Department for Energy and Mining

Assessment of SAPEX Ltd's Proposed fracture stimulation activities within the Arckaringa Basin

Energy Resources Division

March 2019

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SOUTH AUSTRALIA

Government of South Australia

Department for Energy and Mining

PGER 00335

Energy Resources Division
Department for Energy and Mining
Level 4, 11 Waymouth Street, Adelaide
GPO Box 320, Adelaide SA 5001

Email dem.petroleum@sa.gov.au
www.energymining.sa.gov.au/petroleum

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13/3/2019–205118

Contents

List of figures

Executive Summary

SAPEX Limited (a company that forms part of the Tri-Star Petroleum Group) has proposed to use fracture stimulation techniques on petroleum wells in PELs 122 & 123 in the Arckaringa Basin of South Australia.

SAPEX intends to evaluate the size and commerciality of the oil and gas resources within target shale formations including the Stuart Range and Boorthanna Formation. Shale targets are expected to range between 650m to 1,800m deep, and are located approximately 100 km away from the Coober Pedy Township.

This report details the Department for Energy and Mining – Energy Resource Division (DEM-ERD) review of the Environmental Impact Report (EIR) and draft Statement of Environmental Objectives (SEO) for fracture stimulation in the Arckaringa Basin as proposed by SAPEX.

For further more general information on the fracture stimulation process please see the (DEM-ERD) FAQ on their website:
http://www.petroleum.statedevelopment.sa.gov.au/frequently_asked_questions

Approval process

The review was undertaken as part of Stage 2 of the three-stage approval process under the *Petroleum and Geothermal Energy Act 2000* (PGE Act) that all prospective operators must submit to. These stages are:

1. Licensing: Stage 1 approval grants exclusive rights to an area but does not grant rights to undertake on-ground activities.
2. EIR assessment and SEO approval: In this stage a draft SEO is prepared on the basis on an EIR. The draft SEO identifies the environmental objectives and conditions that the licensee will be required to achieve to ensure it addresses the risks identified in the EIR. Both the EIR and draft SEO for the proposed SAPEX fracture stimulation project were the subject of public consultation. Stage 2 approval is only granted when all relevant issues raised through this public consultation process are addressed.
3. Activity notification and approval: The Stage 3 process requires submission and approval of technical and operational plans in consultation and technical input from co-regulatory bodies such as the Environmental Protection Agency (EPA) and the Department for Environment and Water (DEW). Also notification of intentions to undertake a regulated activity to all relevant landowners. After Stage 3 approval, on-ground activities can begin.

During the Stage 2 consultation process (7 February to 4 June 2018) a number of issues were raised by government and the wider public in a total of 35 submissions.

These submissions are available on the DEM-ERD's environmental register[1]. SAPEX Limited responded to these submissions within Appendices 6 and 7 of their EIR prior to formally submitting the revised EIR to the DEM-ERD on 29 October 2018.

Key concerns from public consultation

The key concerns raised in the consultation process were:

- potential for fracture propagation into overlying Great Artesian Basin (GAB) aquifers causing contamination, and/or aquifer depletion and/or impacts to GAB springs;
- potential impacts on Aboriginal heritage;
- potential for fracture stimulation induced seismicity causing stability problems for underground houses within Coober Pedy and/or impact on tourism.

Recommendation

The Energy Resources Division recommends Stage 2 approval, based on:

- its detailed review of the EIR and draft SEO as summarised in this report;
- SAPEX Limited's responses to comments submitted as a result of public consultation; and
- consultation with co-regulatory agencies including (but not limited to) the Environmental Protection Agency (EPA) and the Department for Environment and Water (DEW).

[1] http://petroleum.statedevelopment.sa.gov.au/legislation_and_compliance/environmental_register

1.0 About this document

This document summarises the main findings of the assessment undertaken by the Energy Resources Division within the Department for Energy and Mining (DEM-ERD) in relation to the potential issues and environmental risks associated with the SAPEX Limited (a company that forms part of the Tri-Star Petroleum Group) fracture stimulation within the Arckaringa Basin proposal.

Information from the Environmental Impact Report (EIR)[2] submitted by SAPEX Limited and additional information acquired by the DEM-ERD as the lead regulator of this project was used along with public submissions and advice from other co-regulatory agencies to inform the approval process for the Statement of Environmental Objectives (SEO)[3] under the *Petroleum and Geothermal Energy Act 2000* (PGE Act) for this proposal.

This document sets out the approval process (Section 2.0) and provides an overview of the Arckaringa Basin (Section 3.0), the existing environment (Section 4.0) and the SAPEX Limited fracture stimulation proposal (Section 5.0). Issues raised during public consultation (Section 6.0 and 7.0) are also presented, along with the final recommendation from DEM-ERD (Section 8.0).

[2] SAPEX Limited PEL 122 & 123 Fracture Stimulation Activities SEO

[3] SAPEX Limited PEL 122 & 123 Fracture Stimulation Activities EIR

2.0 Approval process

At the outset, it is important to clarify the process for regulatory approval under the PGE Act.

The approval process consists of three stages[4]:

1. Licensing
2. Environmental Impact Report (EIR) assessment and approval of Statement of Environmental Objectives (SEO) and criteria that the proponent will need to demonstrably achieve
3. Activity notification and approval.

Stage 1: Licensing

The licensing stage involves the licence application and grant process, where a proponent applies for the appropriate licence to give them the right to undertake regulated activities within a licence area. A licence granted under this stage is not a right to do any on-ground activities; rather it is simply an exclusive right to an area within which the licensee can then apply for approval to undertake activities. Only parties with the adequate demonstrated financial and technical capacity to invest and safely conduct regulated activities are eligible to become PGE Act licence holders.

On-ground activities can only be undertaken subsequent to approvals granted under Stages 2 and 3, which address the environmental and operational aspects of activities.

SAPEX Limited was granted its petroleum exploration licences (PEL 122 & 123) in October 2006.

Stage 2: Statement of environmental objectives assessment and approval

The grant of a PGE Act licence does not provide an automatic entitlement to land access to conduct operations. Rather, regulated activities under the PGE Act (under Section 96) may not be carried out unless an approved SEO is in place, prepared on the basis of an EIR. The EIR describes the specific features of the environment where the activities will take place and identifies all potential impacts, the risks relating to the activity and the proposed risk-mitigation strategies. The SEO identifies the environmental objectives and conditions (assessment criteria) that the licensee will be required to achieve to ensure it addresses the risks identified in the EIR.

[4] See the DEM-ERD's approvals flowchart: Exploration_and_Production_Flowchart_September_2015

Examples of the information and potential impacts that the EIR and final SEO are expected to address include:

- Impacts and disturbance to Aboriginal sites;
- Impacts on aquifers, including pressure and contamination;
- Impacts on groundwater use;
- Contamination of surface water and shallow groundwater and soil;
- Impacts on native vegetation and native fauna and stock;
- Disturbance to existing land uses (e.g. within reserves under the *National Parks and Wildlife Act 1972*, pastoral land, etc.) or to local heritage features;
- Air pollution and greenhouse gas emissions;
- Impacts on the health and wellbeing of the local community; and
- Remediation and rehabilitation requirements.

It should be noted that SAPEX Limited has an approved SEO[5] and associated EIR[6] for drilling within the Arckaringa Basin, developed and first approved in 2007 and currently under review subject to Regulation 14 under the Act. The next revisions are to be in place before the drilling of any further wells in the Arckaringa Basin.

Stage 3: Activity notification and approval

Once the relevant SEO, is gazetted in accordance with Part 12 of the PGE Act, the proponent has to proceed to the third and final approval stage to obtain approval to commence on-ground activities. This entails submission to DEM-ERD for evaluation and approval of all technical and engineering designs relating to this activity are in accordance with recognised industry standards and fit for the purpose for achieving the requirements of the final approved SEO objectives and conditions. This Stage 3 approval process will also include, evaluation and approval of the licensee's Environmental, Health and Safety Management Systems, monitoring plans, fracture stimulation modelling, environmental assessments, environmental management plans, rehabilitation plans, cultural heritage assessments and emergency response procedures that are critical to the demonstrable achievement of the SEO objectives.

Under Stage 3, the licensee is also required to notify all relevant landowners about its intentions to undertake any regulated activity and to clearly describe pursuant to the requirements under Part 10 of the PGE Act, the nature of its activities to be undertaken, the potential impacts those activities may have on the landowner and the right of the landowner to dispute such entry including any compensation that may arise from such activities.

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[5] SAPEX Limited – Arckaringa Basin Drilling Activities SEO, October 2007 (under review)

[6] SAPEX Limited – Arckaringa Basin Drilling Activities EIR, October 2007 (under review)

3.0 The Arckaringa Basin

3.1 Arckaringa Basin Exploration History

Petroleum exploration commenced in the Arckaringa Basin in the 1960s with Delhi's Oodnadatta aeromagnetic survey and was followed by gravity surveys. Limited reflection and refraction seismic was also recorded in this period.

These surveys delineated the deep Boorthanna Trough. The first exploration wells were Cootanoorina 1 (1967, Department of Mines) and Weedina 1 (1970, Pexa Oil). There were no indications of hydrocarbons in the Permian section, but trace of natural gas and bituminous material were recorded from the Cootanoorina Formation.

In 1969 the department commenced a seismic and seven well stratigraphic drilling program aimed at evaluating the Boorthanna Trough. At the same time surveys continued in the Boorthanna Trough (seismic and one wildcat — Weedina 1) commissioned by Pexa as part of a farm in commitment. No significant hydrocarbons were recorded.

The next phase of exploration was by Delhi in the mid 1980s and included seismic and two wells. Hanns Knob 1 terminated in Cootanoorina Formation and Birribiana 1 in Proterozoic dolerite. Traces of natural gas were recorded in the latter. The Arckaringa Block was relinquished by Santos and Delhi in 1989.

SAPEX currently operates PELs 117-124 (granted in 2006), where targets are coal seam methane plays in the Mt Toondina Formation, oil in the underlying Officer Basin and Boorthanna Formation sandstone, and oil in the Stuart Range and Boorthanna Formation shales.

A preliminary correlation of the Early Permian succession in the Southern Arckaringa troughs and the Boorthanna Trough has been postulated; in particular the organic rich marine shales appear to have been deposited in a transgressive system that can be identified in both areas of the basin. The organic rich shales are a prospective shale oil target if sufficient maturity levels can be identified. Alternatively, biogenic generated shale gas may be a possibility in parts of the basin.

The recent drilling in the basin (14 exploration wells since 2009) has greatly increased the knowledge of the basin (previously there had only been 4 exploration wells drilled in the basin since 1970). It is now clear that the basin has oil prone source potential, and significant potential remains for oil in conventional and unconventional reservoirs.

Similarly, the recent understanding of the significance of the organic rich shales of the Stuart Range Formation are being explored as a possible shale oil target.

3.2 Arckaringa Basin Geology

The Arckaringa Basin shown in Figure 1 is a Permo-Carboniferous intracratonic basin which covers an area of ~80,000 km^2. The basin comprises two main depocentres, the Boorthanna Trough in the east and the southern Arckaringa troughs (West, Phillipson, Penrhyn and Wallira), separated by shallow basement with a thin veneer of Permian sediments. The troughs contain up to 1,300m of Permo-Carboniferous sediments overlain by up to 300m of Late Jurassic to Early Cretaceous Eromanga Basin sediments and generally less than 10m of Tertiary cover. The stratigraphy of the Arckaringa Basin is outlined in the cross-section shown in Figure 9

The Boorthanna Trough is broad, and underlain in part by Neoproterozoic and early Palaeozoic sediments of the Adelaide Rift complex. The southern Arckaringa troughs are narrow, and underlain by Archaean to Early Mesoproterozoic rocks of the Gawler Craton. Both depocentres show evidence of infill of basement topography.

Boorthanna Trough

Diapirism in the Neoproterozoic Adelaide Rift succession is evident on a number of seismic lines over the Boorthanna Trough, and Permian sediments at Mt Toondina are deformed by a piercement structure. Extensional tectonics and differential loading are postulated as the driving mechanisms for initial diapiric movement and subsequent growth, with Neoproterozoic salt as the source.

There is also seismic evidence for salt movement influencing deposition during the Permian. Otherwise, the Permian depositional and tectonic history in the Boorthanna Trough is similar to that in the southern Arckaringa troughs.

Vitrinite reflectance data from three wells in the Boorthanna Trough suggests that the Permian section has been subjected to pre-Jurassic uplift and erosion in the order of 0.5–1 km. Minor late stage structuring occurred in the Late Miocene.

Boorthanna Formation (Sequence 1)

Boorthanna Formation Total Organic Carbon (TOC) content is generally <0.5%. However two samples from the Boorthanna Formation in Linc Energy's 2011 Arck 1 well returned TOC values of 5.7% and 6.2%.

Stuart Range Formation (Sequence 2)

Organic rich shales of the Stuart Range Formation have high TOC and HI (hydrogen index) values indicating oil-prone source potential. In Arkeeta 1, all twelve samples from a 200m interval recorded TOC values >2% (up to 7.4%) and HI values >400 (up to 654). The Tmax vs HI cross plot shows that these organic rich shales are Type II source rocks at the threshold of oil generation (Linc Energy, 2012). The Arck 1 stratigraphic well also intersected around 70m of organic rich shale (Type I/II kerogen) with very high potential oil yields. Analyses indicate that these shales are also at the onset of oil generation ranging from 0.41 to 0.66% Ro (vitrinite reflectance). The target maturity window for shale oil plays in North America is 0.6 to 1.4% Ro.

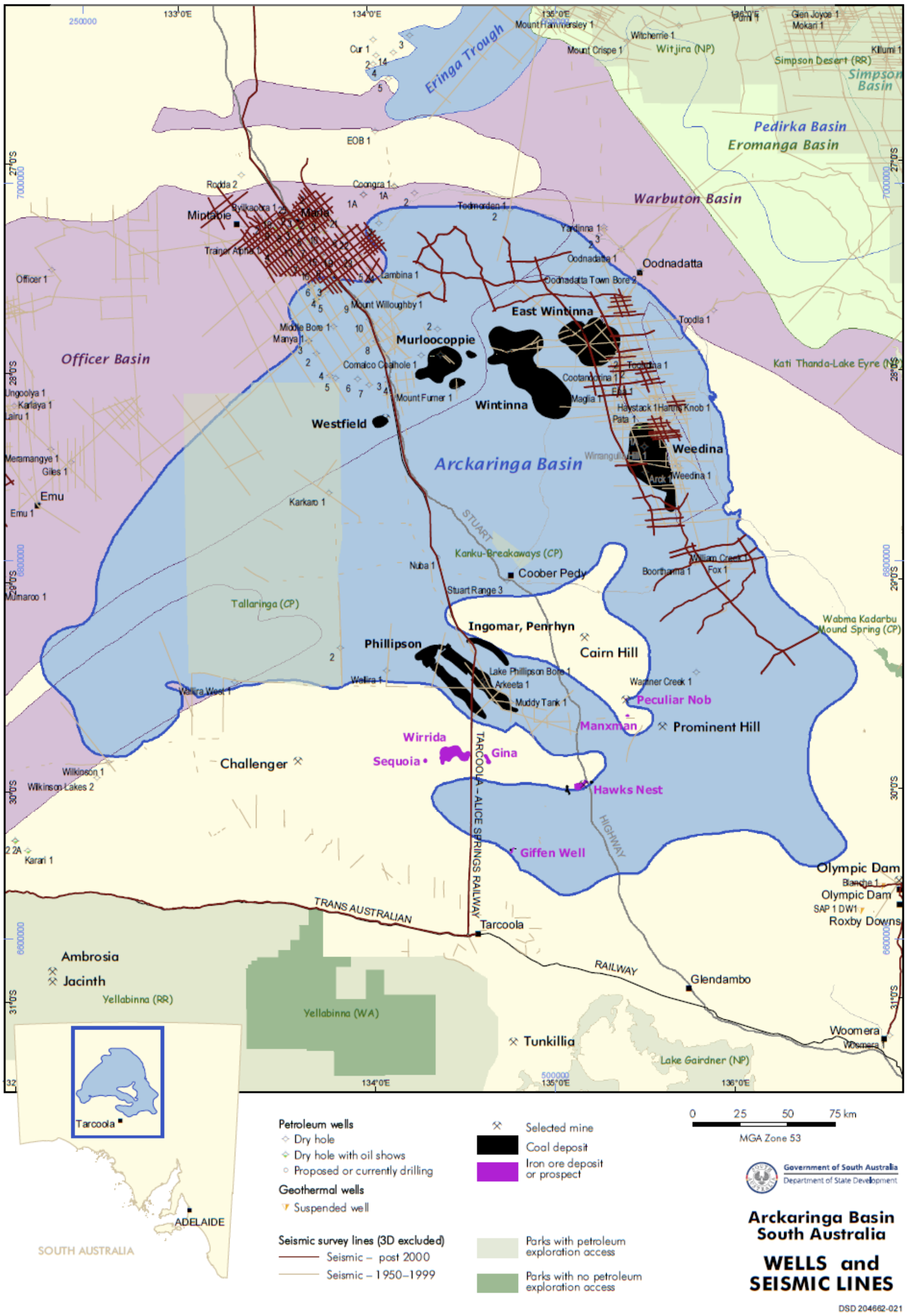

Figure 1: Map of the Arckaringa Basin showing all wells, mine sites and seismic lines

4.0 Existing environment

4.1 Project area

The target area for fracture stimulation in the Arckaringa Basin is predominately in the Boorthanna Trough, shown as the dark blue area in Figure 2 below. The Boorthanna Trough is approximately 100 km east of Coober Pedy. The target Permian formations in this area are the Stuart Range shale between 650m and 1,200m depth, and the underlying Boorthanna Formation between 1,000m and 1,800m depth.

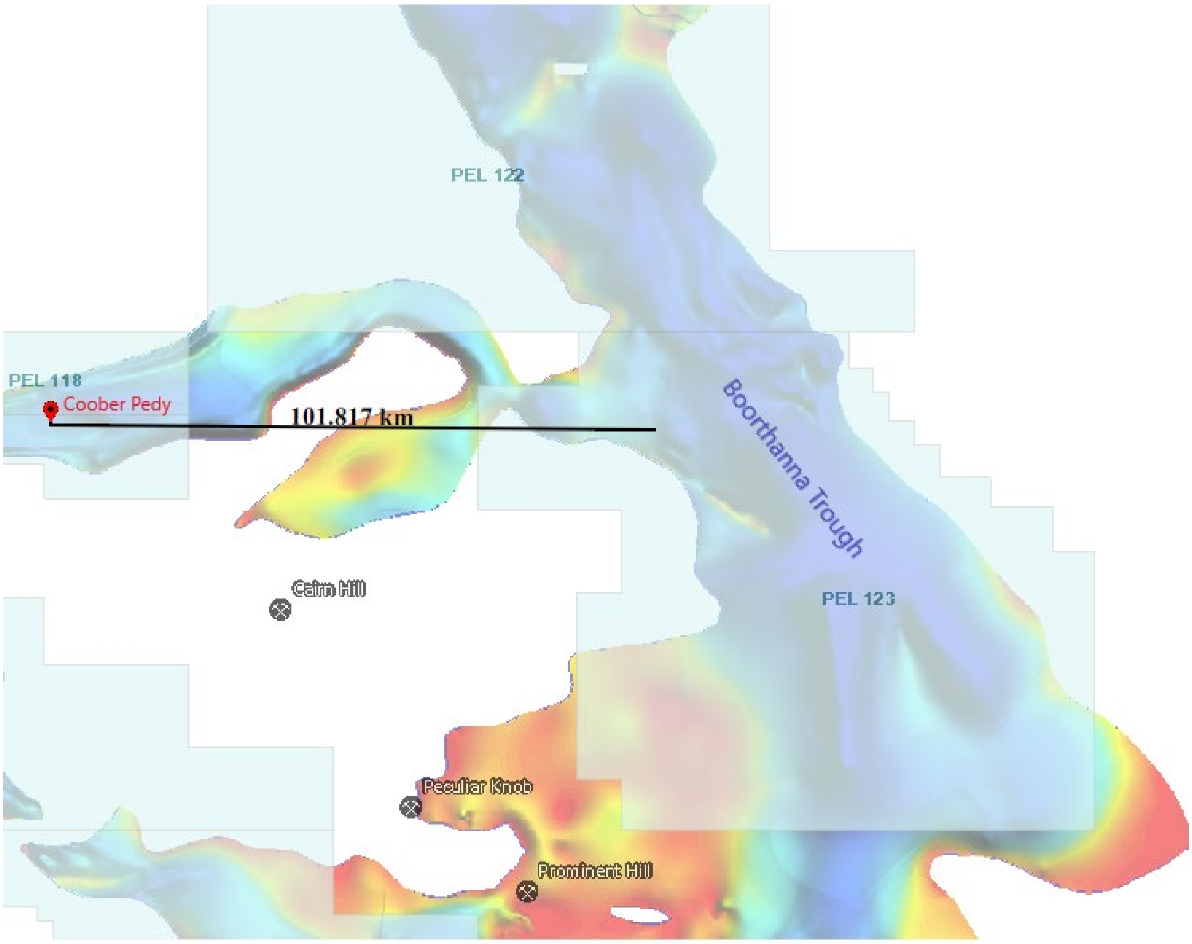

Figure 2: Isopach map of the Boorthanna Formation

4.2 Regional water bores

In the region around PEL 122 and 123, groundwater from the Great Artesian Basin (GAB) is extracted for stock and domestic use. Water bores drilled for this purpose are on average less than 100m deep.

Water production bores that supply the Coober Pedy Township are located approximately 13 km west of the PEL 122 boundary and approximately 80-100 km away from the Boorthanna Trough.

Major mine sites at Prominent Hill, Peculiar Knob and Cairn Hill have also drilled groundwater production and monitoring bores to support mining operations. These bores extract water from the Boorthanna Formation, outside of the Boorthanna Trough to the south of PEL 123. The following Figure 3 map shows all water bores in the region.

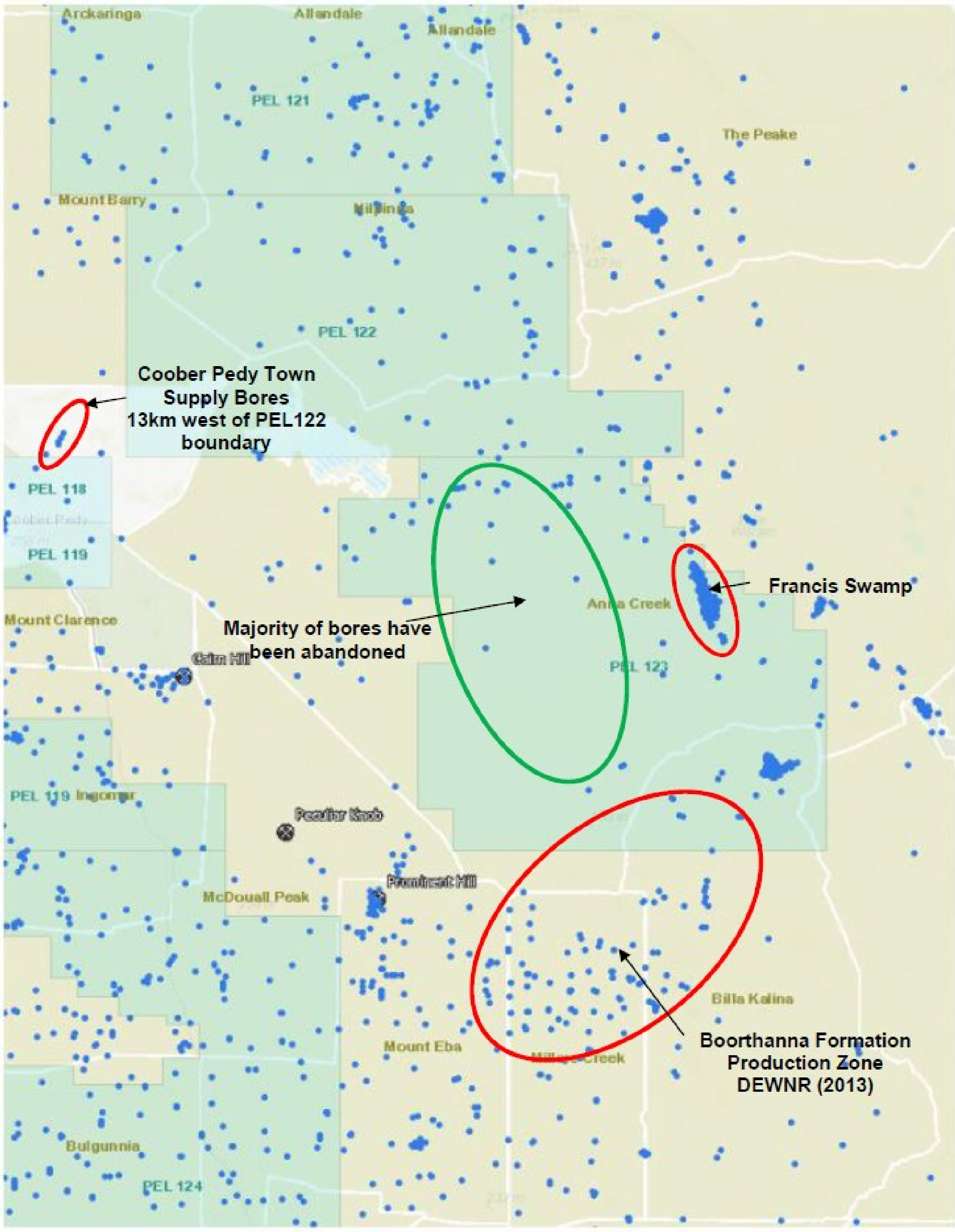

Figure 3: Water bores in the region around PEL 122 and PEL 123 - from the SAPEX EIR for fracture stimulation activities in the Arckaringa Basin

4.3 GAB springs

The GAB springs in the region are widely identified as having very high biological and cultural significance. GAB springs are present on the eastern side of PEL 123, and northern and southern boundaries of PEL 122 as shown in both Figure 4 and Figure 5. The source aquifers for the springs are the GAB and Boorthanna formation outside of the Boorthanna Trough.

The Far North Water Allocation Plan under the *Natural Resources Management Act 2004* addresses activity restrictions (exclusion zones) in proximity to springs or clusters.

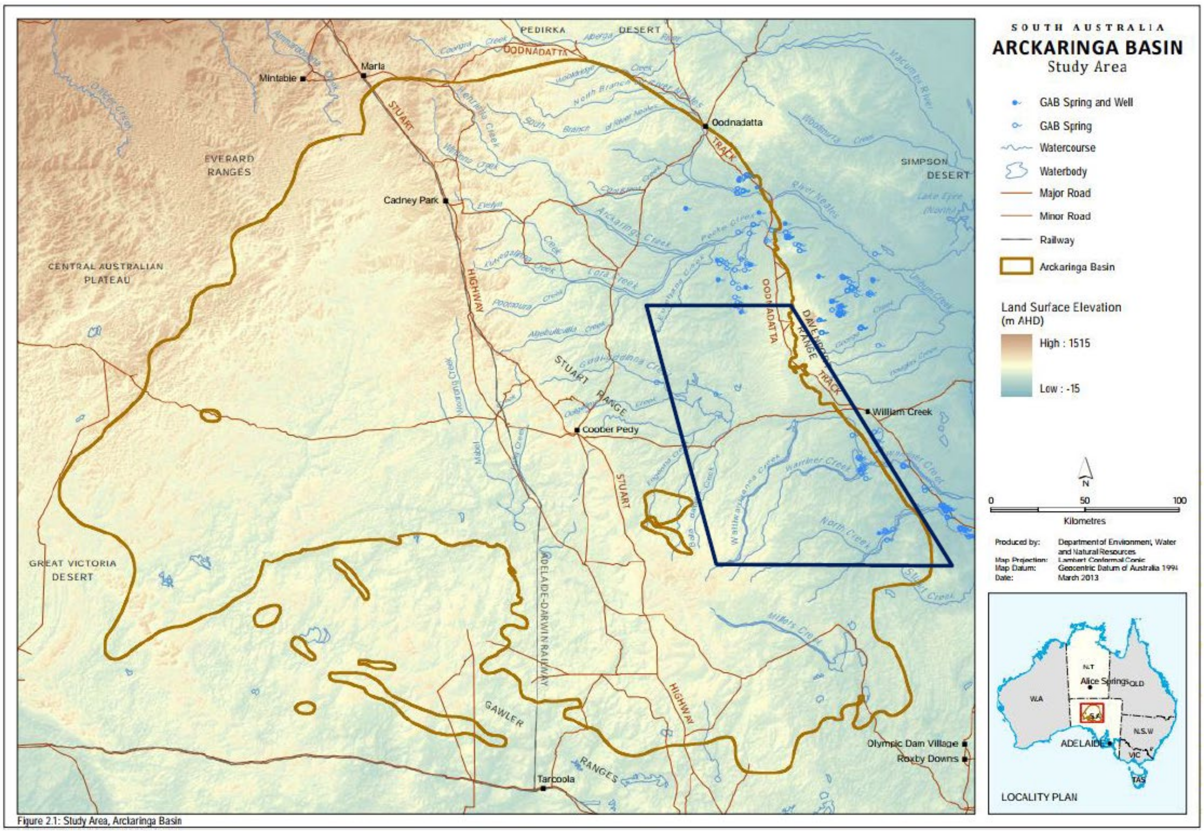

Figure 4: Arckaringa Basin GAB Spring locations (approximate location of PEL 122 and 123 shown by dark blue polygon) – from DEWNR, 2013

The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin or GAB springs are listed as a threatened ecological community under the *Environment Protection and Biodiversity Conservation Act 1999*. The assessments of any impacts to threatened species and other matters of national environmental significance (MNES) under the EPBC and subsequent referral to the Australian Government Minister for the Environment is further discussed in Section 7.0.

Given the sensitivity and significance of the GAB Springs and the community of native species dependent on natural discharge of GAB, SAPEX through consultation with DEM-ERD and DEW have identified a 5 km trigger zone around GAB springs as shown in Figure 5.

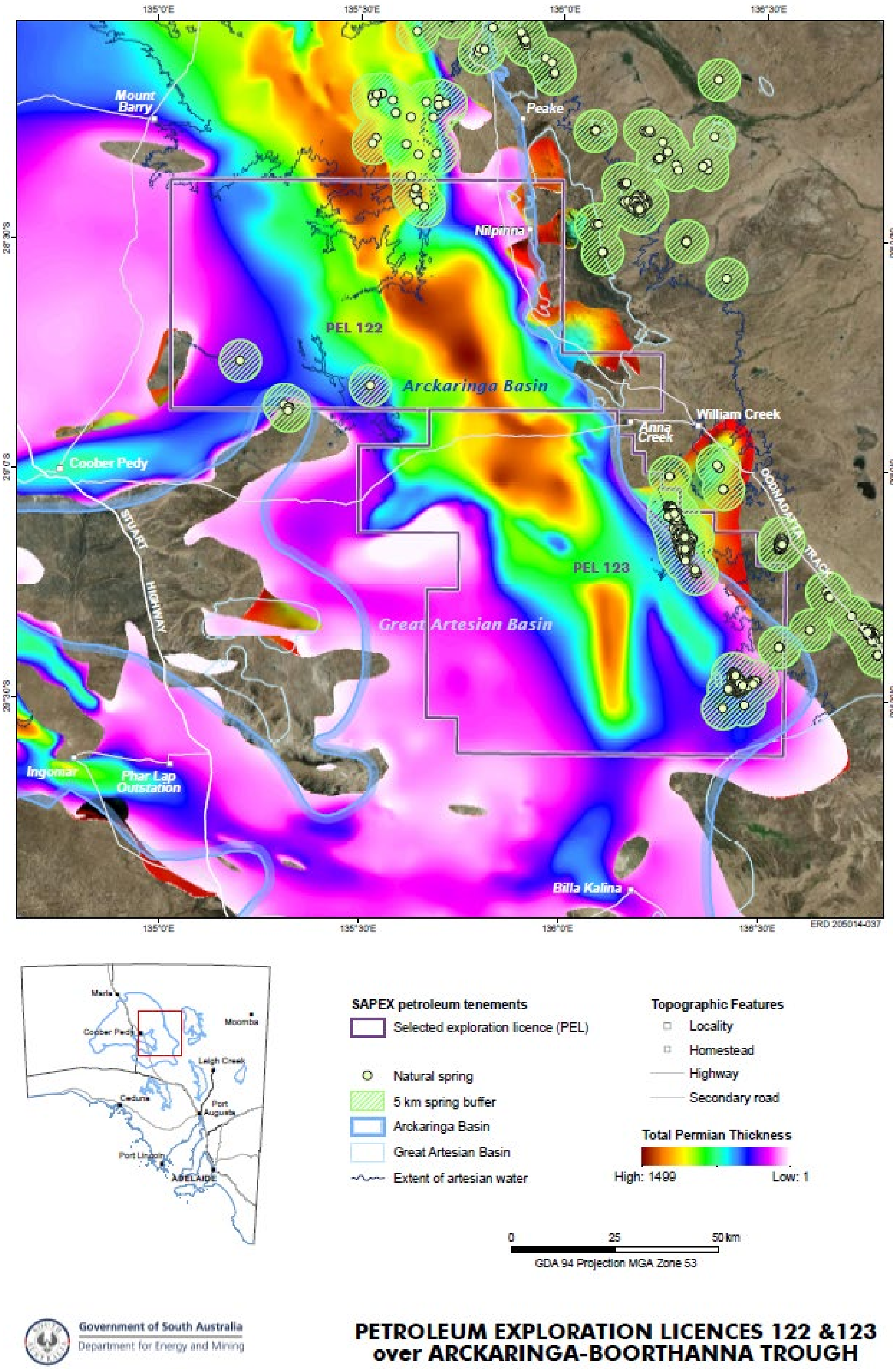

Figure 5: Petroleum Licences 122 & 123 over Arckaringa-Boorthanna Trough with 5 km trigger zone around GAB Springs – from DEM-ERD and DEW 2018

This trigger zone was defined on the basis of the South Australian Arid Lands (SAAL) Natural Resources Management Bard (NRM) Water Allocation Plan (WAP) for the Far North Prescribed Wells Area[7]. The WAP under Section 6 water allocation criteria defines that water shall not be allocated for any new well established within a 5 km radius of any GAB springs (the exclusion zone).

Any proposed fracture stimulation within the 5 km trigger zones will be subject to further assessment and consultation with both State (DEM-ERD and DEW) and Federal Government Agencies (potential impacts to MNES under the EPBC Act).

4.4 Connectivity with the Great Artesian Basin

Based on research from DEWNR 2015/14 and Priestley et al. 2017, there is no evidence for connectivity via enhanced inter-aquifer leakage (e.g. conductive faults) between the GAB and deeper target formations for fracture stimulation in the Boorthanna Trough.

Thickness of the Stuart Range Shale aquitard is sourced from Priestley et al., 2017 (Figure 6). SAPEX's target formations for fracture stimulation are where the Stuart Range shale is thickest in the Boorthanna Trough (partially shown in light pink to the North of the map below).

[7] SAAL NRM Water Allocation Plan for the Far North Prescribed Wells Area

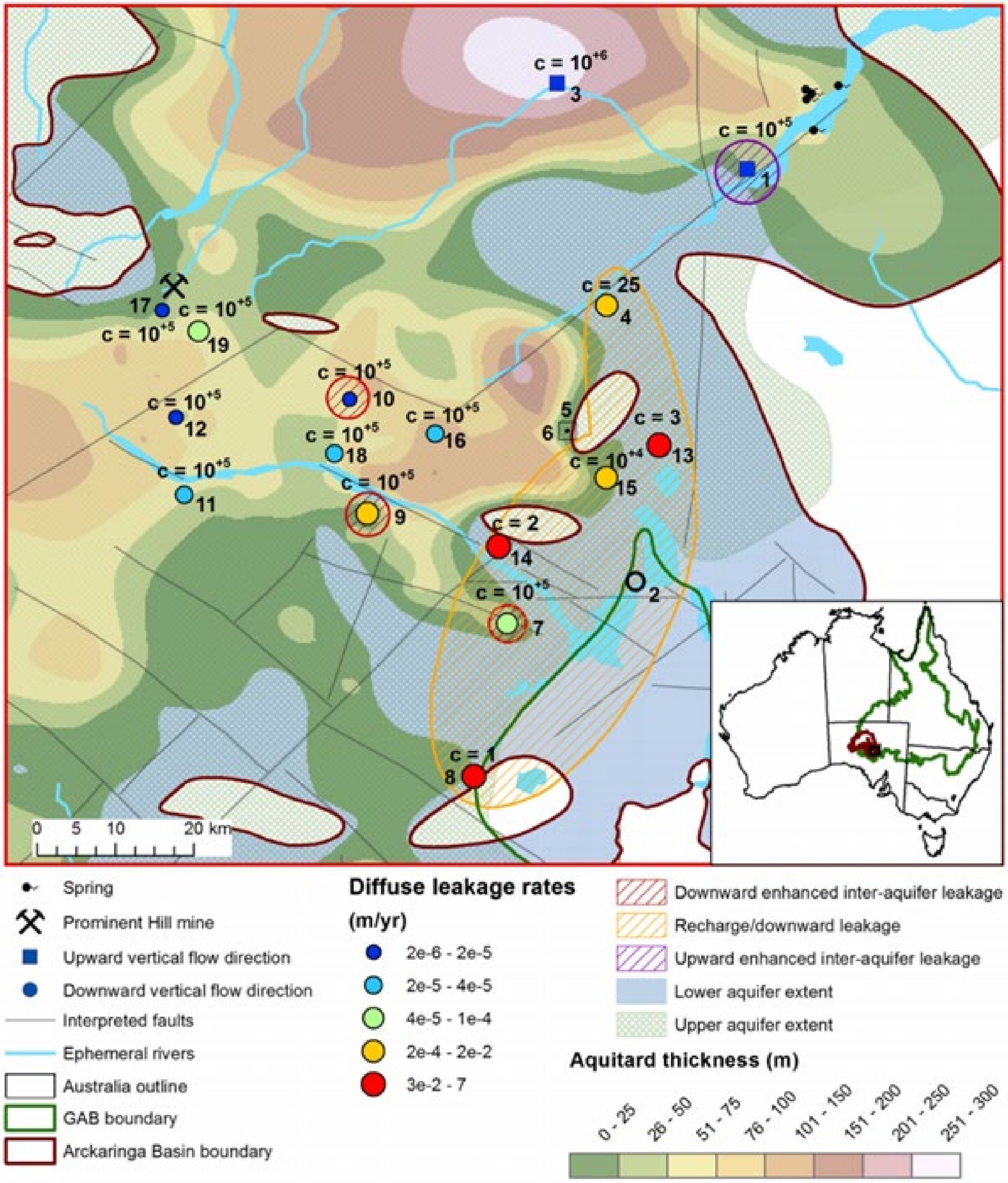

Figure 6: Thickness of the aquitard (Stuart Range shale), interpreted faults and location of wells with hydraulic flow data. Hydraulic resistance (c) is labelled in years above the wells and is highest where the aquitard is present – from Priestley et al., 2017

The Stuart Range shale is of very low permeability and has a diffuse leakage rate less than 1 mm/year in the Boorthanna Trough where the shale is thick and continuous.

There is evidence of connectivity via enhanced inter-aquifer leakage between the GAB and deeper target formations where the Stuart Range shale is thin or not present, (e.g. the Billa Kalina Sub-Basin). However, this occurs outside of the Boorthanna Trough and thus is not the target area for fracture stimulation.

Seismic interpretation to date (DEWNR, 2013) indicates the Eromanga Basin sediment deposition did not re-activate deep Permian faults, the Eromanga Basin generally drapes such features. There are no identified faults connecting the shallow GAB to deep Permian formations in the targeted areas of the Boorthanna Trough.

An example of a seismic slice through the central Boorthanna Trough is provided in Figure 7 below.

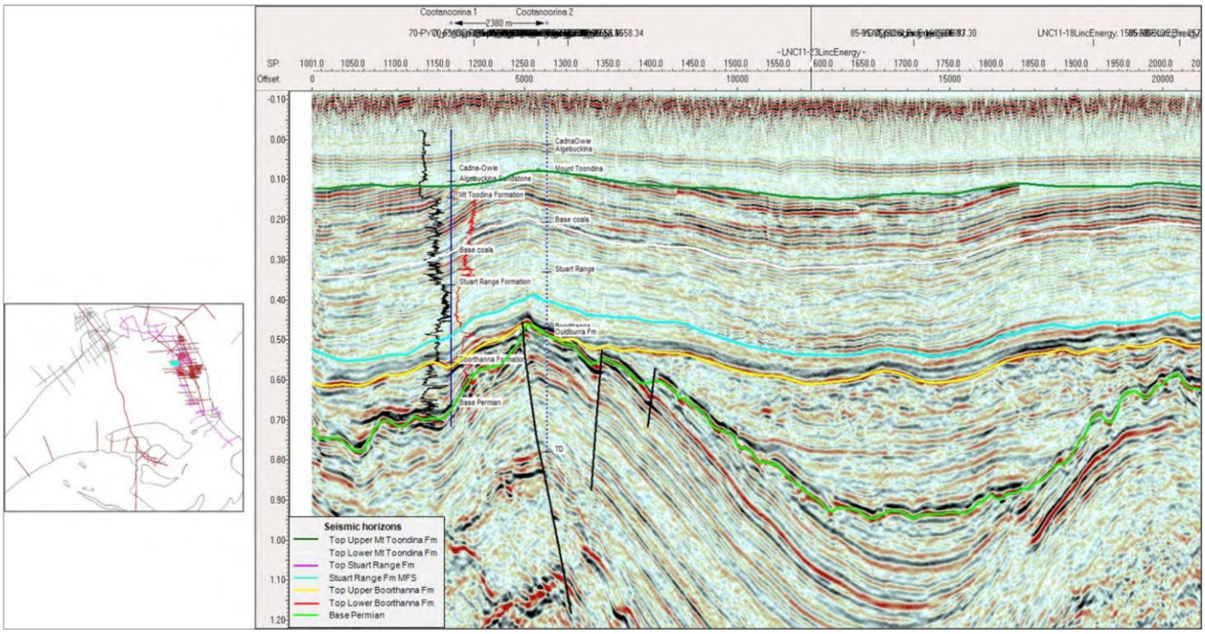

Figure 7: Seismic interpretation in the central Boorthanna Trough – from DEWNR, 2013

Stage 3 of the approvals process requires specific data (e.g. geophysical and well data) for a chosen location to be gathered and submitted, which will further characterise the local hydrogeology.

4.5 Connectivity between sub-basins

The Boorthanna Formation is present closer to surface outside of the Boorthanna Trough, and is used as water supply for mining sites and pastoralists. This is evident in Figure 3 above where water bores are located to the south in the Billa Kalina Sub-Basin.

Geological separation is apparent between the Billa Kalina Sub-Basin and the Boorthanna Trough as illustrated in the C-C' cross-section in Figure 8, being bound to the east and north by the Billa Kalina Fault and the Boorthanna Fault respectively (DEWNR, 2013). The geological separation is also highlighted by the displacement shown in the Figure 9 cross-section. Furthermore, the Boorthanna Formation aquifer within the Billa Kalina Sub-Basin occurs in isolated semi discontinuous pods with limited lateral aquifer extent, evidenced by large observed drawdown pressures from producing bores (DEWNR, 2013).

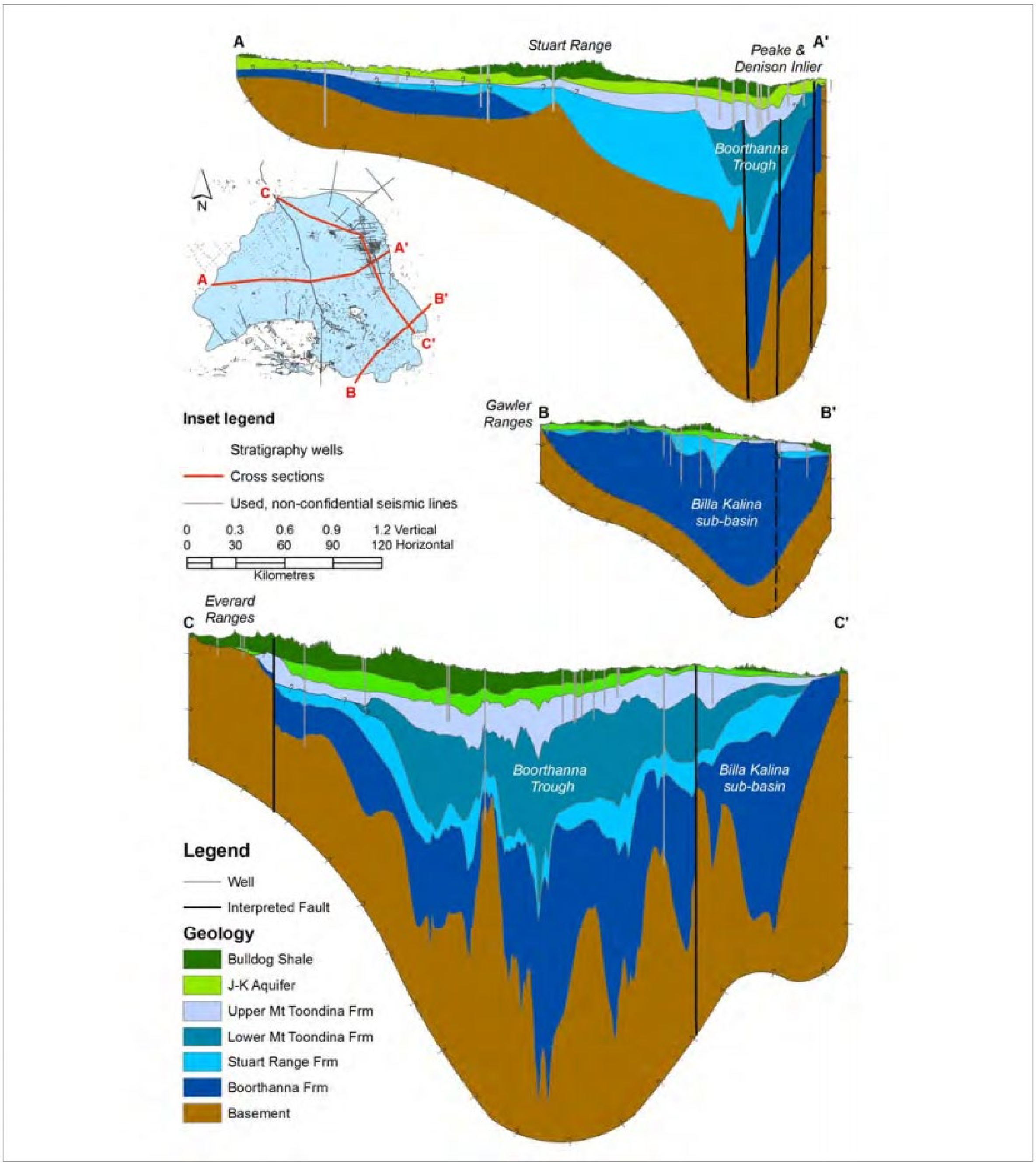

Figure 8: Interpreted cross-sections of the Arckaringa Basin based on surfaces from seismic and well data – from DEWNR, 2013

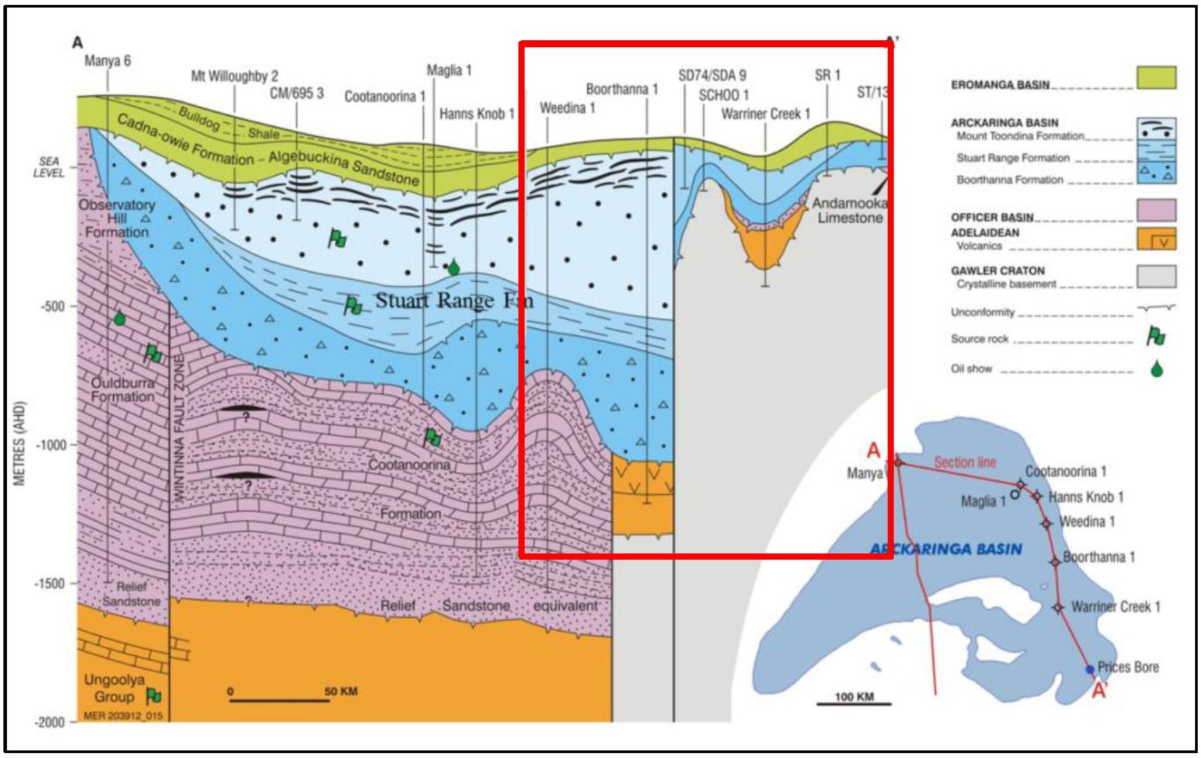

Figure 9: Interpreted cross-section through the Boorthanna Trough – from Baker Hughes

4.6 Stress regime

The in situ stress regime in a formation will determine the orientation of an induced fracture (either vertical or horizontal). Fractures propagate parallel to the maximum principal stress and open against the minimum principal stress.

As strike slip or normal stress regimes have the minimum principal stress in a horizontal direction, induced fractures are oriented vertically. In a reverse stress regime the minimum principal stress is in the vertical direction; hence, induced fractures are oriented horizontally. Figure 10 portrays the stress magnitudes and fracture orientation for both a strike slip and reverse stress regime.

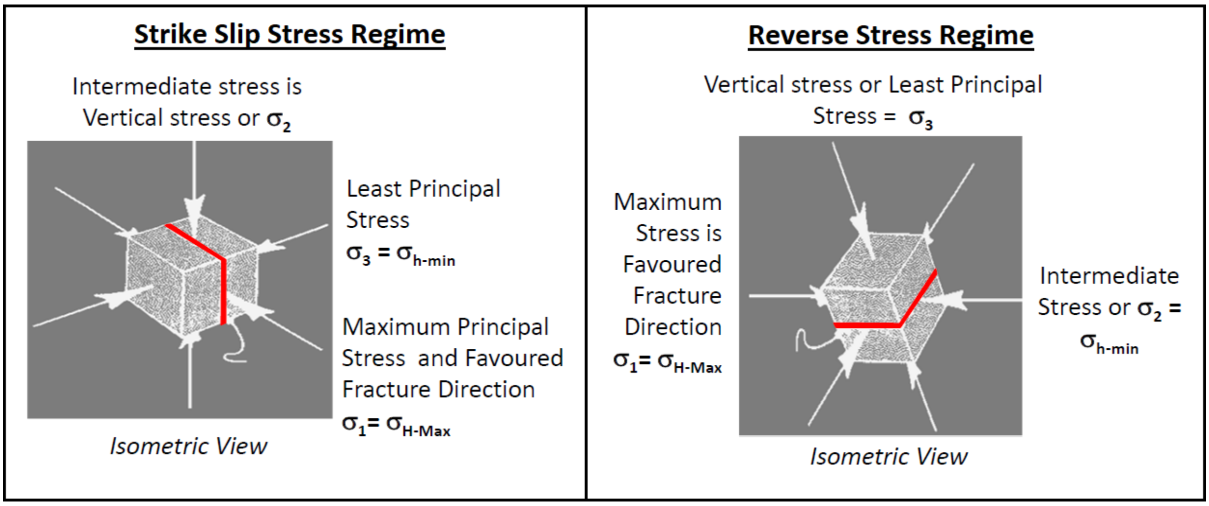

Figure 10: Fracture orientation associated with strike slip and reverse stress regimes – From Johnson, 2018

Geomechanical studies using borehole data (caliper and image logs) shown in Figure 11 from an existing exploration well in the Arckaringa Basin shows that the upper Mount Toondina Formation is in a reverse stress regime changing to a strike-slip stress regime at greater depths (in the lower Mount Toondina Formation at approximately 300m depth). Fractures below the lower Mount Toondina Formation are likely to be of vertical orientation and propagate horizontally in the maximum stress direction.

Fracture growth is limited where there is a change in stress regime from vertical orientation of induced fractures to horizontal orientation of induced fractures, limiting fracture stimulation height growth.

In addition, the variation in elastic properties between lithologies (e.g. sandstone, siltstones, shale, mudstone), evident in Figure 11 (see Poisson's ratio in red) acts as stress barriers between targeted zones and overlying aquifers, and will further impede height growth of induced fractures.

Before fracture stimulation occurs, in order to predict growth of induced fractures a geomechanical model will be developed based on the specific geomechanical data obtained from a well during drilling operations. This geomechanical model will confirm the stress regime present and the geological/geomechanical properties of various formations that will affect induced fracture growth.

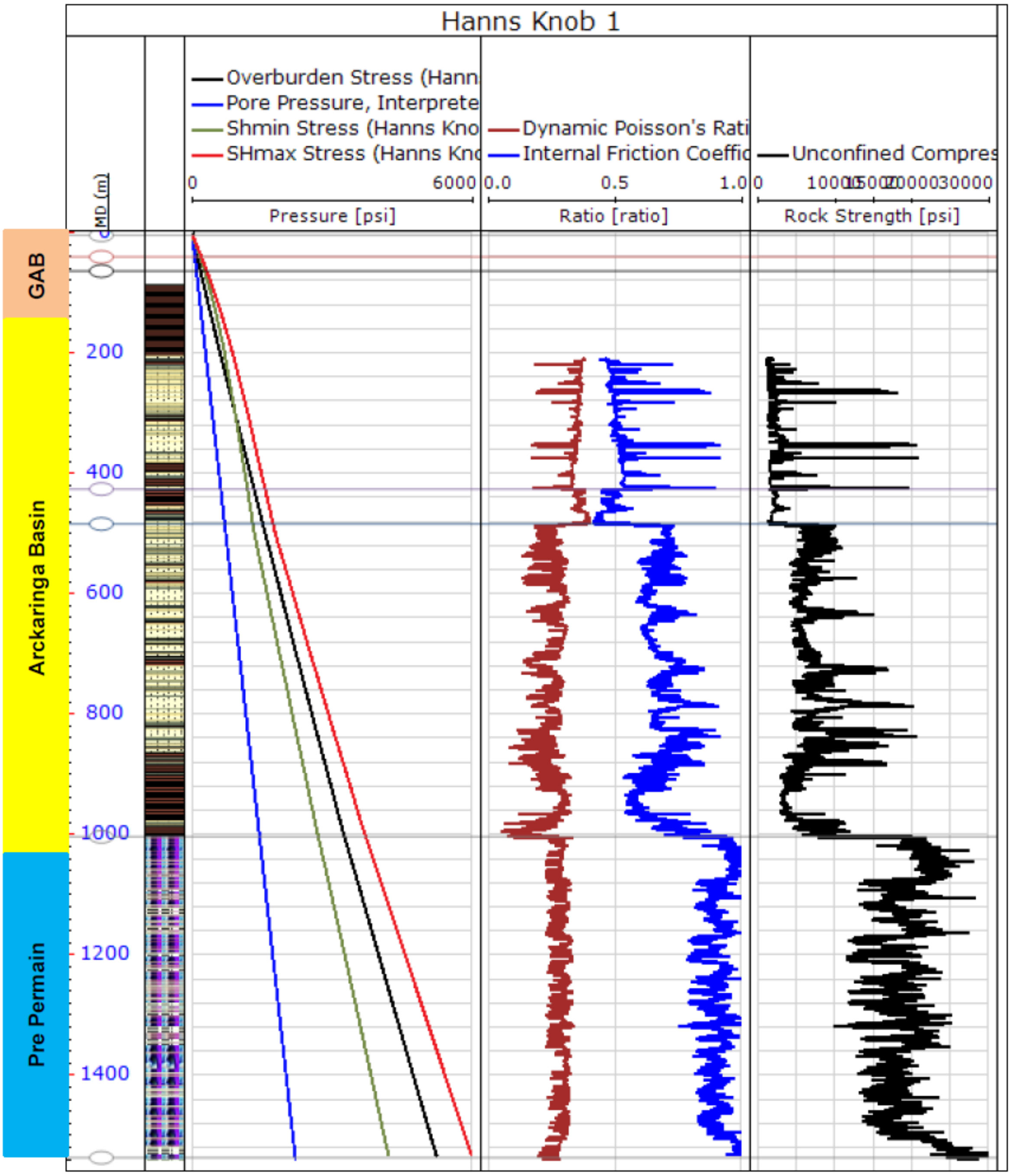

Figure 11: Geomechanical data from Hanns Knob 1 – from the SAPEX EIR for fracture stimulation activities in the Arckaringa Basin

5.0 SAPEX Limited's fracture stimulation proposal

5.1 Well design and construction

Well design and drilling operations are covered in the existing approved EIR and SEO for exploration drilling activities in the Arckaringa Basin[8]. Under Stage 3 of the activity approvals process, before drilling approval can be considered, a drilling program must be submitted that demonstrates the well will be designed for the expected downhole conditions in accordance with recognised industry standards. Furthermore, a fitness for purpose assessment of all contractors and management systems to be used during operations must also be submitted in accordance with the PGE Act.

In regards to well integrity, it is known throughout the history of well construction and operations that there have been documented failures of casing and cement behind casing. However, in all documented cases the failures have mainly been attributed to historic well construction practices that have led to poor coverage of cement (preventable mishaps) within the annulus or annuli between various casing strings. It has widely been documented (such as through Davies et al., 2014) that where industry best practice is applied, worldwide industry experience in both conventional and unconventional petroleum resources suggests that well integrity failures are low for both active and abandoned wells.

Well integrity monitoring systems are required in South Australia for all active wells in order to identify any adverse changes downhole that must be remediated. Ultimately, all wells and facilities are decommissioned and rehabilitated upon licence relinquishment, such that the land is brought back to its original state to the satisfaction of state regulatory agencies and the land owner, as agreed under the relevant SEO.

Decommissioned wells are plugged with cement and pressure tested to ensure no cross-flow occurs between formations or to the surface. Studies on the length of time cement lasts behind casing have shown that it can take tens to hundreds of thousands of years to degrade 25mm of cement (Duguid, A. 2009), depending on the local downhole environment and cement design.

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[8] Exploration Drilling Activities in the Arckaringa Basin – Environmental Impact Report, 2013
https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/PGER00011EIR%20DRILLING%20OPERATIONS.pdf

Exploration Drilling Activities in the Arckaringa Basin – Statement of Environmental Objectives, 2013
https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/PGER00012SEO%20DRILLING%20OPERATIONS.pdf

An indicative vertical exploration well design is shown in Figure 12 along with potential formation depths.

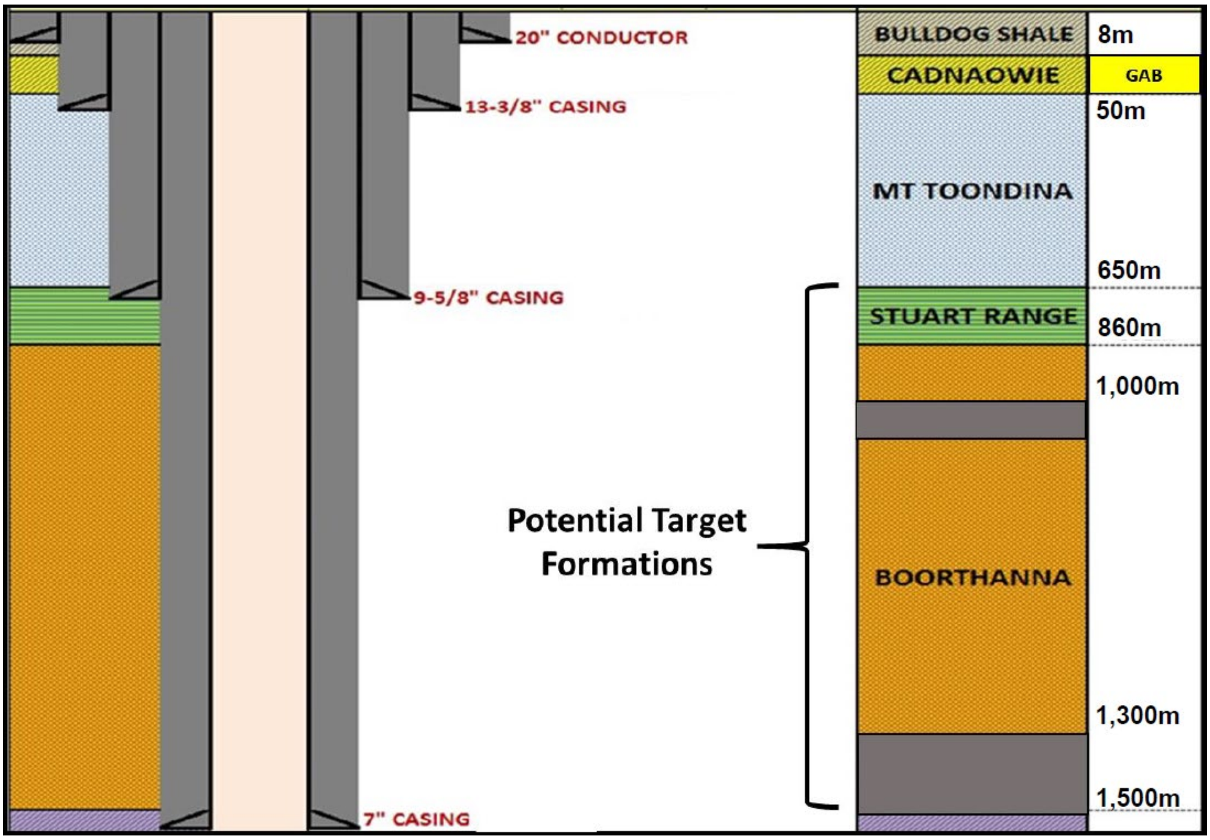

Figure 12: Indicative vertical well design and formation depths – from the SAPEX EIR for fracture stimulation activities in the Arckaringa Basin

Figure 12 shows the Stuart Range shale at approximately the shallowest depth where it may be a potential target (targeted depths are up to 1,200m for this formation).

5.2 Fracture stimulation design, modelling and implementation

Under Stage 3 of the activity approvals process, before approval can be considered for fracture stimulation operations, a detailed technical program must be submitted in accordance with recognised industry standards that demonstrate all operations can demonstrably achieve the objectives of an approved SEO, which includes avoiding contamination of aquifers and surface water.

The fracture stimulation program must use data collected during seismic, drilling and logging to determine fracture treatment design factors such as the number of fracture stages, pumping pressure and fluid composition. Prior to operations, a fracture geomechanical model is constructed to predict the growth of fractures. During fracture operations, pressures and rates are monitored in real time to keep within the predicted limits of the model and ensure the treatment proceeds as designed. An example of a pre-frac model is shown in Figure 13.

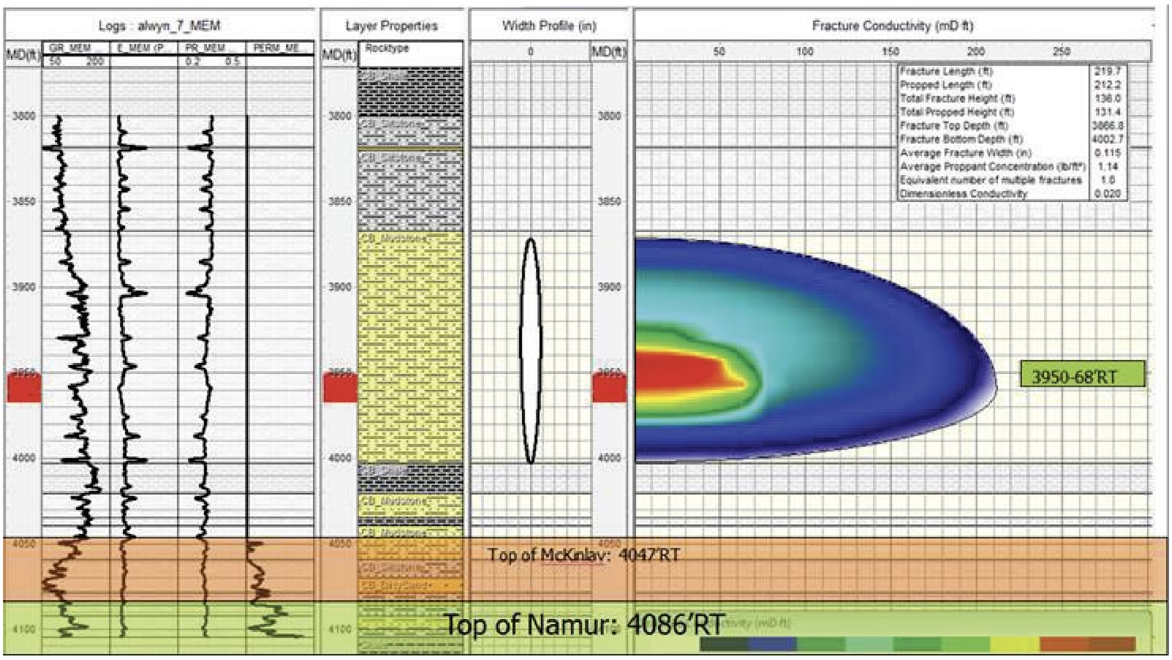

Figure 13: Pre-frac fracture stimulation model for a well located in the SA Cooper Basin – from the Santos EIR for Cooper Basin Drilling, Completions and Well Operations

A graphical representation of the indicative depths for the SAPEX fracture stimulation project in the Arckaringa Basin are shown in Figure 14.

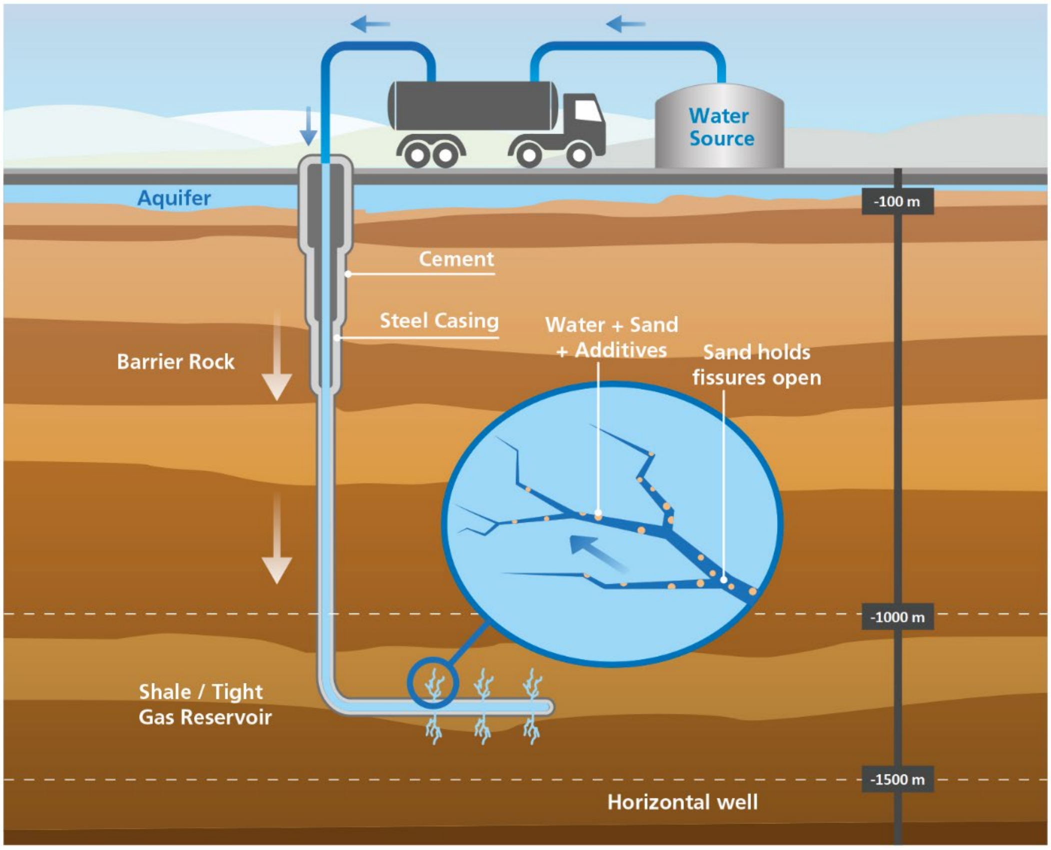

Figure 14: Indicative fracture stimulation depths – from DEM-ERD

5.3 Fractures stimulation fluid composition and surface management

Additives used in fracture stimulation are at very low concentration by volume in the hydraulic fracturing water (on average 0.1 to 0.5%). The types and purposes of additives expected to be used in the fracture stimulation of shale targets in the Arckaringa Basin are summarised in the EIR, including links to Safety Data Sheets (SDSs), which contain detailed information about each additive.

As has been demonstrated in the South Australian Cooper Basin and around the world, with recognised good industry practice, fracture stimulation fluids will be contained to the target formation and wellbore downhole; and within pipelines, tanks and lined ponds at the surface before being disposed of appropriately.

Typical water use during fracture stimulation operations in shale is approximately 1 mega-litre (ML) per stage. Thus, for a vertical well with 5 fracture stimulation stages approximately 5 ML of water is required for fracture stimulation. Horizontal wells usually are designed to have a greater amount of fracture stimulation stages, up to 30 or more in some cases. Horizontal wells fracture stimulated in shale in the South Australian Cooper Basin have been in the order of 10 fracture stimulation stages per well.

Once a well has been fracture stimulated, the well is flowed back and approximately 40% to 50% of the injected fluid can be recovered and re-used in ongoing operations. Otherwise, flow back water is left to evaporate and pond liners with any waste are removed and disposed of at an EPA licenced waste disposal facility.

Water use for fracture stimulation will be in accordance with the Far North Prescribed Wells Area Water Allocation Plan.

5.4 Fracture growth and monitoring

As described in Section 4.6, variations in rock stress and elastic properties within the lower Mt Toondina Formation overlying the Stuart Range shale in the Boorthanna Trough will impede vertical height growth and keep fractures within the targeted formation.

Furthermore, the energy imparted into the fracture stimulation treatment via pumping pressure will directly influence the extent of the induced fracture network.

The expected fracture stimulation height is less than 200m based on analogue shale in the United States (as shown in Figure 15) and from experience in the Cooper and Eromanga basins at similar depths.

The below Figure 15 is an example of microseismic monitoring, which is the measurement of the movement (microseisms) of rocks induced due to fracture stimulation using sensitive listening devices called geophones placed at the surface or down nearby wells.

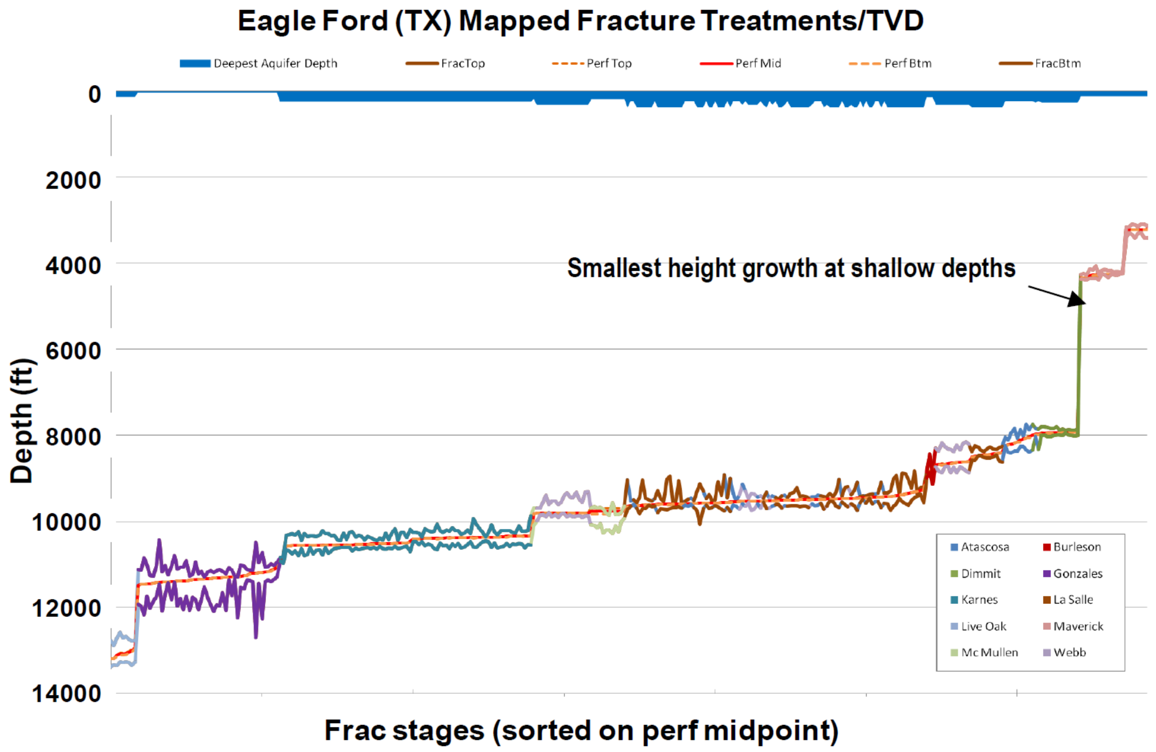

Figure 15: Microseismic monitoring for fracture stimulation treatments in the Eagle Ford Shale – from Fisher and Warpinski, 2011

From Figure 15 above, fracture stimulation heights of approximately 100m are evident at 1,000m depth in the Eagle Ford shale, which is close to the depth of the shale targets in the Arckaringa Basin. Fracture stimulation heights of 556m have been observed in the Eagle Ford shale, but only at depths around 3,300m. This is expected, as fracture stimulation at this depth requires approximately 3-4 times the energy (pumping pressure) relative to shallow fracture stimulation at 1,000m depth, in order to generate a fracture network.

Deep fracture stimulation in general is in rock where the vertical stress (overburden) is the maximum or intermediate principal stress (i.e. normal or strike-slip regime), leading to vertical orientation of fractures. At shallower depths the vertical stress is more likely to be the minimal principal stress (i.e. reverse regime), leading to horizontal orientation of fractures which limit height growth.

Simply put, as wells get shallower, and the overburden stress lessens, mapped fractures are typically observed exhibiting increasingly larger horizontal components (Fisher and Warpinski, 2011). Figure 16 below illustrates how mapped fractures have recorded a larger horizontal component at shallower depths, whereby the blue curve represents the average of fracture orientation.

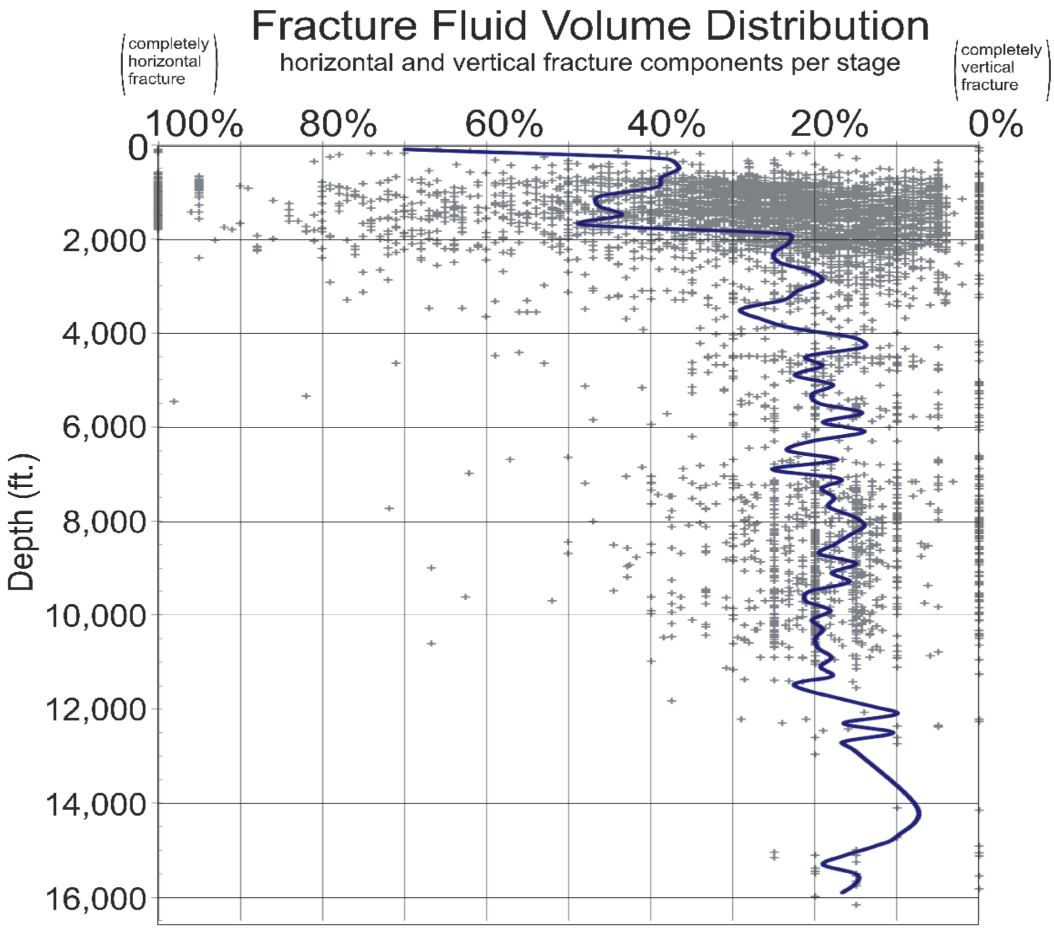

Figure 16: Horizontal and vertical component of fracture orientation vs. depth from tiltmeter data – from Fisher and Warpinski, 2011

Warpinski, 2009 has demonstrated that microseismicity accurately monitors fracture stimulation extent including when a fault is intersected by a fracture (larger moment magnitudes are evident than what is found in the target reservoir zone as identified in Figure 17). The reactivation of a pre-existing fault will depend on whether it is critically stressed and suitably oriented relative to the in-situ stress. Geomechanical modelling prior to fracture stimulation is able to model the likelihood of fault activation.

The below figure also provides an indication of the distance which microseismic sensors are able to pick up microseisms from an induced fracture. Based on this data from the United States, low magnitude microseisms more difficult to see as viewing distance increases.

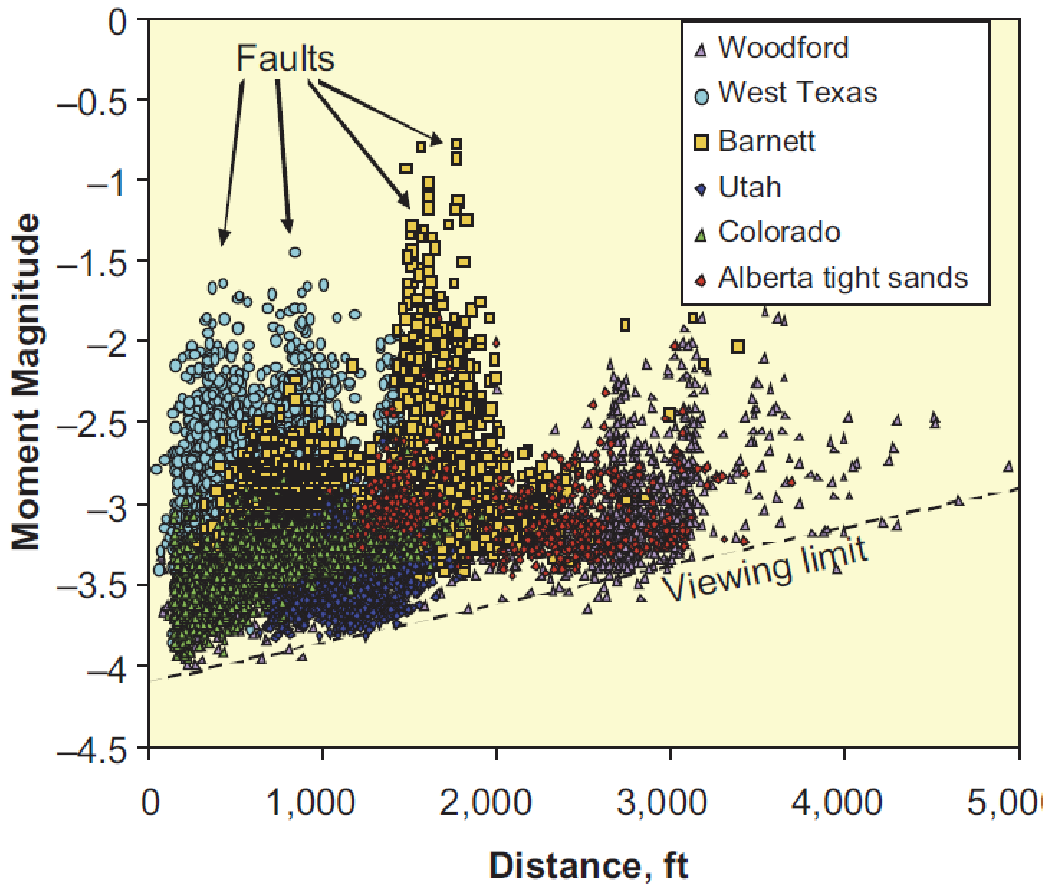

Figure 17: Moment magnitudes vs. microseismic sensor viewing distance from microseismic in the United States – from Warpinski, 2009

Microseismic validation tests have been undertaken and are described in Warpinski, 1998. The most extensive validation test being the M-Site test in Colorado, funded by the US Department of Energy. Several approaches were taken to verify the microseismic data at this test site, including tiltmeter installation and intersection wells drilled both before and after the fracture treatment. All parameters – length, height, and azimuth – exhibited close agreement between the microseismic results and the verification technologies.

Newer techniques such as Tomographic Fracture Imaging (TFI) can detect more subtle activation of natural fractures, and has the potential to give a more accurate representation of the fracture network. Maximum induced fracture stimulation heights up to 1 km have been published for both microseismic monitoring and TFI, however these fractures occur in deep wells at high pressures.

Furthermore, lateral migration of any significant quantities of injected fluids away from the fracture treatment zone in the Boorthanna Trough is highly unlikely, as once the fracture stimulation treatment has been completed, the well is flowed back, creating a pressure differential and a flow path from the end of the fracture treatment to the well. This pressure differential increases into the production phase of the well as production of reservoir fluids continues. Consequently, injected fluids would flow back to the well. Therefore, it is unlikely that a pressure gradient to drive lateral migration would exist.

5.5 Fracture stimulation operational experience in South Australia

Operational experience in the SA Cooper and Eromanga basins include over 900 fracture stimulated wells (including 120 wells fracture stimulated in the oil zones of the Great Artesian Basin), without any evidence of groundwater contamination due to fracture propagation. Figure 18 shows the number of petroleum wells fracture stimulated each year in South Australia since 1969.

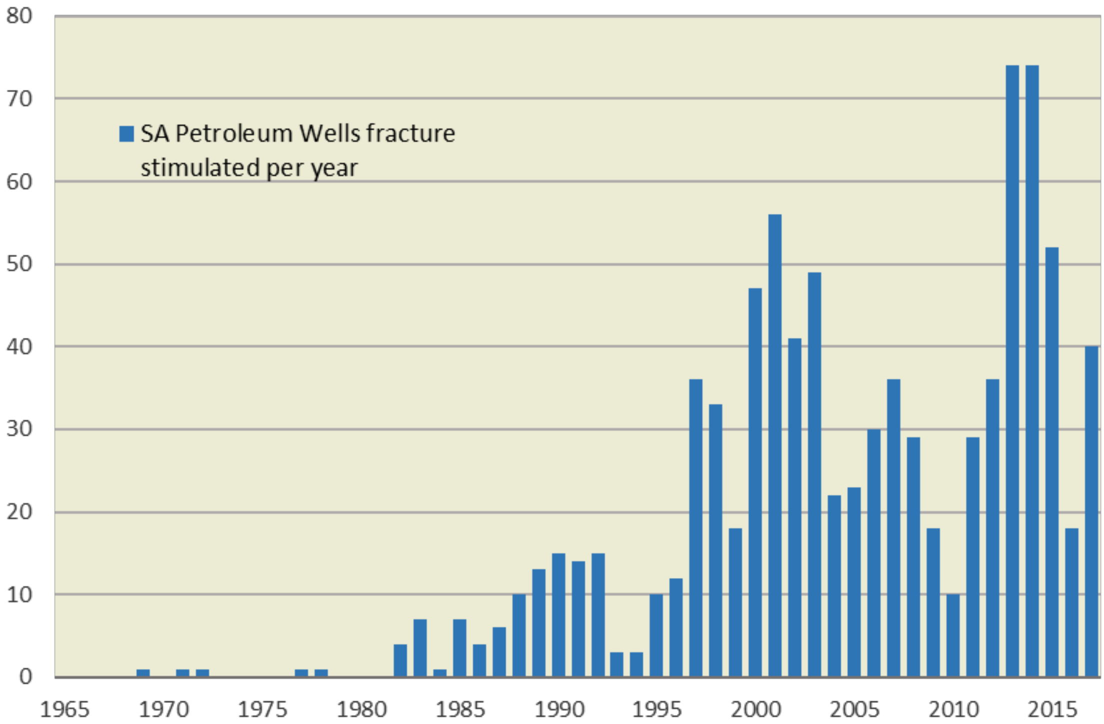

Figure 18: Number of South Australian petroleum wells fracture stimulated per year – from DEM-ERD

Furthermore, microseismic monitoring has taken place in the South Australian Cooper Basin for fracture stimulation in unconventional reservoirs including shale. Aggregated height data from the observed fracture network for 34 of these fracture stimulation stages are presented as follows in Figure 19.

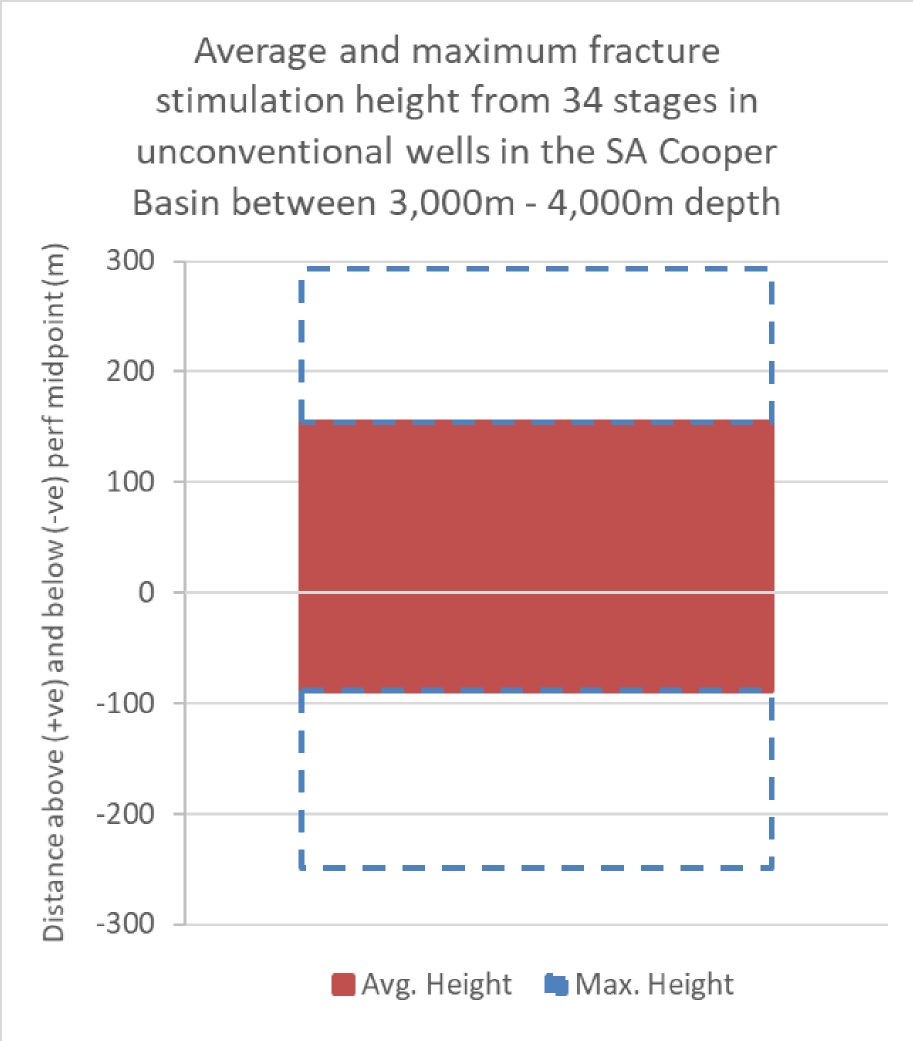

Figure 19: Average and maximum fracture stimulation height observed from microseismic monitoring of fracture stimulation in unconventional reservoirs in the South Australian Cooper Basin – from DEM-ERD

Based on the above data, average vertical fracture stimulation height observed was 155m and maximum height observed was 293m. These fracture stimulation treatments occurred in both vertical and horizontal wells at depths between 3,000m to 4,000m, with high injection pressures of approximately 14,000 psi. For a shale at 1,000m depth (e.g. the Stuart Range shale) injection pressures would be expected in the order of 3,500 to 4,000 psi.

All values for height in the above data were taken as the maximum height observed in each fracture stimulation stage (i.e. 100% cumulative moment). Thus, the information provided in Figure 19 is considered to be the upper limit of the true fracture stimulation heights.

5.6 Induced seismicity

There is a thorough understanding of the microseismic activity associated with fracture stimulation in the petroleum industry.

The results from one study by Warpinski et al., 2012, assessed over one thousand fracture treatments in United States shale plays, and showed that the largest microseismic event recorded had a measured magnitude of approximately 0.8. This is approximately 2000 times less energy than a magnitude 3.0 earthquake. The magnitude 3.0 earthquake is commonly used to describe deep earthquakes that can be felt at the surface, but still much smaller than an earthquake that could be damaging or harmful.

It is known however, that the disposal of water underground through injection wells has led to an increase in earthquakes in areas of the United States. In South Australia's Cooper Basin, the petroleum industry mainly disposes of water by evaporation (or re-uses the water) and there have been no reported links to earthquakes felt at surface after over 900 fracture stimulated petroleum wells in the Cooper Basin since 1969. Furthermore, water disposal underground anywhere in South Australia is currently not permitted under the *Petroleum and Geothermal Energy Act 2000*.

6.0 Issues raised during the consultation period

During the Stage 2 consultation process (7 February to 4 June 2018) a number of issues were raised by government and the wider public in a total of 35 submissions. These submissions are available on the DEM-ERD's environmental register[9]. SAPEX Limited responded to these submissions within Appendices 6 and 7 of their EIR prior to formally submitting the revised EIR to the DEM-ERD on 29 October 2018.

6.1 Potential for fracture propagation into overlying Great Artesian Basin (GAB) aquifers causing contamination, aquifer depletion and/or impacts to mound springs

Public concerns were raised regarding the potential for contamination and aquifer depletion of the Great Artesian Basin (GAB) due to uncontrolled fracture propagation. Further concerns were raised regarding the potential impact that a contamination or aquifer depletion event would have upon groundwater receptors including Coober Pedy Township and/or GAB springs.

As outlined in Section 5.2 a detailed technical program must be submitted in accordance with recognised industry standards that demonstrate all operations can demonstrably achieve the objectives of an approved SEO, which includes avoiding contamination of aquifers and aquifer depletion as outlined within the Objectives of SAPEX's PEL 122 & 123 Fracture Stimulation SEO (Table 1 and Table 2).

Following drilling, and prior to fracture stimulation operations a site specific geomechanical model will be constructed to predict the growth of induced fractures. This model will be constructed using site specific geomechanical data gathered during the drilling process. This will include, but is not limited to, formation thicknesses, separation distances from aquifers (in particular the GAB), rock mechanics and stress magnitudes to determine the extent and orientation fractures will propagate.

This model, along with a site specific fracture stimulation risk assessment and how it will be monitored/verified will be submitted to DEM-ERD as part of the Stage 3 approval process for assessment by the regulator and relevant co-regulatory agencies.

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[9] http://petroleum.statedevelopment.sa.gov.au/legislation_and_compliance/environmental_register

Based on DEM-ERD's review, three key factors ensure that induced fractures for this project will be confined to their target zone between 650m and 1,800m and not propagate into shallow aquifers:

1. The variation in elastic properties between lithologies (e.g. sandstone, siltstones, shale, mudstone) above the target zone act as stress barriers that impede fracture stimulation height growth.
2. The stress regime changes fracture orientation from predominately vertical in the target zone to predominately horizontal at shallower depths, limiting fracture stimulation height growth.
3. The energy imparted into the fracture stimulation treatment via pumping pressure will be of a magnitude such that the induced fracture network height is not expected to extend beyond 200m.

Subject to the demonstrated geology of the chosen drilling location and target formation for fracture stimulation aligning with the information presented by SAPEX within their EIR (in particular separation distances, connectivity and geomechanical properties), DEM-ERD deem there not to be any credible risk of fractures propagating into shallow aquifers and causing contamination or pressure depletion, in particular within the GAB.

Should the chosen drilling location be located in close proximity to a potential receptor such as a water bore or GAB spring (noting SAPEX have identified a 5 km trigger zone around GAB springs, as defined in Section 4.3), SAPEX through their Stage 3 activity notification will be required to demonstrate that the receptor will not be impacted. This will include as previously outlined site specific data, modelling and risk assessments prior to operations. The requirement for hydraulic fracturing diagnostics to assess fracture stimulation height growth and/or a groundwater monitoring plan to be developed to the satisfaction of DEM-ERD during and post operations may also be required, dependent on the assessed risk to receptors.

With regards to impacts to Coober Pedy Township water, as supplied by GAB water bores on the Oodnadatta Track, the target location within the Boorthanna Trough is approximately 80-100 km to the East of these water bores. Given the volumes of water used when fracture stimulating in the order of 1 ML per stage there is no credible risk of water extraction at this level 80-100 km away affecting upon the town's water supply.

Due to the above, the potential risk of contaminating the town's water supply and the GAB springs from migrating fracture stimulation fluid and/or hydrocarbons is negligible.

Furthermore, through the approved SEO, it is an offence under the PGE Act to impact on aquifers and any ground water dependent ecosystems as detailed here in the SEO extract pertaining to the relevant objectives for this purpose.

Environmental Objectives	Assessment Criteria	Guide to How Objectives Can Be Achieved
1. Minimise loss of aquifer pressure and avoid aquifer contamination.	Compliance with assessment criteria relating to well integrity in the Drilling Activities SEO No loss of aquifer pressure or contamination of aquifers as a result of fracture stimulation operations. Appropriate controls exist to protect separate aquifer systems and / or hydrocarbon reservoirs that are typically in natural hydraulic isolation from each other	Well Integrity Casing and wellhead designed to meet pressure, temperature, operational stresses and loads. Well pressure tested prior to commencing fracture stimulation. Monitoring programs implemented (e.g. through well logs, pressure measurements, casing integrity measurements and corrosion monitoring programs) to assess condition of casing and cross-flow behind casing. Trip systems installed to shut off stimulation pumping units if pre-set operational maximum pressure is reached. Note: well integrity issues are subject to requirements of the Exploration Drilling Activities SEO (Sapex 2013) Fracture Stimulation Planning and Monitoring Assessment of geological and geomechanical settings undertaken during design of fracture stimulation treatments to avoid growth into undesired strata. Fracture design (including pressures, injection rate, fluid makeup and proppant concentration) undertaken to provide confidence that the fracture treatment does not extend into overlying or underlying aquifers Fracture stimulation treatment modelled prior to all operations Injection pressures monitored and compared to expected fracture initiation pressure. Investigation undertaken if unexpected water flows occur during production testing, to determine source (e.g. may indicate communication with aquifer). Hydraulic fracturing diagnostics used to assess fracture height growth where appropriate. Specific diagnostic tools (e.g proppant tracers, chemical tracers etc) will be selected based on parameter of interest Monitoring of aquifer pressure and water quality to be implemented where athere is potential for impacts to groundwater dependant ecosystems and/or groundwater users. Refer to Objective 3 for criteria relating to surface pond location, construction and leak detection.
2. No impacts on groundwater dependant ecosystems No significant impacts on existing groundwater users	Landholder complaints regarding impact on groundwater users are documented and reasonable steps taken to resolve them can be demonstrated No impact on groundwater dependent ecosystems resulting from extraction of groundwater or fracture stimulation. No change in the capacity of third party groundwater users to undertake their respective activities	Water extraction, if required, will be in compliance with licensing and water allocations where applicable. Liaise with DEW to ensure appropriate authorisations are in place Landowners consulted regarding water well locations and water use Water extraction for fracture stimulation in accordance with licensing and water allocation plan where applicable. Monitoring of water extraction volumes and pressures Options for alternative water supplies investigated / used where feasible (e.g. produced formation water, recycling, reuse). Avoid extracting groundwater where there is potential for impacts to groundwater dependent ecosystems and/or existing groundwater users. Where it is not possible to avoid extracting groundwater from these aquifers and there is potential for impact a monitoring plan will be implemented Within the 5km trigger zones, any actions (activities) that have, or are likely to have a significant impact on MNES (impacts to the community of native species dependent on discharge of groundwater from the GAB) under EPBC will be referred to and require approval from the Australian Government Minister for the Environment

Table 1: SAPEX PEL 122 & 123 Fracture Stimulation Activities SEO – Objective 1 & 2

6.2 Potential impacts on Aboriginal heritage

DEM-ERD and all South Australian Government agencies continue to recognise and respect the sensitivities of all Aboriginal heritage matters in the State and the importance that these are appropriately addressed through the regulatory process, both during the approval stage and the compliance monitoring and enforcement stages.

PEL 122 and 123 overly the Arabana Native Title determination with the exception of a small section of the western most edge of PEL 122 that falls within the Antakirinja Matu-Yankunytjatjara (AMYAC) Native Title determination area. It must however be noted that the area overlying the AMYAC Native Title area is well outside of SAPEX's target and is therefore deemed outside of the scope of the EIR and SEO.

SAPEX Limited entered into a Native Title agreements with the Arabana Aboriginal Corporation Registered Native Title Body Corporate (RNTBC) in October 2006 for exploration, development and production activities. Since this time SAPEX have continued to liaise with the Arabana people and have consulted directly with them on the PEL 122 & 123 fracture stimulation proposal.

In their submission to the EIR and draft SEO, the Arabana Aboriginal Corporation RNTBC have outlined they do not support the fracture stimulation activities within PEL 122 and PEL 123 and particularly within the GAB and Lake Eyre Basins, which are culturally significant to the Arabana People.

As extracted from the final approved SEO, the requirements outlined within Table 2 have been incorporated into the SEO in relation to the protection of Aboriginal heritage. In particular, a key risk management measure that SAPEX must comply with prior to any on-ground works and to receive Stage 3 activity approvals is undertaking Work Area Clearances (WAC) surveys with representatives of the Arabana people. This will ensure any identified sites, objects, remains and places of Aboriginal heritage are avoided.

It is well known that the GAB springs within the Arckaringa Basin and other areas are of great cultural significance to both Aboriginal and non-Aboriginal people. To provide assurance for the protection of these significant sites, SAPEX through consultation with DEM-ERD and DEW have identified a 5 km trigger zone around GAB springs as shown in Figure 5.

Further to this, SAPEX must at all times comply with the *Aboriginal Heritage Act 1988*, in particular they must not damage, disturb or interfere with any Aboriginal site, object or remains as per section 23 of this Act. The key management measure to ensure SAPEX comply with this requirement is to undertake WAC surveys as discussed above.

As an owner of land, the Arabana Aboriginal Corporation RNTBC will also be issued a Notice of Entry (NOE) by SAPEX 21 days prior to entering the land as required under the *Petroleum and Geothermal Energy Act 2000*. As an owner of land the Arabana Aboriginal Corporation RNTBC have the right to dispute entry as per section 62 of the Act.

Environmental Objectives	Assessment Criteria	Guide to How Objectives Can Be Achieved
7. Avoid disturbance to Aboriginal and non-Aboriginal heritage sites, objects, remains and place unless prior approval under relevant legislation obtained.	Areas of proposed land disturbance have been surveyed and any identified sites, objects, remains and places of Aboriginal and non-Aboriginal heritage have been avoided. Any Aboriginal and non-Aboriginal heritage sites, objects, and remains discovered during operations have been appropriately reported and responded to. If disturbance occurs outside of an approved work area an assessment to evaluate the impacts has been carried out and if required rehabilitation is undertaken in accordance with legislation and/or consultation with Native Title Claimant groups and other Aboriginal people or heritage groups who may have an interest.	Activities confined to cleared areas (e.g. access roads, prepared well lease) within area subject to Work Area Clearance for cultural heritage. Training and induction for all personnel to educate them on the importance of remaining within designated / approved areas. Approved work areas and restricted areas clearly delineated on site Where necessary, cultural heritage sites or exclusion zones in the vicinity of the well site flagged and / or fenced off to prevent disturbance. A mechanism is in place to appropriately report and respond to any sites discovered during operations

Table 2: SAPEX PEL 122 & 123 Fracture Stimulation Activities SEO – Objective 7

6.3 Potential for seismicity causing stability problems for underground houses within Coober Pedy and/or impacts to tourism

Public concerns were raised regarding the potential for induced seismicity affecting the stability of underground houses within Coober Pedy and the impact this may have upon the tourism within the area.

Whilst DEM-ERD understand these concerns and the unique nature of underground housing within Coober Pedy, as outlined within Section 5.6 of this report, it is highly unlikely that any microseismic event will be felt at the surface at the exact location above the fracture stimulation activity. It is therefore considered that there is no credible risk of an induced seismic event being measured, or felt and in particular impacting upon housing within the Coober Pedy Township approximately 100 km to the west at its closest point to the Boorthanna trough target area. This conclusion is based on studies from the US and from experience in the South Australian Cooper Basin where over 900 petroleum wells have been fractured stimulated since 1969, with no reported links to earthquakes felt at surface.

With regards to fracture stimulation increasing earthquake events, it is known that the disposal of water underground through injection wells has led to an increase in earthquakes in areas of the United States. In South Australia's Cooper Basin, and as proposed by SAPEX within the Arckaringa Basin, the petroleum industry mainly disposes of water by evaporation (or re-uses the water). Furthermore, water disposal underground anywhere in South Australia is currently not permitted under the *Petroleum and Geothermal Energy Act 2000*.

As extracted from the final approved SEO, the requirements outlined within Table 3 were incorporated into the SEO in relation to the protection of stakeholders and/or associated infrastructure.

Environmental Objectives	Assessment Criteria	Guide to How Objectives Can Be Achieved
10. Avoid or minimise disturbance to stakeholders and / or associated infrastructure.	No disturbance to landholder/owner activities as a result of regulated activities unless by prior arrangement Stakeholder complaints are documented and reasonable steps taken to address them can be demonstrated Where disturbance is unavoidable or accidental, infrastructure or and use is restored to the satisfaction of the landholder / owner or as near as practicable to undisturbed condition	Induction for all employees and contractors covers pastoral, conservation, tourism, legislation and infrastructure issues. Relevant stakeholders notified prior to undertaking operations (pursuant to Regulations). Fracturing not carried out in close proximity to towns or pastoral station residences. Ponds securely fenced to exclude stock and large native fauna. Landowner liaison regarding notification / management of works and site issues including livestock management All gates left in the condition in which they were found (i.e. open/closed). Potential sources of contamination fenced as appropriate to prevent stock access. System is in place for logging landholder complaints to ensure that issues are recorded, addressed as appropriate and complaints are resolved in a timely manner. Appropriate, necessary authorisations are obtained for access to the Woomera Prohibited Area. In the event of an oil or fluid spill, contingency plan to be implemented after the spill event.

Table 3: SAPEX PEL 122 & 123 Fracture Stimulation Activities SEO – Objective 10

7.0 Environmental Protection and Biodiversity Conservation Act 1999 Referrals

Under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), actions that have, or are likely to have, a significant impact on a matter of national environmental significance (MNES) require approval from the Australian Government Minister for the Environment (the Minister). The Minister will decide whether assessment and approval is required under the EPBC Act.

The nine MNES protected under the EPBC Act are:

- world heritage properties
- national heritage places
- wetlands of international importance (listed under the Ramsar Convention)
- listed threatened species and ecological communities
- migratory species protected under international agreements
- Commonwealth marine areas
- the Great Barrier Reef Marine Park
- nuclear actions (including uranium mines)
- a water resource, in relation to coal seam gas development and large coal mining development

Under the EPBC Act, a referral can only be made by:

- the person proposing to take the action (which can include a person acting on their behalf); or

- a Commonwealth, state or territory government, or agency that is aware of a proposal by a person to take an action, and that has administrative responsibilities relating to the action.

A referral must be made by the person proposing to take an action if the person thinks that the action will have, or is likely to have a significant impact on a matter protected by Part 3 of the EPBC Act. This test also applies to a government agency who has administrative responsibilities in relation to the action.

The EPBC Act provides for the listing of nationally threatened native species and ecological communities, native migratory species and marine species. The community of native species dependent on natural discharge of groundwater from the GAB are listed under the EPBC Act as Endangered. This includes Mound

Springs and other spring complexes and their associated Groundwater Dependent Ecosystems (GDE) that are reliant on the GAB.

DEM-ERD will assess any potential impacts to communities of native species dependent on natural discharge of groundwater from the Great Artesian Basin and other matters of MNES during the Stage 3 approvals process when the licensee provides details including locations of their drilling and fracture stimulation activities relevant to GAB springs.

Further to this, as outlined in Section 4.3, given the sensitivity and significance of the GAB Springs and the community of native species dependent on natural discharge of GAB, SAPEX through consultation with DEM-ERD and DEW have identified a 5 km trigger zone around GAB springs as shown in Figure 5.

Any proposed fracture stimulation within the 5 km trigger zone automatically be subject to further assessment and consultation with both State (DEM-ERD and DEW) and Federal Government Agencies (potential impacts to MNES under the EPBC Act).

8.0 Recommendation and further information

The Energy Resources Division recommends Stage 2 approval, based on:

- its detailed review of the EIR and draft SEO as summarised in this report;
- SAPEX Limited's responses to comments submitted as a result of public consultation; and
- consultation with co-regulatory agencies including (but not limited to) the Environmental Protection Agency (EPA) and the Department for Environment and Water (DEW).

For all enquiries regarding this assessment, DEM-ERD can be contacted through the Director of Engineering Operations, Michael Malavazos at michael.malavazos@sa.gov.au.

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