A New Resource for Honeymoon and Associated Uranium Deposits in the Eastern Callabonna Sub-Basin; The Integration of 40 Years of Exporation Drilling

A Rao
Boss Resources Ltd
Subiaco, WA, 6008
arao@bossresources.com.au

P K Williams
Boss Resources Ltd
Subiaco, WA, 6008
pwilliams@bossresources.com.au

M Z Abzalov
MASSA Geosciences
Subiaco, WA, 6008
marat.z.abzalov@gmail.com

SUMMARY

The Honeymoon Uranium Deposits were first discovered in the late 1960's, and since then there has been sporadic exploration, and one concerted attempt to develop the deposit as an In Situ Leach (ISL) operation (2011), when the uranium priced peaked briefly. Ownership of the deposit changed in 2017, and in the last 3 years there has been a systematic effort to bring all the past and recent drill hole information up to a common JORC 2012 Compliant standard, and hence calculate a new JORC Compliant Resource.

Much of the geological interpretation has been derived from a series of geophysical logs, and there has been reliance on uranium grades being calculated from prompt fission neutron (PFN) and natural gamma logging. Recent drilling has been focussed on adding additional control and removing ambiguity from historic results. The new Mineral Resource over Honeymoon's Re-start Area now totals 24Mt at 660 ppm U3O8 for 36Mlbs U3O8 (30% increase over previous) and the Global Mineral Resource now stands at 71.6 Mlbs U3O8, 52Mt at 620 ppm U3O8 .

The increase in resource has been due to a number of important factors; disequilibrium modelling which has improved parity between the eU3O8 gamma data and the pU3O8 PFN data, honouring local variations and trends; introduction of interpreted mineralisation zones to better honour local geology, palaeovalley and palaeo-channel profile, tenor of mineralisation, and disequilibrium characteristics; improved resource classification through additional drilling, PFN data in key areas, localized correction of the gamma data and classification according to confidence issues related to individual mineralised zones, and additional drilling throughout the project area including additional PFN data in key areas of geological and economic significance.

Key words: Uranium, ISL, Geophysical logging, JORC Resources

INTRODUCTION

The Honeymoon uranium deposit is located in the Callabonna sub-basin approximately 80 km northwest of Broken Hill, at latitude 31.7420°S, long 140.6619°E, and consists of three sub-deposit domains, being Brooks Dam, Honeymoon and East Kalkaroo. Uranium mineralisation is hosted within the sediments of the broad-scale, buried Yarramba Palaeovalley and is present in the form of tabular lenses in a palaeovalley-type, sandstone-hosted deposit. The Callabonna sub-basin also hosts Gould's Dam, Beverley, Four Mile, Oban and several smaller sandstone-hosted uranium deposits.

In December 2018, a total of 189 rotary mud holes were drilled for a total 23,386 meters. The results were used to recalculate the project's Mineral Resources and led to a 30% increase in Mineral Resource over Honeymoon's Re-start Area totalling 24Mt at 660 ppm U3O8 for 36Mlbs U3O8. The Honeymoon Global Mineral Resource now stands at 71.6 Mlbs U3O8, 52Mt at 620 ppm U3O8 (Boss Resources, 2019a). Important refinements and development in the area of processing optimization have also been made, which will make material improvements to the Project Economics (Boss Resources, 2019b) and be used in a re-calculation of the JORC compliant Reserves of the Project in the latter half of 2019.

EXPLORATION AND MINING HISTORY

Exploration for sediment-hosted uranium deposits in the Callabonna sub-basin commenced in the late 1960's. The exploration and early development history are described in summary form in Abzalov (et al. 2017).

Pilot production at the Honeymoon deposit commenced in 2011, however because of lower than expected production efficiencies and recoveries in the start-up operations and a sharp decrease in the price of Uranium, efforts were ceased in favour of further investigations on recovery and process options. The Pilot Production study was never completed.

Boss purchased the Honeymoon Project in 2017, and in 2018 has initiated a systematic restart strategy, which aims to build on the knowledge gained from the previous uncompleted pilot study, and to expand the resource base of the project.

REGIONAL GEOLOGY

The Regional Geology has been described previously (Abzalov et al., 2017)

The mineralised domains of Brooks Dam, Honeymoon and East Kalkaroo are hosted by the Yarramba Palaeovalley, which is approximately 150 kilometres long (Fig. 1).

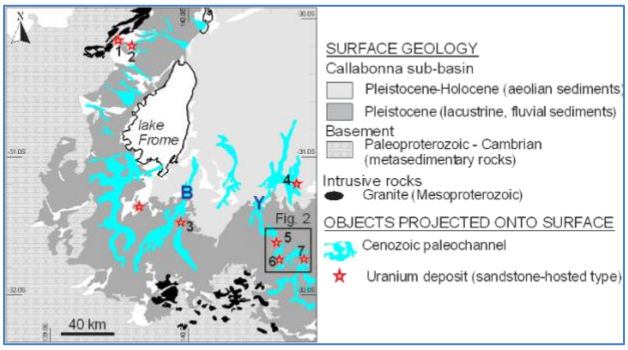

Fig. 1 Generalised geological map of the Callabonna sub-basin. Paleochannel outlines are modified from Hou et al. 2007. Deposits: 1 Four Mile, 2 Beverly, 3 Gould's Dam, 4 Oban, 5 Yarramba, 6 Honeymoon, 7 Saffron. Paleochannels: B – Billeroo, Y – Yarramba.

In the central part, the palaeovalley is approximately 2 – 4 km wide with locally-occurring swarms of braided and meandering streams that form wide palaeochannels (Fig. 2).

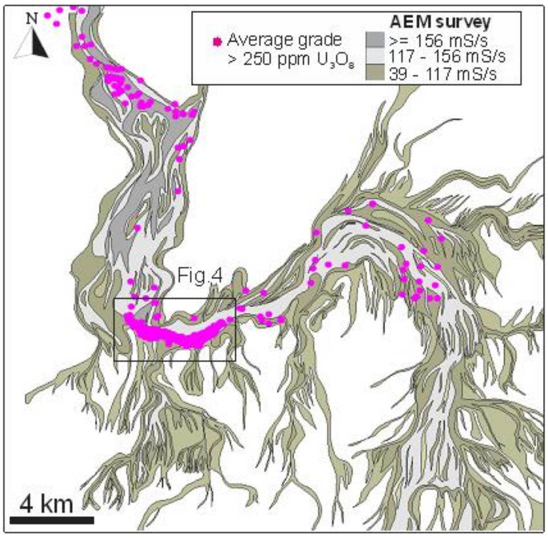

Fig. 2. Geological map of the Yarramba paleochannel interpreted from TEMPEST™ airborne electro-magnetic (AEM) survey results (BOSS Resources, unpublished data). Different colours denote lithofacies. Dots denote the drillholes intersecting uranium mineralisation.

Average depth to the basement at Honeymoon is approximately 120 metres, which includes a 50 to 60-metre thick Eocene sequence of unconsolidated sands and clay (Eyre Formation). The sequence is subdivided into three sedimentary cycles, referred to as Lower, Middle and Upper Members of the Eyre Formation. Each cycle starts with coarse, gravelly sand sequence gradually fining upward and capped by a silt or clay layer (Fig. 3).

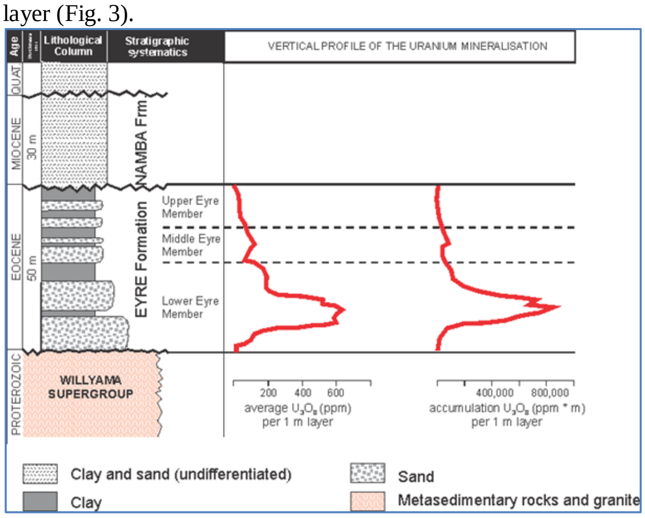

Fig. 3. Stratigraphic column of the Yarramba paleochannel and vertical profile of the uranium mineralisation (based on 1689 drillholes).

ORE DEPOSIT FEATURES

Mineralisation within Honeymoon is hosted within the fully saturated sediments of the Lower Eyre Member at depths between 80 to 120 metres (Fig. 3). Current strike length of the known mineralised palaeovalley exceeds 6 kilometres with a variable strike width of 300 – 700 metres (Fig 4.).

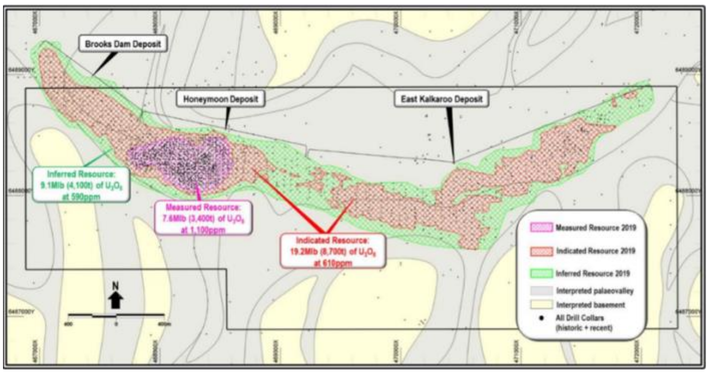

Fig. 4. Distribution of the uranium mineralisation grade at the Honeymoon deposit (restart area). Based on the resource block model (BOSS Resources 2019a).

GEOLOGICAL CONTROL OF MINERALISATION

Mineralisation is mainly associated with the vertical and lateral movement of oxidation-reduction interfaces throughout the sediments of the broad-scale, buried Yarramba Palaeovalley. The sediments infilling the buried palaeovalley are situated from approximately 70m below ground surface to a maximum depth of approximately 130m and filled by fining upward sequences of sand, interbedded silts and clays. The valley systems were incised into the surrounding country bedrock of the Willyama Supergroup, and drain into Lake Frome to the northwest of the Project area.

Mineralisation characteristics are slightly different throughout the resource area, with the uranium ore situated at varying depths. This led to the decision to separate the deposit into 3 soft domains: comprising the Honeymoon deposit (100 – 120m) and shallower at the Brooks Dam and East Kalkaroo deposits (80 – 110m). The majority of the mineralisation is hosted in the Eyre Formation, with the tabular lenses distributed between the Lower, Middle and Upper Eyre Members. A small part of the orebody is also hosted within the weathered saprolitic zone at the top of the basement bedrock. This is unsurprising given that weathering and erosion processes have destroyed the integrity of the basement bedrock, increasing the porosity and permeability of the saprolite zone and allowing uraniferous groundwaters to flow through the top of the basement. The reduction and subsequent precipitation of the uranium from the oxidised aquifer water is likely explained by the sulphides inherent within the basement lithologies.

Within the Honeymoon Domain, "pods" or "shoots" of high-grade uranium mineralisation are generally confined between impermeable rocks of the Proterozoic basement and the Lower Clay unit of the Lower Eyre Member which forms continuous tabular-type bodies (Fig. 5).

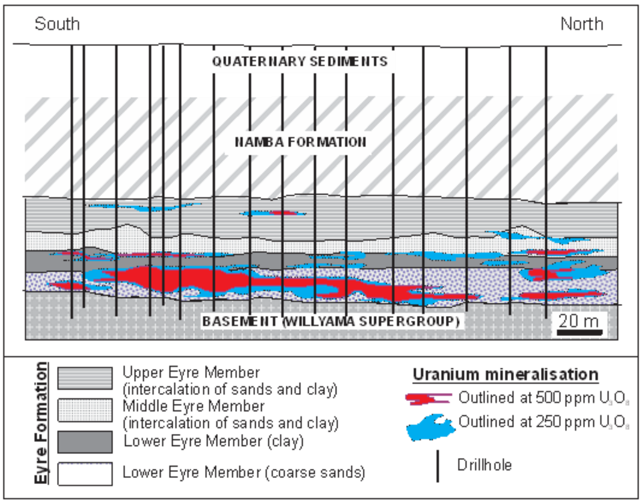

Fig. 5. Typical cross-section of the deposit.

Its distribution is controlled by fluid pathways that have transported the dissolved uranium along the permeable sands located in the paleochannel. Organic matter is likely to have served as reductants causing precipitation of uranium. Interplay of these two main factors has created the uranium mineralisation at the Honeymoon deposit which occurs as tabular bodies elongated along the flow path of the paleochannels (Fig. 5). Uranium mineralisation is also present in the Middle and Upper Members of the Eyre Formation; however grade and thickness of the mineralisation is generally lower than that situated within the Basal Sand unit.
Mineralogy and hydrogeology characteristics have been reported by Abzalov (et al., 2017)

RECENT DRILLING

An infill drilling campaign was conducted between June and December 2018. A total of 189 rotary mud holes were drilled for a total 23,386 metres. All holes were drilled vertically and designed to infill existing drilling to obtain an overall average drill spacing of 80m by 40m (required for the conversion of Inferred to Indicated Resource), or 40m by 20m (required for conversion of Indicated to Measured Resource).
Each rotary mud hole was logged with a suite of downhole geophysical tools consisting of gamma, prompt fission neutron (PFN), nuclear magnetic resonance (NMR or BMR), resistivity, induction, neutron porosity, self-potential conductivity, calliper and magnetic deviation. Results from the BMR tool provided extremely valuable information about the hydrological properties of the measured material, including total porosity, relative pore size distribution and estimated hydraulic conductivity. The data gathered from the combined downhole logging suite is also utilized in the continual improvement of the deposit-specific geology and mineralisation models. On a more regional scale, these models are being applied and continually reviewed to improve the exploration model.
Drill chips collected for geological logging were analysed with a handheld XRF (X-Ray Fluorescence) spectrometer to qualitatively measure sulphide and iron contents within the host sediments.
The compiled dataset formed from the collective results of the various tools created the most advanced modelling to date for mineral delineation on the Honeymoon Uranium Project. This dataset, together with chemical results of the XRF analysis and the updated lithostratigraphic/mineralisation models will be invaluable in optimising the design and development of the final wellfields.

A revised wellfield design criterion will be applied over the new Mineral Resource estimate to determine the optimal size and shape of a practical mineable area. The design methodology will be based on an Economic Grade Model (or grade times thickness, GT) and on the resource block model, to determine the minimum GT value for material that can be economically mined. A minimum GT of 650m.ppm is currently defined for an individual well.

DRILLING AND SAMPLE COLLECTION

Most of the drilling undertaken historically on Honeymoon has been completed using rotary mud technique. Other historical fieldwork programs have also involved relatively small amounts of rotary air blast, diamond and sonic core, rotary mud with core tails, and rock bit drilling. Assay data has consisted predominantly of downhole geophysical logging comprising the use of tools such as natural gamma, resistivity, conductivity and density. Since 2003 downhole logging suite have included the use of PFN tools alongside the natural gamma, allowing the compilation of a large enough dataset with which to estimate the disequilibrium factor for the deposit.
Most of the drilling activity has predominantly focused on the Eastern Region near-mine area. Drill densities have also been variable through the different generations of drilling, with an average spacing of approximately 80m x 200m. The infill drilling undertaken in 2018 reduced the spacing to approximately 40m x 20m which is reasonable for the purpose of upgrading part of the existing Mineral Resource to Ore Reserve category. Uranium grade data was composited to 25cm intervals to aid in the geological interpretation and assignment of mineralisation to the respective zones.
A small sonic core program was completed at the end of 2018, consisting of nine holes for a total of 1,080m. The purpose of the sonic drilling was to provide physical samples for the purpose of verifying the uranium grades derived from the downhole PFN, and to provide samples for metallurgical test work as part of the DFS. The results of the sonic drilling were not utilized directly in the Mineral Resource estimation process; however, they have been reported here in the announcement of Boss Resources (2019).
The principal assay collection method has been via downhole geophysical logging. Uranium grades for all drilling undertaken prior to 2003 were derived mostly from downhole natural gamma logging. A minor amount of physical sampling had also been conducted during the early diamond and sonic core programs, however these results were only used for verification of the gamma-derived assays. Calibration of the gamma sondes was completed at the Glenside facility in Adelaide, while PFN tools were regularly calibrated in the calibration pits installed at the Honeymoon Uranium Mine itself, designed specifically for this purpose. Gamma data was collected at variable sample rates between 5 and 10cm, for the different generations of drilling. PFN logging data was collected at sample rates between 1 and 3cm. Assays collected from the 2018 infill drill program involved downhole PFN logging (Boss Resources) and a suite of gamma, Borehole Magnetic Resonance (BMR), self-potential (SP) conductivity, resistivity/induction, caliper and magnetic deviation, completed by independent contractor Wireline Services Group (Perth, W.A). Uranium grades estimated from the data collected by Wirelines Services was required as an independent verification of the corresponding grades calculated in-house from the Boss-owned PFN tools. All tools were maintained by specialised electronic companies and technicians based in Adelaide and Perth.
Standard industry procedures were used for geophysical logging of the drill holes and estimation from the geophysical

logs for the eU3O8 (from the gamma-ray logs) and pU3O8 (from the PFN instruments) grades. Uranium grades (pU3O8) were calculated from the PFN tools after proper calibration and compositing to 25cm sample intervals. Calibrations of the PFN tools were completed in the calibration pits installed at the Honeymoon Uranium Mine itself. Each of the calibration test pits was constructed at a particular hole size diameter, based on the most commonly used drill technique and corresponding hole sizes in the Honeymoon database. The appropriate calibration model was determined and subsequently applied to the PFN logging data, along with the relevant hole size correction factor.

In-hole radiometric uranium grade data was also determined by Wireline Services with equivalent gamma grades (eU3O8) determined from the post-calibration, downhole natural gamma-logs, moisture correction and disequilibrium correction factors, and were also composited to 25cm sample intervals. The natural gamma sondes were also calibrated at the Glenside calibration test pits in Adelaide and the appropriate calibration model and hole-size correction factors applied to the gamma data.

The downhole gamma tool measures gamma emission from particular daughter isotopes in the uranium radioactive decay series. If the parent 238Uranium is in secular equilibrium with its respective daughter products, the response of the natural gamma is directly proportional to the amount of uranium in the surrounding formation. If, however, the concentration of gamma-emitting daughter isotopes is greater than that of the parent 238Uranium, the environment is said to be in a state of secular "disequilibrium" and the resulting gamma data corrected accordingly in order to provide a more realistic uranium grade. The correction process for generation and application of the disequilibrium factors is discussed as part of the Mineral Resource estimation process.

MINERAL RESOURCE ESTIMATION METHODOLOGY

It should be noted that the uranium mineralisation hosted by palaeovalley, or narrower palaeochannel, systems is not always uniform in grade and tenor. There are often "pods", or shoots, of high-grade material accumulated in areas associated with either an increased concentration of a particular reductant or bounded by structural elements such as faults – the latter creating "trap sites" in which the continuity of the permeable horizons is suddenly broken by an offset in the geological unit/s. This "pod"-like characteristic of the mineralisation is seen within the Project area, where the highest-grade material is found concentrated within the lower zones of the Honeymoon deposit within the existing wellfield area. Figure 4 illustrates this by showing the updated Mineral Resource (hatched coloured areas) overlain by the previous 2016 Mineral Resource (light coloured lines).

A comprehensive three-dimensional wireframe model of the uranium mineralisation at Honeymoon was produced and passed on to independent resource consultants, for review and use in the resource estimation process. An updated Mineral Resource for the Honeymoon Uranium Project incorporating the Honeymoon Re-Start Area (Brooks Dam, Honeymoon and East Kalkaroo domains) has been generated in January 2019 (see Boss Resources 2019a).

The estimations used the interpreted mineralised zones as hard-boundaries in all cases.

PFN data was validated against chemical assays from a relatively small number of core holes and sonic holes, concluding that the PFN data is comparable. Local disequilibrium factors for the gamma data were modelled for the mineralised zones using a large data set of 10,511 at 0.25 meter intervals containing pairs of gamma data grades and PFN data grades. The data pairs were modelled using an inverse distance interpolation method and power of 1 (ID1) into 20m by 20m panels for each of the individual mineralised zones, with a panel disequilibrium factor calculated from the estimated values (DISEQFAC=pU3O8 /eU3O8). The local estimated disequilibrium factors (DISEQFAC) were assigned to any 0.25 metre intervals for the mineralised zone data sets occurring within the panel area and applied to the gamma data (eU3O8). The factors tended to be low (negative) or neutral for portions of the Lower Eyre Formation hosted mineralised zones and were increasingly high (positive) for portions of the Middle and Upper Eyre Formation hosted mineralised zones. Data is prioritized such that preference is given to any PFN data and then factored eU3O8 data where no PFN data exists for the interval.

Statistics for high grade cuts were generated for individual mineralised zones and subsequent regroupings of Lower, Middle, and Upper Eyre zones. Light high-grade cuts were applied to the prioritized data on the original 0.25 meter intervals. Cuts ranged from 4,000 ppm U3O8 for a relatively low-grade mineralised zone to 30,000 ppm U3O8 for a relatively high-grade mineralised zone.

The accumulation estimation process utilized full zone width composites based on the high grade cut 0.25 meter interval data resulting in composites having variable length or thickness.

Two dimensional directional experimental variograms were generated for the accumulation variable according to individual and grouped mineralised zones within the Lower, Middle and Upper Eyre Formation. Sample search parameters were defined based on the estimation method, variography and the data spacing. A two-pass search strategy with hard boundaries was used for all zones. The experimental variograms were generally well structured with moderate to high nugget variance ranging from 35% to 75% and major axis ranges from 130 to 350 meters dependent on data quantity and consistency within the mineralised zones.

Given relatively thin mineralised zones, variable grades within the zones and mining by in situ leach ("ISL") methods, U3O8 grade estimation was completed using a Restricted Ordinary Kriging ("ROK") accumulation process. Dynamic anisotropy was used during estimation to accommodate the variable and complex orientations of the palaeovalley and paleochannels at the different stratigraphic levels. The accumulation process involved estimation of an accumulation variable (U3O8 grade multiplied by thickness in centimeters) and the thickness variable (in centimeters) via ROK using full zone width composites and a restricted search neighborhood. Variogram model and search parameters were kept identical for both the accumulation variables and the thickness service variables. Estimation was into selective mining unit (SMU) sized panels with dimensions of 5m by 5m by modelled thickness in RL and using a limited search neighborhood. The estimated U3O8 grade was back-calculated from the estimated accumulation and thickness variables. The 5m by 5m SMU panel dimension considers the typical production borefield drillhole spacing approaching 20m by 20m and stated vertical selectivity within production bores at the scale of the interpreted mineralised zones.

Another part of the reinterpretation and review exercise involved the creation of a working, three-dimensional stratigraphic model. This modelling process involved the interpretation of combined downhole geophysical data, XRF analysis from the drill chips, and geological logging from both the drill chips and sonic core to determine the depths of each of the stratigraphic contacts between the formations. The resulting

model was utilised in the Mineral Resource estimation to more accurately group the zones into their associated stratigraphic positions within the Eyre Formation.
Mining by In-situ Recovery ("ISR") has been conducted in parts of the Honeymoon domain. Recovery of metal was tracked for well fields and a factor included in the model to adjust for metal removed from targeted mineralised zones.

CONCLUSIONS

The recent drilling and analysis has led to a 30% increase in Mineral Resource over Honeymoon's Re-start Area to 36Mlb U308, being 24Mt at 660 ppm U3O8 for 36Mlbs U3O8. The Honeymoon Global Mineral Resource now stands at 71.6 Mlbs U3O8, 52Mt at 620 ppm U3O8 (Boss Resources, 2019a).

The 2019 Honeymoon Mineral Resource upgrade varies from the previous Mineral Resource due to:
• Disequilibrium modelling has improved parity between the eU3O8 gamma data and the pU3O8 PFN data, honouring local variations and trends.
• Introduction of interpreted mineralisation zones to better honour local geology, palaeovalley and palaeochannel profile, tenor of mineralisation, and disequilibrium characteristics.
• Improved resource classification through additional drilling, PFN data in key areas, localized correction of the gamma data and classification according to confidence issues related to individual mineralised zones.
• Additional drilling throughout the project area including additional PFN data in key areas.

ACKNOWLEDGMENTS

The authors thank BOSS Resources for permission to publish the company data.

REFERENCES

Abzalov, M. 2012. Sandstone-hosted uranium deposits amenable for exploitation by in situ leaching technologies. Applied Earth Science, v.121, no.2, pp.55-64.

Abzalov M.Z., Williams P.K., and Inwood N.A. – Honeymoon, Beverley and Four Mile uranium deposits, pp. 655–658 in Phillips N ed. 2017. Australian ore deposits, AusIMM Monograph 32. 6th edn. Australasian Institute of Mining and Metallurgy, Carlton, Victoria.

BOSS Resources. 2016a. ASX announcement. BOE – substantial increase and upgrade in Honeymoon resource, (20 January 2016).

BOSS Resources. 2016b. ASX announcement. BOSS increases Honeymoon project uranium resource, (8 April, 2016).

BOSS Resources. 2016a. ASX announcement. Substantial increase and upgrade in honeymoon uranium resource (20 January 2016) https://bossresources.com.au/wp-content/uploads/2016/02/160120-1-Honeymoon-resource-update-FINAL-4.pdf

BOSS Resources. 2016b. ASX announcement. Boss increases honeymoon uranium project resource by 90% to 53mlbs U3O8 (8 April 2016) https://bossresources.com.au/wp-content/uploads/2016/04/160408-1-Goulds-Dam-Resources-Final-5.pdf

BOSS Resources, 2017. ASX Announcement. Substantial resource update for Jason's deposit, (15 March 2017) https://bossresources.com.au/wpcontent/uploads/2017/03/170315-1-Jasons-Resource-Upgrade-1-7.pdf

BOSS Resources, 2019a, ASX Announcement. 149% Increase in Measured & Indicated Mineral Resources over Honeymoon Re-start Area, (25 February 2019). https://bossresources.com.au/wp-content/uploads/2019/02/02078959.pdf

BOSS Resources, 2019b, ASX Announcement. Optimisation Testwork Identifies Improvements to Honeymoon's Uranium Re-start. (28 February, 2019). https://bossresources.com.au/wp-content/uploads/2019/02/02081007.pdf

Bush, P.D. 2000. Development considerations for the Honeymoon ISL uranium project. CIM Bulletin, v.93, no.1045, pp.65-73.

Curtis, J.L., Brunt, D.A. and Binks, P.J.,1990. Tertiary palaeochannel uranium deposits of South Australia, in Geology of the Mineral Deposits of Australia and Papua New Guinea (Ed. F E Hughes), pp. 1631-1636 (AusIMM, Melbourne).

Hou, B., Zang, W., Fabris, A., Keeling, J., Stoian, L. and Fairclough, M. 2007. Palaeodrainage and coastal barriers of South Australia 1: 2 000 000. CRC LEME, Geological Survey branch, PIRSA, Adelaide

Roach, I.C. (Ed) 2012. The Frome airborne electromagnetic survey, South Australia: implications for energy, minerals and regional geology. Geoscience Australia Record 2012/40 DMITRE report book 2012/00003, 296 pp.

Penney, R. 2012. Australian sandstone-hosted uranium deposits. Applied Earth Science, v.121, no.2, pp.65-75.

Wulser, P-A., Brugger, J., Foden, J. and Pfeifer, H-R. 2011. The sandstone-hosted Beverley uranium deposit, Lake Frome Basin, South Australia: mineralogy, geochemistry, and time-constrained model for its genesis. Economic Geology, v.106, no.5, pp.835-867.