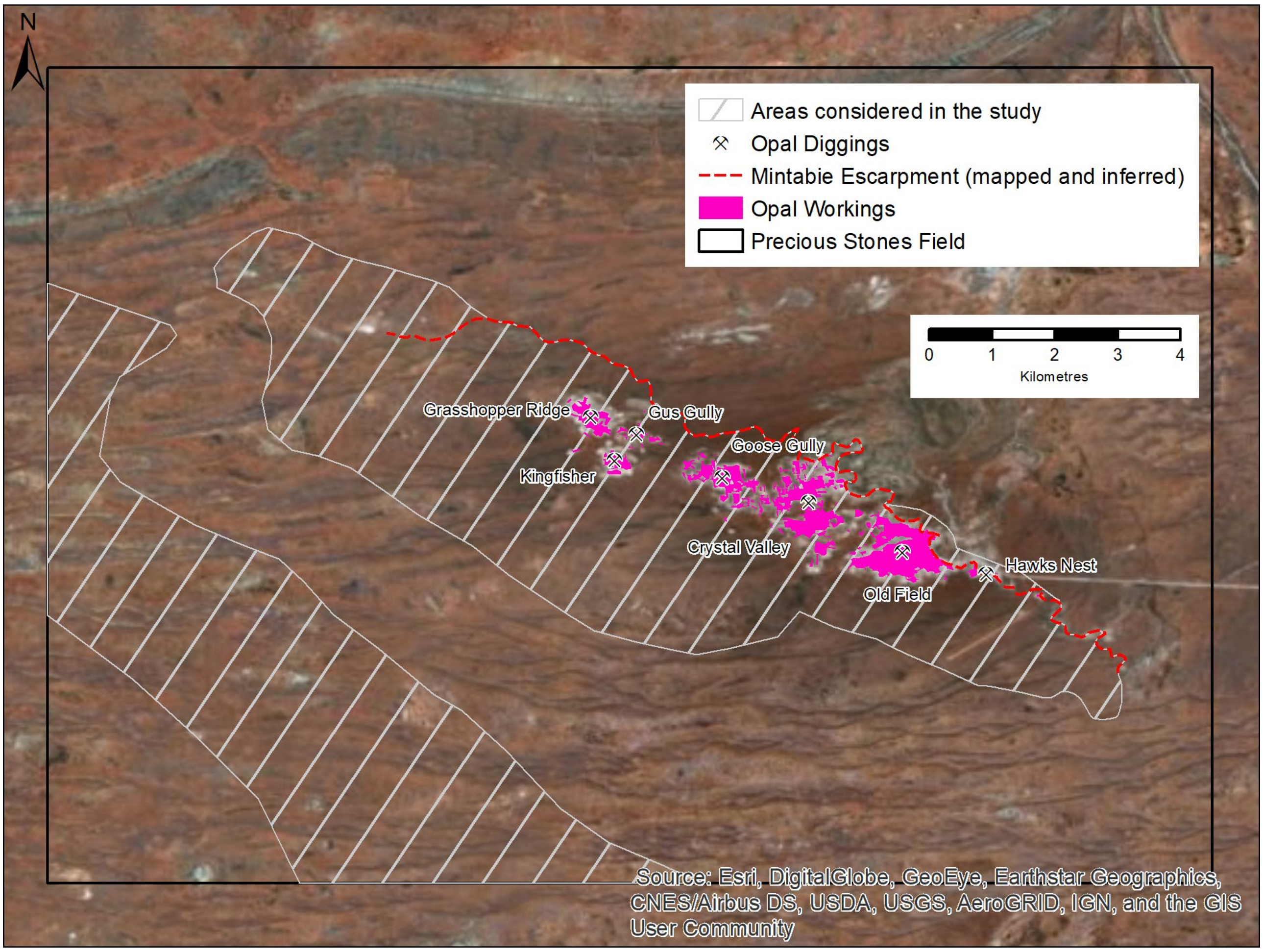


Figure 1. The Mintabie Precious Stones Field. The magenta areas are those that have had intensive mining activity.

GEOLOGY OF THE MINTABIE OPAL FIELD

GEOLOGICAL OVERVIEW

Townsend (1990) still provides the most in-depth description of the geology of the MPSF to date. Additional updates on the geology derive from the Mintabie opal drilling programs carried out in 2000 and 2001 by the Geological Survey of South Australia (Gum 2002, Appendix 1). Since then not many studies on the geology around Mintabie have taken place. A review on opalisation of the Great Australian Basin (GAB) by Rey (2013) sheds some new light on why precious opal has formed there in such abundance.

The geology of the MPSF differs from all of the other major opal producing fields in South Australia, being the only field that produces opal within Palaeozoic rocks as opposed to Mesozoic rocks elsewhere (Barnes and Townsend 1992). The field is located at the eastern outcrop margin of the Officer Basin (Townsend 1990) where its Palaeozoic sediments overlie unconformably Marinoan-aged sediments of the Adelaide Rift System. The Mintabie opal field developed around the Mintabie beds, which crop out extensively along the Mintabie escarpment (Fig. 1) and dip gently to the southwest. The beds are unconformably capped by a thin veneer of Cretaceous sandy shale and/or an unnamed silicified Tertiary sandstone. These rocks are overlain by recent sand dunes up to 10 m in height and by 0.5 to 3 m thick interdune deposits (Townsend 1990, Fig. 2). The upper sediments are often silicified, forming a massive silcrete capping which is present in many areas. This capping, known locally as 'cap-rock' (Fig. 2) requires blasting to penetrate in most areas of the MPSF.

The host rock for opal at Mintabie are the Mintabie beds (Fig. 2), recorded in South Australia's stratigraphic system as a formation within the Munda Group. The Mintabie beds in general comprise white kaolinitic, well sorted sandstones with minor claystone interbeds. The claystone interbeds are believed to be important in the opal formation as they are interpreted to be acquicludes.

The Mintabie beds are separated into two members (Townsend 1990):

- Lower member (units 1–4): interbedded (variably weathered) shales, siltstones and sandstones;
- Upper member (units 5–11): variably silicified, kaolinitic, massive to cross-bedded, fine- to medium-grained sandstones alternating with more massive, coarser-grained quartzose sandstones. Clay interbeds and clay lenses up to half a metre are common throughout the upper member (Townsend 1990). The upper member also dominates the Mintabie scarp.

Most of the opal mined today at Mintabie occurs in unit 10 and 11 of the upper member of the Mintabie beds. Unit 11 comprises kaolinitic, massive to cross bedded fine- to medium-grained sandstones which are variably silicified in its upper 3–5 m. Unit 10 contains more clay but is otherwise similar to unit 11. Due to logistical limitations of mining operations in the MPSF deeper units of the Mintabie beds have been rarely mined despite the fact that opal has been encountered in these parts of the succession. Hence, a limitation of opal-bearing to units 10 and 11 of the Mintabie beds as suggested by Townsend (1990) may not necessarily be appropriate. The top of the Mintabie beds is undefined due to cover of overlying sediments. The upper few metres of the Mintabie beds in the area of opal workings is silcreted. Silicification is inferred to be of late Tertiary, Miocene- to Pliocene, age (Townsend 1990, p. 37).

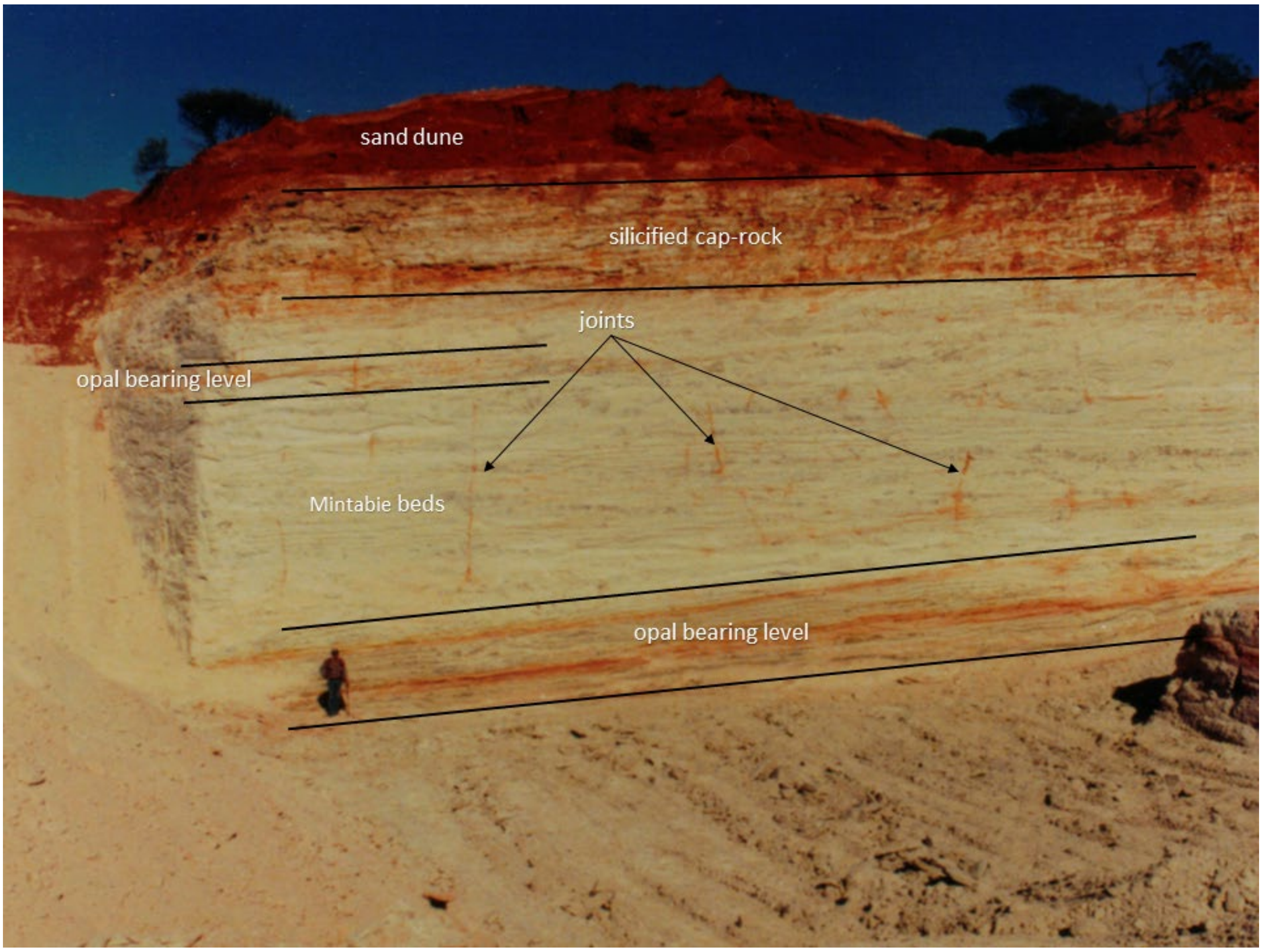


Figure 2. Section of an open cut mine at Crystal Valley, Mintabie, displaying opal-bearing Mintabie beds, joints, opal-bearing levels, cap-rock and dune sand. Person for scale.

OPAL FORMATION, OCCURRENCES AND TIMING

Opal formation has been widely discussed and various mechanisms were proposed. Opal is a form of silica, chemically similar to quartz, but containing water within the mineral structure. Precious opal (Fig. 3) generally contains 6–10% water and consists of small silica spheres arranged in a regular pattern (Fig. 4). The silica spheres are considered to have been deposited from a colloidal suspension due to evaporation and/or filtration, which then have accumulated in regular horizontal layers, predominantly in a cubic close-packed structure (Barnes and Townsend 1992). Opal displays a body tone ranging through translucent to opaque. Body colours of clear, white, grey, yellow, green, blue or black are quite common and many others are possible. The body colour of opal does not have a play of colour. The colour play visible in opal is the result of light diffracted through the ordered arrays of silica spheres as shown in Figure 4. The geometric arrangement of the silica spheres result in the patterns visible in opal and these range in size from small through large (Fig. 3).

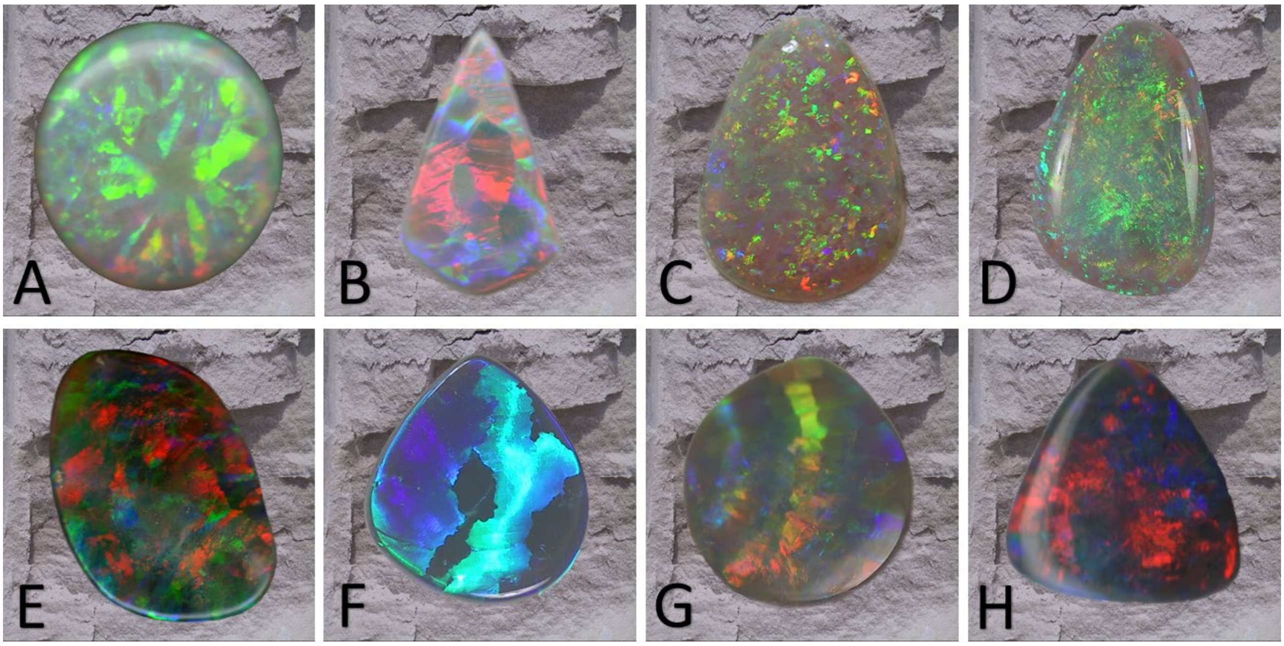


Figure 3. Precious opal from Mintabie. (A) Crystal opal with a translucent body tone and a multi-coloured, radiating pattern. **(B)** Red-blue crystal opal with a large pattern. **(C)** Semi-black opal with a small pattern. **(D)** Semi-black opal with a translucent body colour and layered patterns. **(E)** Black opal with a large pattern. **(F)** Black opal with a broad flash. **(G)** Black opal with a ribbon pattern. **(H)** Blue and red on black opal, considered to be among the rarest colour combination. Images courtesy L Katona (2019).

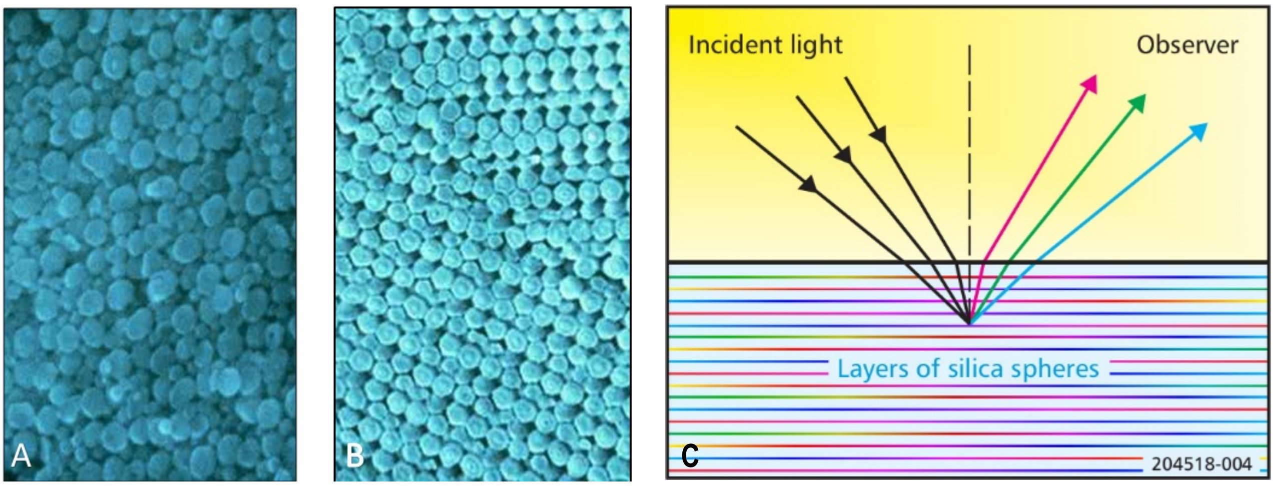


Figure 4. Scanning electron micrographs of common opal (A) and precious opal (B). The variation in the arrangement of silica spheres in (B) is a pattern boundary that would be visible as a play of colour when the opal is viewed. **(C)** illustrates how light is diffracted by layers of silica spheres, producing the colour play seen in precious opal. (Photos T015001 and T015003)

The formation of opal in and adjacent to the GAB is attributed to weathering (Townsend 1990; Barnes and Townsend 1992). At Mintabie, weathering lead to kaolinisation of the Mintabie beds and also the overlying Cretaceous rocks. The intense chemical weathering of the feldspar-rich sedimentary rocks supplied silica-rich fluids that were mobilised and pooled along bedding planes and in fractures, and subsequently precipitated as potch and precious opal most likely in multiple opal forming events.

Townsend (1990) suggests that the upper 15 m below the ground surface within unit 10 and 11 of the Mintabie beds seem to be the optimum area for opal occurrence. However, levels are discontinuous and laterally not extensive. Throughout the life of the opal field, opal in the MPSF has actually been found to depth greater than 30 m below the ground surface. Due to logistical limitations of mining operation as mentioned before, most finds have been concentrated between depths of 5–20 m (Townsend 1990; 25 m SA MER 2004 in Burton 2018; Katona pers. comm. 2019).

The timing of precious opal formation is poorly constrained and precious opal in the GAB and adjacent areas like Mintabie may have formed either during the Late Cretaceous to Early Tertiary (Rey 2013) and/or during Late Oligocene to Early Miocene (Idnurm and Senior 1978; Schmidt and Dickson 2017). Rey (2013) suggests that in the GAB most opal deposits that are now at the surface were formed by ca 60 Ma and were protected from erosion by the deposition of the widespread Eyre Formation in the late Paleocene to Eocene. At Mintabie, opal formation post-dates the deposition of the Early Cretaceous rocks as there is some evidence that opal occurs within the cretaceous rocks in the Mintabie region (Townsend 1990) and precious opal is abundant in adjacent areas like Coober Pedy and Andamooka.

STRUCTURAL CONTROLS ON OPALISATION

The main structural control for opal formation at Mintabie is the elevated Mintabie ‘plateau’ of which the north-eastern extent is defined by the Mintabie escarpment (Figs 1 and 7). The plateau may have originally been a topographic low in which opal forming fluids concentrated and later silcrete formed. Successive erosion inverted this area and lead to the formation of the escarpment. The Mintabie escarpment is the southwestern limb of an eroded anticline (Townsend 1990). However, its fold axis does not appear to have influenced the spatial distribution of opal mineralisation (Townsend 1990; Fig. 3). Faults do not appear to have any influence on opal localisation.

Within the plateau, vertical joints act as additional structural controls and conduits for potential opal formation in the Mintabie beds sandstones. The joints have been controlled by older structures and are oriented in a northwesterly direction, crossed by less-frequent vertical southwesterly joints. The joints are steeply dipping to vertical and have a limited lateral extent at field-scale. The joints themselves may carry opal intermittently and connect with horizontal silicified bands in the sandstones that host opal in horizontal and sub-horizontal seams known locally as ‘pockets’. These silicified bands define the opal-bearing levels, but are not regularly distributed throughout the field either laterally or vertically, making it difficult for miners to consistently find opal using underground mining methods. Horizontal pockets of opal mostly occur where cracks have opened between sedimentary layers of sandstone and been infilled with opal, these cracks sometimes occur within a sedimentary layer of hard, silicified sandstone. Other structural controls include small-scale east-west trending ‘micro-joints’ that often occur for a short distance directly above and feeding into opal-bearing levels where pockets of opal occur. Variations in the dip of bedding planes have also been observed to be associated with opal formation and are believed to be ‘stoppers’ that helped trap silica-rich fluids, precipitating precious opal. Lateral variations in the hardness of the sandstone adjacent to opal formations are also believed to be a trap for opal-bearing fluids.

Townsend (1990) reports that the Mintabie beds are especially well jointed in their upper silicified portion and hence there is a trend of concentration of opal finds in that part of the rocks. However, preferential weathering of the silicified upper part of the sandstone enhances the impression of denser jointing without it being necessarily the case.

Pockets of precious opal vary considerably in size and thickness, with horizontal pockets ranging from a few centimetres up to several metres in diameter, from less than a millimetre thick up to 25 mm or more in thickness, but commercially viable opal pockets found at Mintabie typically range from 5–10 mm thick. Vertical opal seams with widths ranging from sub-millimetre up to approximately 25 mm (typically 5–10 mm thick) can run for tens of metres, with a depth up to several metres, intermittently producing precious opal. Thickening of vertical joints are considered a marker for the opal-bearing levels because these joints tend to produce potch and opal at the same opal-bearing levels as the adjacent silicified bands that produce horizontal pockets of opal. Although this is considered a general rule at Mintabie there are cases where there is only vertical opal of any value present (as found in parts of Grasshopper Ridge) and other cases where the vertical seams carry what appears to be kaolinite and produce no opal, while adjacent horizontal seams of opal are in abundance.

A HISTORY OF MINING IN MINTABIE

After the discovery of opal along the Mintabie escarpment in 1931, arduous living conditions (Hiern 1965), the presence of hard, quartz-rich sandstone as a host rock and the silcrete capping deterred mining for decades. It was not until the introduction of heavy machinery in the mid 1970s that the field came into large-scale opal production. Since that time, open cut operations have been the preferred method of mining for opal in the MPSF, although there were some underground mining operations in the field. Early mining equipment was not capable of efficiently mining open cuts to great depths and additionally, with the 50 x 50 m limit on precious stones claim size until the late 1980s, managing overburden from open cut mining operations limited the depth of exploration. For these reasons, the depth of open cut mines during the period from mid 1970s to early 1980s was limited to around 10 to 15 m. At these depths, miners in the ‘Old Field’ often located a greenish coloured clay band and the belief at that time was that the ground became unproductive below this level, so mining would stop once the ‘green ground’ was reached. From the 1970s to the early 1980s almost all of the opal mining took place in the Old Field. The Old Field is situated in the vicinity of a perched aquifer. This aquifer has been used from the early 1980s until the present day to supply water to the town. A consequence of the aquifer is that the sandstone in the Old Field has been permeated by groundwater and is noticeably wetter in comparison to other parts of the opal field. In some cases, miners had to regularly pump water out of underground mines or open cuts while working. In the early life of the opal field there was the perception among some miners that the sandstone had to be moist to be prospective for opal. This possibly deterred miners from prospecting away from the Old Field diggings, where the sandstone is noticeably drier and harder than that found in the Old Field. In the early 1980s the field experienced a decline in production, when the number of bulldozers working in the field went from 30 to 6 (O’Byrne 1982). At this time the miners believed the opal field was on its wane, with harsh living conditions and a lack of confidence associated with prospecting new ground cited as the reasons for the downturn (O’Byrne 1982). Nevertheless, the town continued to develop. In the early 1980s an all-weather airstrip was established on the opal field between diggings that were later to become Goose Gully and Crystal Valley. The airstrip had a generous buffer of approximately 200 m, where mining was prohibited. At the time the miners believed it to be devoid of opal.

Despite the perceived lack of confidence, new miners came to the field and over the next few years major opal discoveries were made to the northwest of the Old Field, along strike of the Mintabie escarpment at Crystal Valley (a merging of diggings originally named First Gully, Second Gully and Third Gully) and Goose Gully (Fig. 1). These discoveries led to a significant surge in opal mining during the mid 1980s. A large influx of mining families saw the population of Mintabie increase to well over 1000, peaking at around 1800 during the latter part of the 1980s. The use of the word ‘gully’ in the naming of some of the opal diggings at Mintabie is in reference to diggings that occupy areas of thin, interdune sand cover between the sandhills that intersect the field in a west-south-west direction. These sandhills increased the sand cover from around a metre to approximately 10 m and were avoided due to inherent difficulties in managing the overburden within the small 50 x 50 m areas that comprised a precious stones claim up until the late 1980s. This problem was exacerbated when interest in the field peaked and the known diggings, including the sandhills, were ‘pegged out’, leaving no open ground for overburden. It also became evident that the airstrip had been placed upon what was now considered prime opal-bearing ground and requests were made to the government to reduce the size of the buffer, opening the area to mining, creating renewed interest and attracting more new miners to Mintabie.

During the mid to late 1980s several additional new diggings along strike of the Mintabie escarpment were discovered as a combined consequence of an influx of Investigator drills and the known diggings being pegged out. Precious opal was found at Hawk's Nest, Gus Gully, Kingfisher and Grasshopper Ridge. Each new digging, with the exception of Hawk's Nest, brought with it additional major opal discoveries that rivalled, and in some cases surpassed, discoveries made in the Old Field. This period also brought new and larger machinery, including scrapers and excavators capable of mining to greater depths. The introduction of the Large Claim (up to 100 x 50 m) and scrapers meant overburden from open cut operations could be managed more effectively and using scrapers, overburden could be deposited some distance from open cut mines. Opal claims in the Old Field began to be reworked to depths from 15 to over 30 m and many large discoveries were made, including discoveries below the green clay bands. This period also saw the introduction of skid-steer loaders which made underground mining easier, as the opal-bearing levels could be accessed from the wall of a disused bulldozer cut. This also enabled a miner to tunnel underground covered by sandhills, provided there was an open cut mine in close proximity.

Eventually the airstrip was completely removed from its original location and a new airstrip was installed in the vicinity of the Hawks Nest diggings in the southeast of the field. The reason the airstrips were established on the plateau and not in lower lying areas is due to the higher elevation providing a better all-weather strip.

From the mid 1990s to the present day, mining methods further evolved to utilise excavators and dump trucks which cut operating costs, although the time taken to work claims may have increased using this method. A combination of these methods and traditional open cut mining are still in use today in various parts of the MPSF.

To date, the Old Field has the deepest workings, with depth of open cut mines up to and in excess of 30 m. These deep excavations were mostly dug during the late 1980s, when a mining operator from Queensland with a fleet of bulldozers and scrapers began systematically working entire 50 x 50 m claims in the heart of the Old Field, employing a crew of salaried workers, resulting in many major discoveries, much to the satisfaction of the claim owners who had previously spent many years working the same claims as much smaller mining operations.

The deepest mines in Crystal Valley and elsewhere rarely exceeded 20 m and were mostly worked to a depth of about 10 to 15 m. A prominent miner, who owned a fleet of bulldozers and scrapers reworked what had been a very productive part of Crystal Valley, to a depth in excess of 20 m and uncovered a number of large pockets of precious opal. This miner remarked that at depths of 60 feet, opal pockets were less numerous than the number found in shallower levels, but tended to be larger pockets than those found at the shallower levels (E Christianos pers. comm. 1995).

From the late 1990s to the present time the population of Mintabie diminished to around 60 in 2017. A small number of mining operations still operated in 2018 and departmental figures of annual production for the decade from 2006 to 2016 is estimated to be around $2.5M per year.

PROSPECTING FOR OPAL IN MINTABIE

Since the early 1980s the Investigator drill has been the instrument of choice for opal prospectors trying to prove a claim worthy of open cut or underground mining. The Investigator Mark X is a 9 inch rotary auger drill with a maximum depth of 25 m. The 'mast' of the drill hosts a 10 m auger with further 5 m 'flights' added as the hole is drilled. A 'carousel' housing three 5 m flights allows a maximum of 25 m depth, although most operators at Mintabie terminate their drillholes at 15 or 20 m, ignoring the deeper levels in preference of making a discovery in shallower ground. The last 5 to 10 m or a 25 m hole often proved to be the most difficult to drill in either damp or hard ground, adding significant time to the completion of the drillhole. A typical day of drilling with an Investigator drill will complete 10 holes to 15 m or more. In areas that are perceived to be shallow (10 m), up to 20 holes can be drilled per day. The Investigator drills are not designed to drill angled holes. The drill is driven by a six cylinder diesel engine powering a hydraulic pump which drives auger rotation and other hydraulic systems on the platform. The Investigator Mark X consumes between 150 and 250 litres of diesel per week (M Lielbelt pers. comm. 2019) under normal operation, depending on the depth drilled and the level of moisture present in the sandstone, with more moisture creating greater resistance against the auger and therefore requiring greater system pressure to rotate, in turn consuming more fuel.

Given the nature of opal formation and distribution at Mintabie (and in opal fields in general), it is extremely difficult to drill into a vertical seam of opal at the precise depth of opal formation. In the search for horizontal seam opal, a typical opal claim may yield only a single pocket of precious opal. However, with rough opal prices commanding up to $20,000 per ounce for the finest quality dark based or crystal opal, a single pocket measuring less than 1 m in diameter and 10 mm thick could yield up to 100 ounces of precious opal worth in excess of hundreds of thousands of dollars. Conversely, a claim may yield many hundreds (or even thousands) of ounces of low grade opal worth a few thousand dollars, or less. If a prospector were to drill a grid of holes at 1 m intervals, the chances of a drillhole intersecting a pocket of opal 1 m wide in a 100 x 50 m claim (assuming that is the only pocket of opal on the claim) is one in 5000. Prospectors in search of opal at Mintabie therefore look for signs of potentially opal-bearing silicified sandstone, opal-bearing levels (hard bands) that are believed to be associated with opal formation or any trace of opal or opaline material within vertical joints or horizontal levels. When prospecting away from productive areas, any variation in these conditions can be off-putting for the prospectors. This helps explain why areas in Mintabie that appear to have been drill-tested are still considered to have high potential in this resource evaluation. The only way to determine with certainty that there is (or isn't) opal in a claim is to excavate the entire area. Prospectors widely acknowledge that out of ten claims in Mintabie, six will not produce enough opal to cover the cost of excavation, three will produce enough opal to make a profit and one will result in a large find. The six claims that don't turn a profit will have all of the hallmarks that prospectors are looking for (silicified hard bands, good sandstone and even traces of opal with good colour). Drilling remains the most economical method of searching for opal at Mintabie.

CURRENT MINING ACTIVITY

A desktop-based Geographic Information System (GIS) analysis in ArcGIS 10.4 of the MPSF using contemporary high-resolution satellite imagery from 2017 identified the following equipment operating in the field: 6 bulldozers, 2 dump trucks, 2 excavators, 2 front-end loaders and 1 noodling plant. With the exception of 2 bulldozers, all of the equipment was located in the Old Field (Fig. 5). As a random sampling of activity in recent time, it is an encouraging sign of mining activity at Mintabie.

A conversation with a former Mintabie opal miner living in the town revealed that all of the miners currently operating in Mintabie are finding precious opal, although the amount of opal produced is not known (Klobuchar pers. comm. 2017).

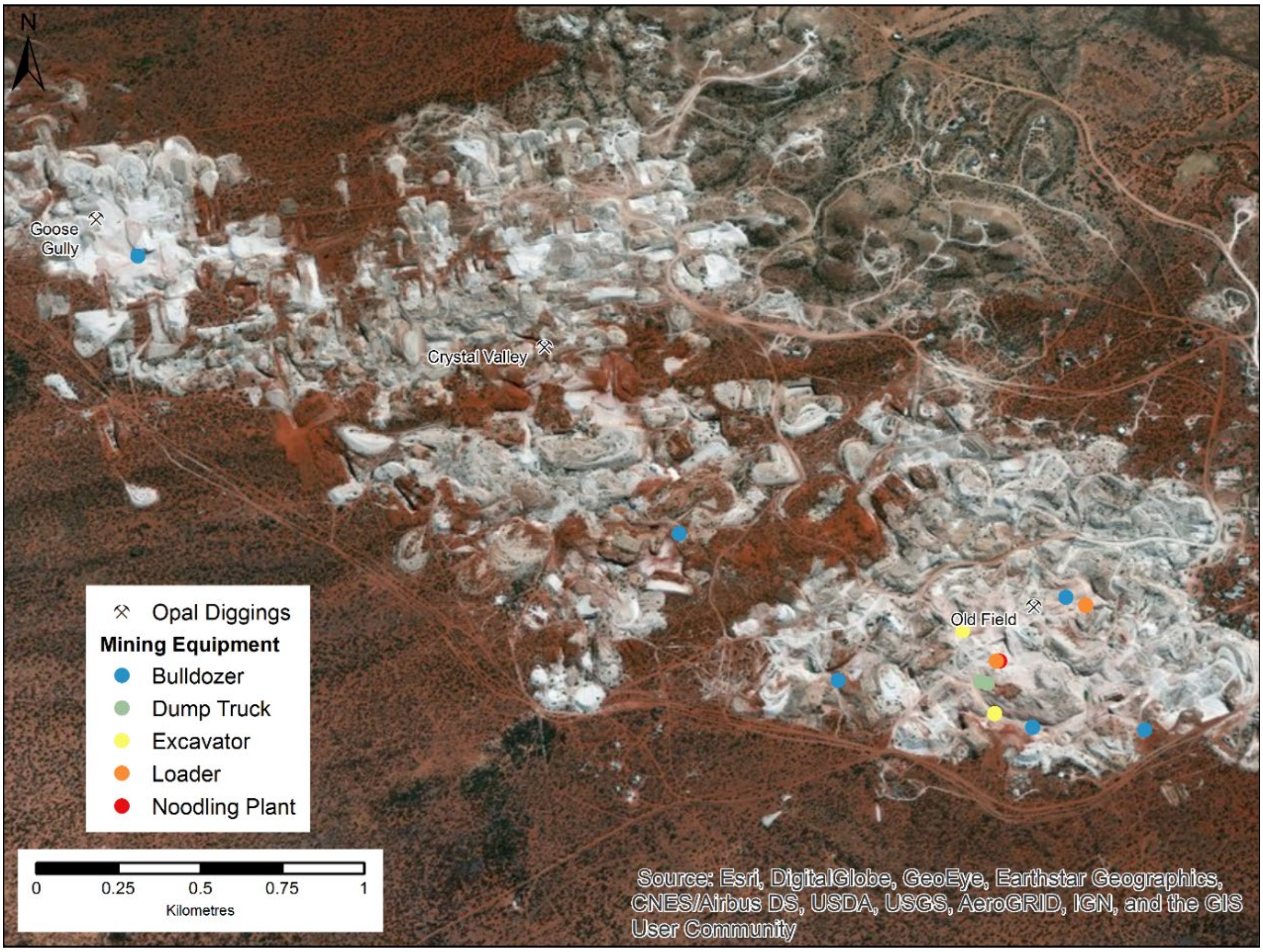


Figure 5. Mining equipment present on the Mintabie Field in 2017. Most of the mining operations were taking place in the Old Field.

ANALYSIS OF CURRENT DIGGINGS

The logistics of open cut mining using bulldozers dictates that for a new open cut opal mine in the MPSF, in almost all cases there must be a rear access ramp with a gradient of approximately 30–45 degrees and a mullock heap ramp with a gradient of approximately 20 degrees to push the overburden out of the cut. The impact of these logistics is that for a bulldozer cut excavating a precious stones tenement measuring 100 x 50 m, the bulldozer runs out of working space at approximately 15 m depth, leaving significant opal-bearing levels beneath the access ramps. In ideal circumstances, an operator can progressively work a line behind the rear ramp, taking all of the ground in the ramp and filling the cut in front, but when there are many operators in the area at the same time competing for working space, this can become unfeasible and as a consequence virgin ground is left behind or buried. Consequently, local miners are currently in the process of reworking the existing fields in preference to seeking out new fields.

Areas affected by intensive open cut mining and adjacent underground mined areas have been digitised from satellite imagery (acquired circa 2017; Fig. 6), leaving out areas that have not yet been mined, or are covered by mullock heaps or scraper dumps, the latter having a high probability of fresh sandstone underneath. The areas of intensive mining activity all lie southwest of the Mintabie escarpment, the base of which is shown in Figure 6 as a dashed red line, digitised from the contoured Shuttle Radar Topography Mission (1sec SRTM) Digital Elevation Model (DEM; resolution 30 m), which approximates the 378 m elevation contour.

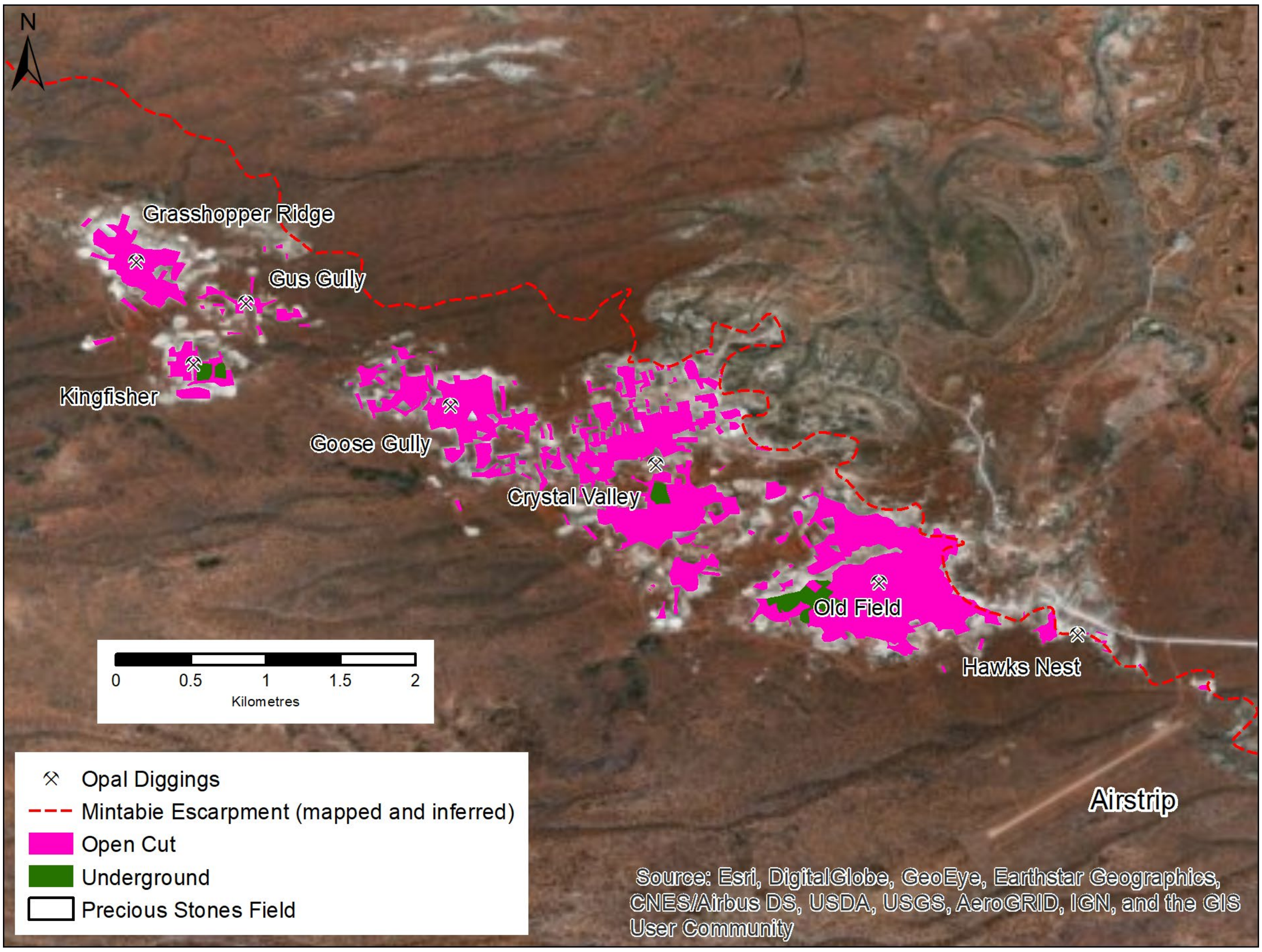


Figure 6. Actual diggings (as opposed to areas covered by overburden or weathered surface material) have been digitised to calculate the area of intensive mining activity at Mintabie. The Mintabie airstrip is visible in the southeastern corner.

PREVIOUS DEPARTMENTAL REPORT ON THE MPSF

Between the years 2000 and 2001, the Mintabie Opal Drilling Programs drilled exploration drillholes to the northwest and southwest of the current workings. A *MESA Journal* article on the program by Gum (2002) delineates tracts prospective for opal based on the drilling results. The drilling program located prospective sandstone and recovered common opal from a number of holes some distance from present workings, confirming the potential of the newly drilled areas to host opal. Figure 7 shows the drilling results and prospective zones. The tract adjacent to the Mintabie escarpment that encompasses and expands the current diggings to the northwest and southwest is 31.5 km^2 in area (shown in yellow and designated ‘Zone of subcropping Mintabie Sandstone prospective for opal’ in Fig. 7). The region to the southeast of the current workings was not drilled most likely due to the presence of the Mintabie airstrip, which disallowed mining and drilling. A second tract, approximately 5 km southwest and running parallel to the escarpment is 27.3 km^2 in area. One of the key interpretations of the drilling program is that poor results were obtained in the areas not spatially coincident with the plateau regions, between with the two zones of subcropping Mintabie beds (Fig. 7; Gum 2002). Interpretation of the drilling program results with the SRTM digital elevation model also reveals that the thickness of sand between the plateau regions is generally greater despite these areas being at lower elevations.

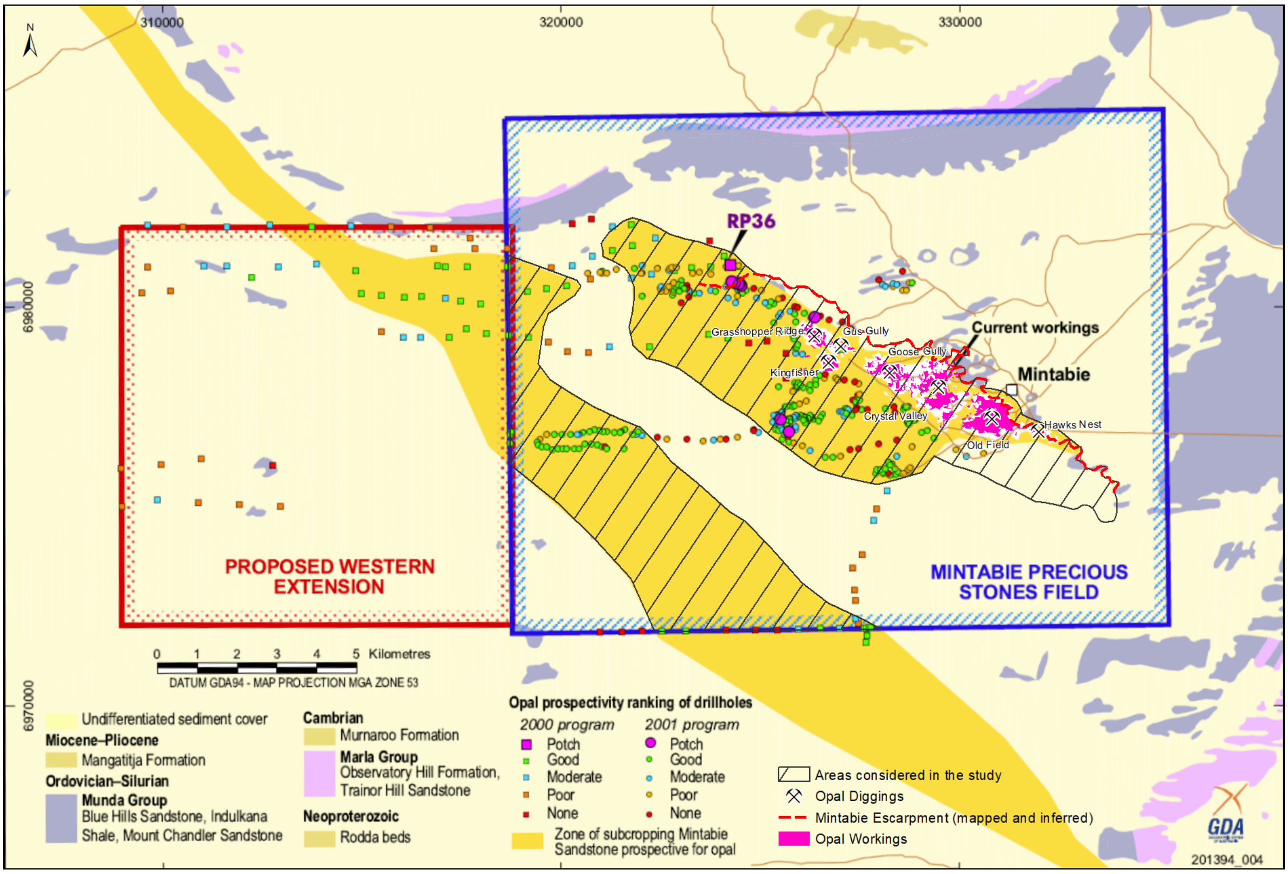


Figure 7. Drilling results that helped define areas permissive for further production of opal at Mintabie, based on the presence of Mintabie beds (image modified from Gum 2002).

POTENTIAL FOR FURTHER OPAL PRODUCTION

For the purpose of this report, the term ‘prospective’ refers to ground within the MPSF that is considered likely to host opal, due to its similarity with ground in the established diggings. The terms ‘highly prospective’ and ‘most prospective’ refer to the tract of unworked ground within the known diggings and along strike of those diggings, parallel with and along the length of the Mintabie escarpment, at a width similar to that of the currently worked diggings. Moreover, the terms ‘most prospective’ and ‘highly prospective’ are indicative of the expectation that those areas contain payable opal of a similar tenor to the established diggings. This is based on the knowledge that all of the known structural and lithological controls thought to be permissive for opal development at Mintabie continue in these regions and there have been no identified structural or lithological controls discovered within these regions that would prevent the formation of payable opal (see Geology chapter).

The Mintabie escarpment is delineated by the SRTM digital elevation model (Fig. 8). The escarpment runs for about 12 km in a northwesterly direction and forms the northeast face of the plateau, which is around 3 km wide and 12 km long (Fig. 8). The opal-bearing Mintabie beds outcrop at and near the face of the escarpment over most of its length. Opal-bearing sandstones have been found in a line parallel with the escarpment, on the elevated western side, currently mined over a distance of 1–1.5 km away from the face of the escarpment and over a distance of about 6 km along the north-west linear extent of the escarpment. The elevated side of the escarpment is protected by a layer of silicified cap-rock, believed to be associated with the formation and subsequent preservation of opal in the MPSF. The plateau is shown in the SRTM data in Figure 8 as the elevated region contiguous with the escarpment. The plateau boundary has been interpreted using a combination of the SRTM digital elevation model and drillhole results that measured the thickness of sand in the region and variations in sandstone.

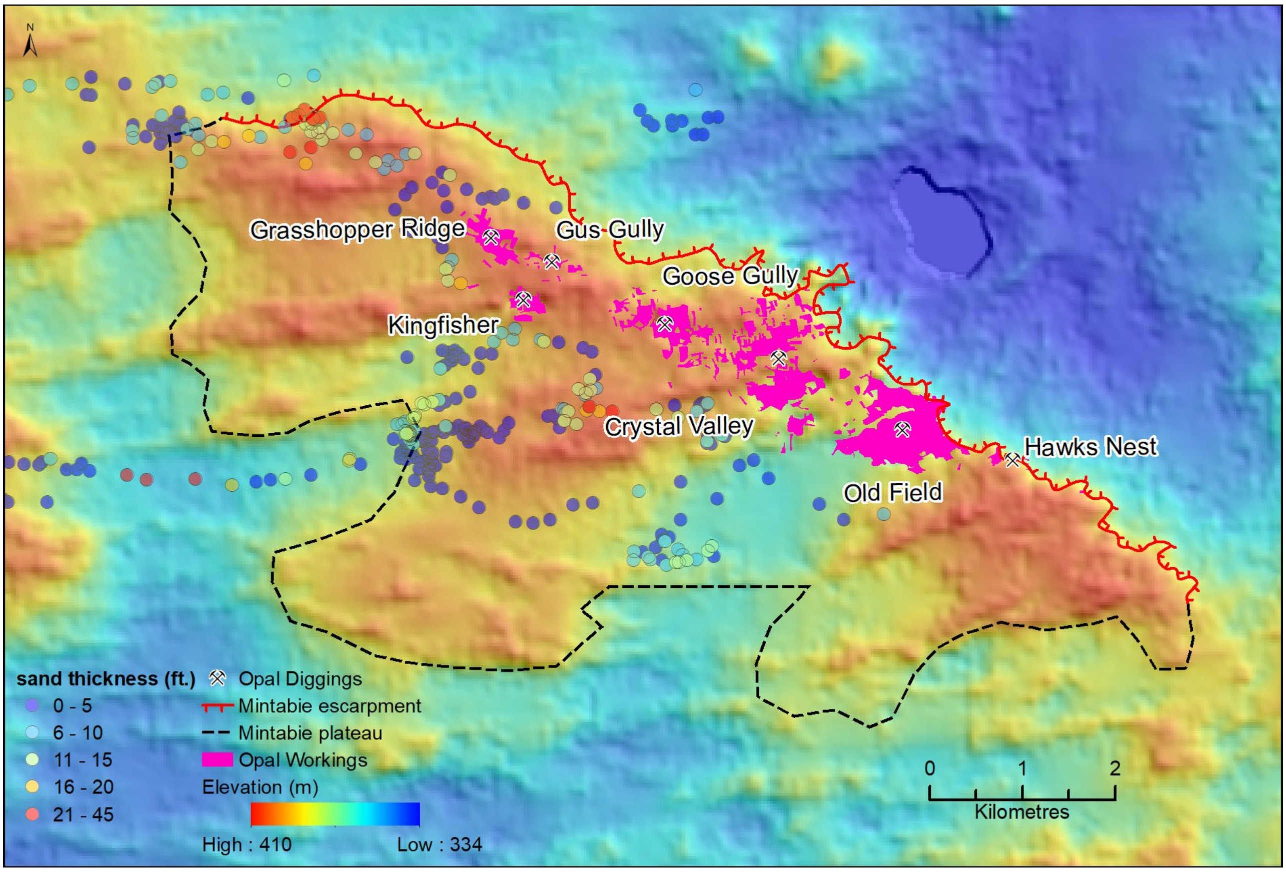


Figure 8. The Mintabie escarpment and interpreted plateau. The interpretation of the plateau has been guided by the SRTM DEM and drillhole data from the drilling programs carried out in 2000 and 2001 (Gum 2002). The opal fields are situated on the southwest side of the escarpment on the up-thrown side.

Although the areas further away from the Mintabie escarpment and to the southeast are considered prospective for payable opal due to the presence of sandstones of the Mintabie beds (Gum 2002), they have not been mined nor sufficiently drill-tested to conclude that they are as likely to contain a similar density of opal deposits as the diggings along the Mintabie escarpment. These additional prospective areas are therefore considered speculative.

To the southwest of the plateau associated with the Mintabie escarpment, drilling in 2000 and 2001 recovered abundantly poor sandstone and had a thicker sand cover even though the elevation is lower, indicating a possible topographic low or even palaeovalley or changes in lithology considered to be un-prospective.

The potential for further sustained opal production from the MPSF is generally very high. The GIS analysis of the current workings using recent satellite imagery reveals that significant areas within the known fields are still underexplored and unworked. The only impediment to further mining in these areas between the existing fields is the increased thickness of the sand covering the opal-bearing sandstone (up to 10 m of sand, where sandhills intersect the field in a predominantly west-southwest direction; Fig. 8). Moreover, the deeper opal-bearing levels in the existing mined areas (particularly the Old Field) are highly prospective and are currently being reworked by miners who understand that there are numerous ramps with unmined opal-bearing levels and previous work that left unmined sandstone at mineable depth. Reworking this ground has been made possible in part due to the lower number of precious stones claims in the area, allowing miners to better manage overburden to reveal and mine the deeper levels. Figure 9 shows a bulldozer at work in a large open cut mine in the Old Field. This mine is a clear example of reworked ground.

Figure 9. A bulldozer works a large area in the heart of the Old Field, indicating significant unmined areas within previously worked ground.

Given the current diggings occupy about half of the strike length of the Mintabie escarpment, as interpreted using the SRTM DEM image shown in Figure 8, it is highly plausible — as demonstrated throughout the mining history of the MPSF — that the unmined sections along the escarpment are highly prospective and the prospective region broadly coincides with the extent of the plateau adjacent to the escarpment as shown in Figure 8. There are no geological controls that preclude opal potential for the entire length of the escarpment. A possible reason it has not been explored further is the thicker sand cover in the northwestern part beyond Grasshopper Ridge, obscuring the escarpment and Mintabie beds. In addition, history has shown that Mintabie miners have consistently been reluctant to venture far beyond producing mines (O’Byrne 1982) and new miners in the area have often made large finds away from established diggings as was the case with Goose Gully and Grasshopper Ridge in the 1980s. Figure 10 displays the region deemed to be the most prospective, as guided by the SRTM DEM, taking into account the extent of the Mintabie plateau, the location of the known diggings along the escarpment and the prospective regions delineated by the drilling programs performed in 2000 and 2001 (Gum 2002). The most prospective region concurs broadly with the findings of Gum (2002) with the key difference being the inclusion of the area in the southeast that overlies the Mintabie airstrip. The most prospective region measures 20.8 km^2 in area. The remaining prospective regions delineated by the 2000 and 2001 drilling programs (not including the most prospective region) cover an additional 44.3 km^2.

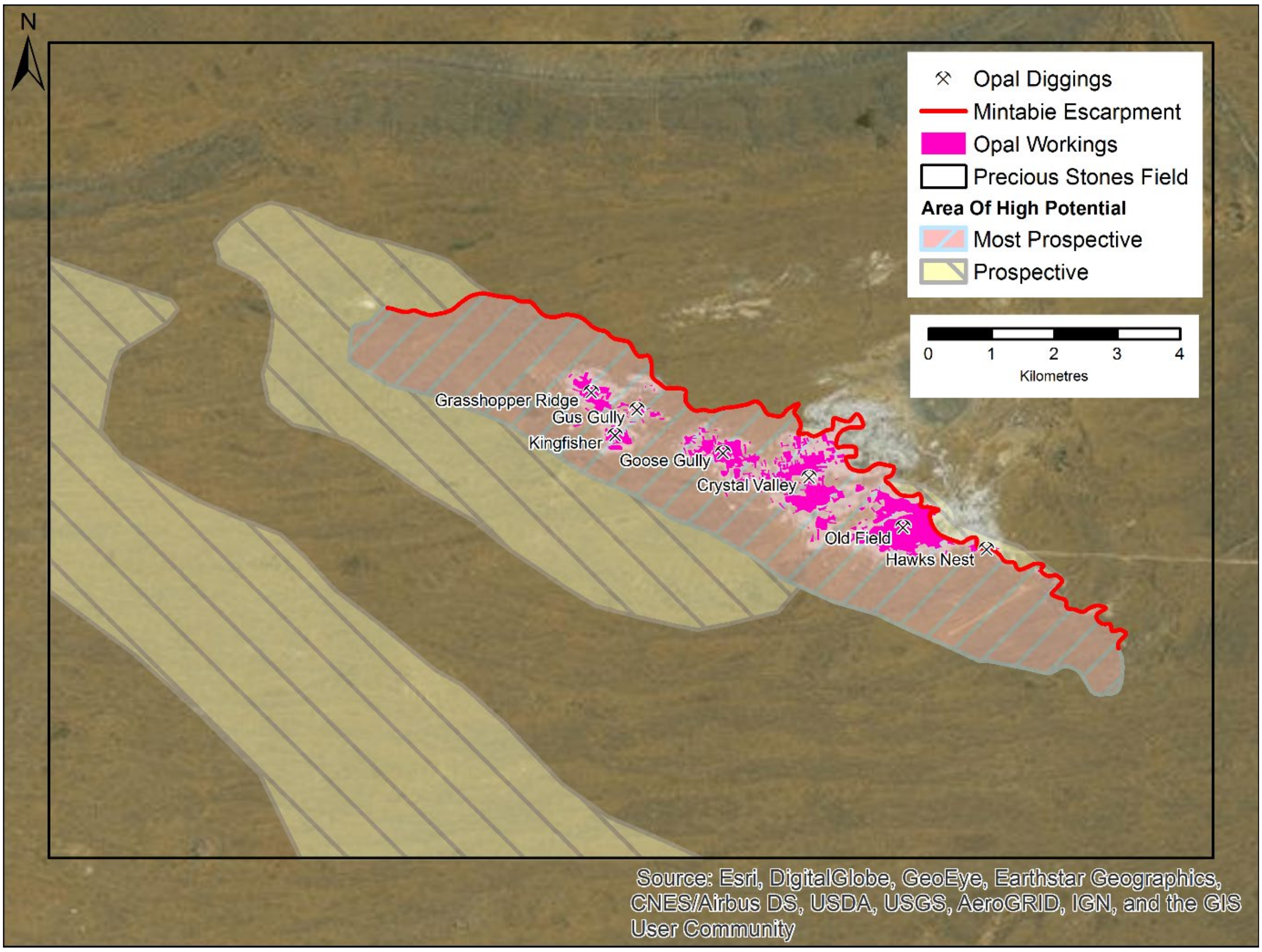


Figure 10. The Mintabie escarpment as defined by the SRTM DEM guides the interpretation of the most prospective area within the MPSF.

Table 1 considers the area that has been mined intensively, shown in magenta in Figure 10. The intensively worked regions total 1.9 km^2. Of the 213 km^2 of the MPSF, the area considered to be the most prospective is that area along strike of the escarpment over a width of about 2 km, producing a region with an area of 20.79 km^2. Subtracting the worked regions from it leaves a highly prospective opal-bearing region of 18.9 km^2 in this area. Since 40 years of mining operations have worked through only 1.9 km^2, the remaining most prospective area will require at least 400 years to exhaust the resource, if worked at the same rate as in the last 40 years.
It is expected that the areas within and immediately surrounding the current diggings will be the focus of mining activity in the immediate future. Only after these areas are perceived to be exhausted will effort extend to those areas laterally adjacent to the current workings, unless new drilling results return significant new discoveries.

Table 1. Evaluation of intensively worked area as a proportion of the total prospective region at Mintabie.

Region	Area
Area of intensive workings	1.9 km^2
Most prospective area	20.8 km^2
Remaining area (high potential minus worked areas)	18.9 km^2
Percentage of most prospective area worked	9%
Other prospective areas (Gum 2002)	44.35 km^2

VALUE OF THE RESOURCE

There are inherent uncertainties in attributing a dollar value to undiscovered minerals or precious stones. Nevertheless, this study has reached the conclusion that the 20.8 km^2 area contained within the Mintabie plateau along the length of the Mintabie escarpment is likely to host a similar density of opal occurrences as the areas within the opal field that have been mined to date (Table 1).

Information collected by the Department since 1978 using methods described by Crettenden et.al. (1980) estimates the value of raw opal produced from Mintabie from 1978 to 2016 to be $412M in raw opal product (Table 2). This estimate does not account for inflation and represents the sum of estimated dollar values, year by year as provided by the Government of South Australia. This value of raw opal has a wholesale processed value of approximately $825M, which in turn translates to a potential retail value of $2477M. These estimates use both conservative and plausible market values within opal wholesale and retail sectors.

The analysis of the undiscovered Mintabie resource estimates a value of around $3.6B in raw product. This represents an empirical value, unadjusted to account for inflation or variations in opal value over time. It takes into account the production figure estimates of the opal mined to date ($412M) with the area mined to date (1.9 km^2) and superimposes those production figure estimates over the 18.9 km^2 unmined high-potential region immediately adjacent to and along strike of the existing diggings, along the length of the Mintabie escarpment.

Table 2 shows that annual production of opal in Mintabie peaked in the five years from 1987 to 1991 before declining in subsequent decades, a trend that continues to the present time. Compared with other major South Australian opal fields, a similar trend is observed at Coober Pedy, while production in Andamooka appears to have peaked from the mid 1990s through the early 2000s, most likely due to the influx of workers from Olympic Dam, who took up residence at Andamooka and mined for opal as a hobby.

Table 2. Annual opal production from Mintabie.

Years of opal production	**Production** ($M)		
	Mintabie	*Coober Pedy*	*Andamooka*
1978–1981	27.28	123.57	14.39
1982–1986	51.85	88.84	14.85
1987–1991	141.12	96.34	17.86
1992–1996	82.6	91.9	21
1997–2001	61.93	83.5	19.84
2002–2006	24.56	81.05	20.78
2007–2011	13.08	48.76	11.79
2012–2016	10.48	46.74	12.39
Total production	**412.9**	**660.7**	**132.9**

CONCLUSIONS AND RECOMMENDATIONS

Opal is Australia's national gemstone, with more than 95% of world opal production coming from South Australia, New South Wales and Queensland. Although South Australia's opal production continues to be significant in quantity, opal production in South Australia is in a steady decline. Decreasing opal production from South Australian opal fields cannot be entirely attributed to scarcity of opal but should also consider rising costs of fuel and explosives, rising living expenses, land access constraints and a shortage of new miners entering the industry.

To reinvigorate opal production at Mintabie, historical air photos could be used to capture and reconstruct the history of open cut opal mining, making it possible to build a time series of open cut operations and thereby permitting the identification of shallow workings or unworked, viable areas beneath mullock heaps. Opal drilling programs such as those in 2000 and 2001 should be continued to (i) better delineate the full extent of the plateau that defines the Mintabie diggings,

(ii) provide baseline geological context and preliminary prospectivity testing of the areas interpreted as being prospective in this report and (iii) test deeper targets.

To better assist opal exploration both within the MPSF and throughout South Australia, scientific methods that make opal targeting possible need to be thoroughly tested. The use of electrical techniques like galvanic resistivity (Zhe and Morris 2006) together with modern high-resolution imagery, mapped regolith and elevation data has potential to aid in delineating lithological and structural information at a scale that can be readily tested with prospecting drills. Spectral methods may also assist with the identification of regions prospective for precious opal, or in identifying viable geology while drilling (Gordon et al. 2016). If any or a combination of these methods result in opal discoveries within the known opal fields, they can then be applied to new regions outside of these areas.

Internationally, opal prices are on the rise (ABC News 2018) and the South Australian opal industry has potential to leverage this trend.

ACKNOWLEDGEMENTS

Gary Burton and Paul Dale from the Geological Survey of NSW are thanked for their comprehensive review and comments on the previous edition of this report (Katona 2018). Their review and comments have been the basis for this updated and extended second edition of the report.

Miners of Mintabie, including Ivan “Sarge” Klobuchar, Emanuel Christianos and Malcolm Liebelt provided personal insight and comment that have been included in this report. Discussion with Geological Survey of South Australia staff included Justin Gum, Stuart Robertson, John Keeling and Marc Twining.

Laz Katona’s deep insight and knowledge about mining in Mintabie, based on him living and mining there for 15 years, has been the basis for this report and reflects his deep insight and expert knowledge of the MPSF.

REFERENCES

ABC News 2018. Mintabie uncertainty sees opal prices rise, viewed November 2018, <https://www.abc.net.au/news/2018-11-01/mintabie-uncertainty-sees-opal-prices-rise/10451422>.

Barnes LC and Townsend IJ 1992. *Opal: South Australia’s gemstone. Revised edition 1992*. Handbook 5. Department of Mines and Energy South Australia, Adelaide.

Cowley WM, Katona LF and Gouthas G 2009. *Assessment of Mineral Prospectivity of the Northern Flinders Ranges using GIS Analysis,* Report Book, 2009/00019. Department of Primary Industries and Resources South Australia, Adelaide.

Crettenden PP, Flintoft MW, Ewen SJ and Watkins DC 1979. *The Opal Industry in South Australia, A survey of mining equipment and a proposed method for calculating the value of production,* Report Book, 1979/111. Department of Mines and Energy South Australia, Adelaide.

Gordon GA, Morris BJ and Talbot J 2016. Regolith Modelling – The Bulldog Shale. In *Proceedings of the 4th Australian Regolith Geoscientist Association Conference. Thredbo, NSW 7–11 February 2016*, p. 56.

Gum JC and Katona LF 2010. *Mineral Potential and Prospectivity Analysis. Musgrave Province/ APY Lands,* Report Book 2010/07. Department of Primary Industries and Resources South Australia, Adelaide.

Gum JC 2002. Mintabie opal drilling program. *MESA Journal* 26:26–27. Department of Primary Industries and Resources South Australia, Adelaide.

Hiern MN 1965. *Report on Mintabie Opal Field,* Report Book 1968/60. Department of Mines, South Australia, Adelaide.

Idnurm M and Senior BR 1978. Palaeomagnetic ages of Late Cretaceous and Tertiary weathered profiles in the Eromanga Basin, Queensland. *Palaeogeography, Palaeoclimatology, Palaeoecology* 24:263–277.

Rey PF 2013. Opalisation of the Great Artesian Basin (central Australia): an Australian story with a Martian twist. *Australian Journal of Earth Sciences* 60:291–314.

Schmidt PW and Dickson BL 2017. Paleomagnetic dating of ironstone nodules ('nuts') from the Yowah opal field, central southern Queensland. *Australian Journal of Earth Sciences* 64:743–752.

O'Byrne D 1982. *Mintabie Magic. Australian Gem and Treasure Year Book, 1982*, 105–109.

Townsend IJ 1990. *Mintabie Opalfield Mining and Geology*, Report Book 1990/73. Department of Mines and Energy South Australia, Adelaide (unpublished).

Zhe J and Morris BJ 2006. High resolution resistivity: a new opal exploration tool. *MESA Journal* 41:34–37. Department of Primary Industries and Resources South Australia, Adelaide.

BIBLIOGRAPHY OF RELEVANT PUBLICATIONS

Hiern MN 1967. *Opal deposits in northern South Australia*, Report Book 60/00070. Department of Mines South Australia, Adelaide.

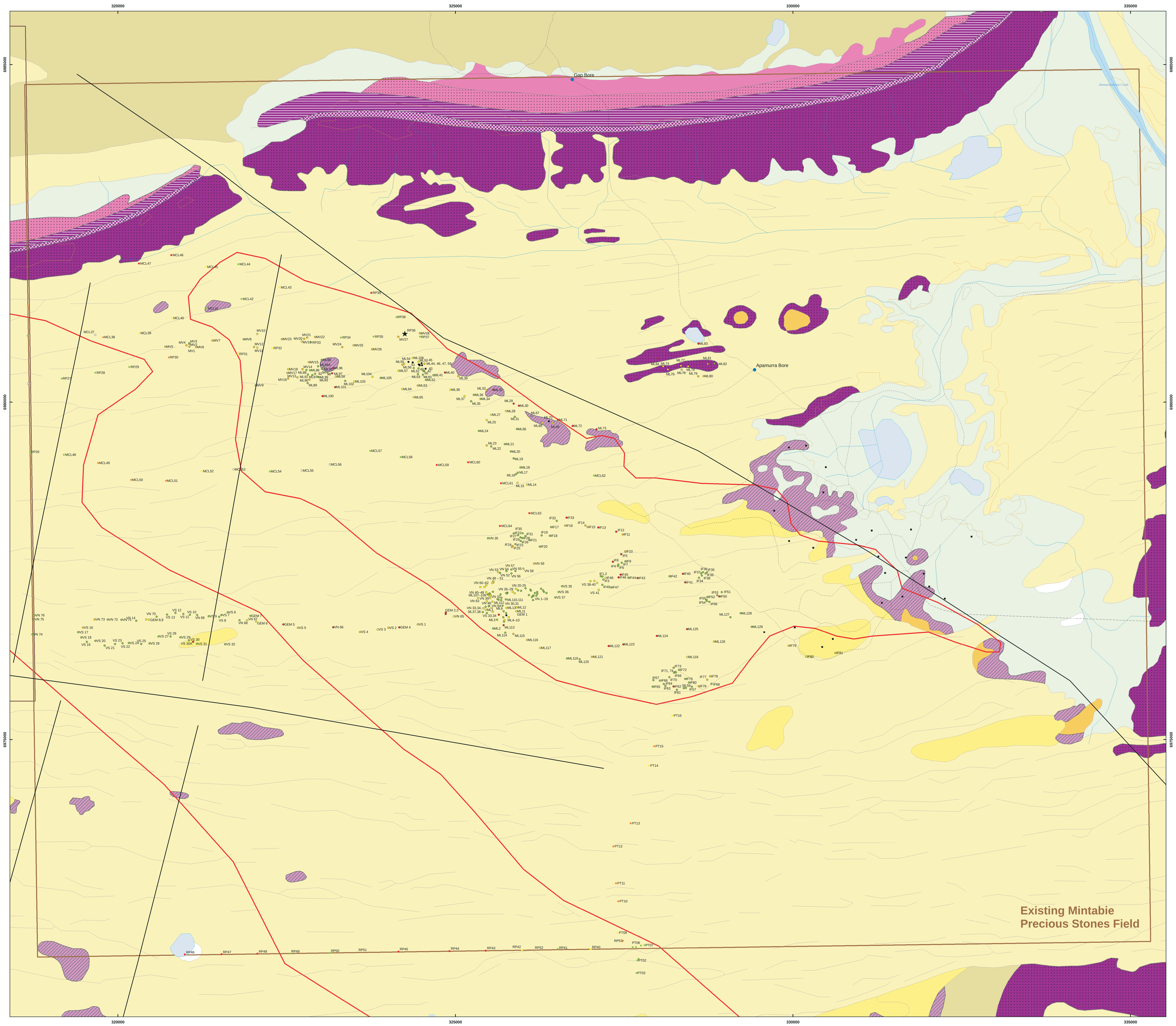
Hiern MN 1976. *Precious opal, SA. In: Knight, C.L. (Ed.) - Economic geology of Australia and Papua New Guinea. 4, Industrial minerals and rocks*, Report Book 74/00034. Department of Mines and Energy South Australia, Adelaide.

Townsend IJ and Robertson RS 1980. *Wallatinna Opal Diggings,* Report Book 80/00034. Department of Mines and Energy South Australia, Adelaide.

Townsend IJ 1980. *Discovery of Early Cretaceous sediments at Mintabie Opalfield*, Report Book 80/00104. Department of Mines and Energy South Australia, Adelaide.

Barnes LC, Townsend IJ and Nicol GJ 1980. *Opal in South Australia,* Report Book 80/00026. Department of Mines and Energy South Australia, Adelaide.

APPENDIX 1. 1:50,000 SCALE GEOLOGICAL MAP OF THE MINTABIE PRECIOUS STONES FIELD



Pleistocene-Holocene
- Gibber-mantled colluvium

Holocene
- Present day alluvium
- Playa sediments
- Sand capping dunes in dunefields
- Low angle slope deposits, gibber outwash

Pleistocene
- Undifferentiated calcrete
- Red sand with maghemite gravel veneer
- Ironstone gravel spreads on alluvium and colluvium

Miocene-Pleistocene
- MANGATITJA FORMATION
  Limestone, red bed facies, sand, grit and flood-plain to fan clay. Palaeochannel fill.

Eocene-Miocene
- Regionally older silcrete

Cretaceous
- CANDNA-OWIE FORMATION
  Sandstone, fine-grained, with coarse-grained sandstone beds and pale grey siltstone, minor conglomerate.

Ordovician-Silurian
- MINTABIE BEDS
  Sandstone, conglomerate, shale.
- INDULKANA SHALE
  Shale, maroon, minor green, calcareous; thin white flaggy siliceous sandstone interbeds; rare limestone lenses. rippled, desiccated, bioturbated.
- BLUE HILLS SANDSTONE
  Sandstone, red-brown,fine to medium-grained, kaolinitic, with pebble beds. Trace fossils, cross bedded.
- MOUNT CHANDLER SANDSTONE
  Sandstone, well rounded, fine to medium-grained quartz; sandstone, feldspathic, burrowed.
- Undifferentiated Ordovician-Silurian rocks.

Cambrian
- TRAINOR HILL SANDSTONE
  Sandstone, red-brown fine-grained, crossbedded; siltstone to claystone, red, micaceous; basal very fine-grained sandstone.
- MOUNT JOHNS CONGLOMERATE MEMBER
  Conglomerate, poorly sorted, red-brown; crossbedded feldspathic sandstone.
- OBSERVATORY HILL FORMATION
  Siltstone and claystone, micacaeous, calcareous and dolomitic in part; minor sandstone; limestone and dolomite. Minor chert.

Neoproterozoic
- PINDYIN SANDSTONE
  Basal conglomerate, coarse-grained and gritty sandstone,cross-bedded, overlain by shale with chert beds limestone and dolomite.
- RODDA BEDS
  Siltstone, grey-green, khaki calcareous and dolomitic, limestone and dolomite as allocthonous blocks.
- WANTAPELLA VOLCANICS
  Basalt, altered, amygdaloidal, tholeiitic; with lithic and gritty sandstone interbeds.
- MURNAROO FORMATION
  Pale grey-green to green sandstone, fine to coarse-grained, with shale interbeds.
- BOUCAUT VOLCANICS
  Rhyolite, andesite, and trachyte; U-Pb.

Mesoproterozoic
- ILLBILLIE ADAMELLITE
  Adamellite.
- Gabbro/microgabbro dykes
- WATARU GNEISS
  Gneiss, granulitic, with hornblende, biotite, orthopyroxene, clinopyroxene.
- Basic granulite

Palaeoproterozoic
- Quartz-biotite-muscovite schist, schistose gneiss, quartz, granitoids of Ammaroodinna Inlier.

- Mintabie Precious Stones Field
- Proposed access area
- Prospective opal ground
- Hill
- Homestead
- Bore, well, waterhole
- Vehicular Road
- Faults
- Drainage
- Sand Ridges

Drilling program

2000	2001
Good	Good
Moderate	Moderate
None	None
Poor	Poor
Potch	Potch
Abandoned	Abandoned

0 0.5 1 1.5 2 Kilometres

Datum GDA94 - Map Projection MGA Zone 53

MINTABIE OPAL FIELD

1:50 000 Geology

Government of South Australia
Primary Industries and Resources SA

PIRSA Publishing Services 202814_001