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Callide Oxyfuel Project

Callide Oxyfuel Project – CO_2 Storage Demonstration

Surat Basin CO_2 Storage Site Selection

Part 1 – Review of Surat Basin CO_2 Storage Options

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Revision History:

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0	27 June 2013	Submitted to GCCSI

SUMMARY

The following study was commissioned by Callide Oxyfuel Services Pty Ltd in order to obtain an appraisal of the storage options in the Surat Basin in the context of the potential to store > 1 Mt CO_2 per year for the life of a large scale CO_2 capture project.

This study builds on previous work undertaken for and on behalf of the Callide Oxyfuel Project including a recent study for the Global Carbon Capture and Storage Institute which provided a high level comparison of the Northern Denison Trough and the Surat Basin.

The overall objective of the report is to present an initial appraisal of a number of potential CO_2 storage reservoirs in the Surat basin based on currently proposed EPQs in the Northern (EPQ 7 & 8) and Southern (EPQ 10, 12, 14) Surat Basin areas in the context of large scale CO_2 storage (> 1 Mt pa). The report includes the following:

1. Description of the assessment methodology applied.
2. Description of general geology of the areas.
3. Characterisation and ranking of the sites in terms of Social and Environmental factors; access and infrastructure; injectivity, storage capacity, containment.
4. Summary of data in appendices based on various cores and bore holes that are available in the public domain, including stratigraphic profiles, and hydrological data.

The Surat Basin CO2 Storage Review is submitted to the Global Carbon Capture and Storage Institute Ltd as fulfilment of Activity 4 Item 4 in accordance with the requirements of the GCCSI-OTPL Funding Agreement.

1 BACKGROUND

1.1 Project Description

The idea of the Callide Oxyfuel Project was first conceived in late 2003 as an initiative of the Australian Coal Association COAL21. In February 2004, a Working Group was established under the umbrella of COAL21, the CRC for Coal in Sustainable Development and the New Energy Development Organization (NEDO) in Japan to undertake a feasibility study on the Oxyfuel conversion of a 30 MWe coal fired boiler at Callide A and the addition of a CO_2 capture plant. The Study was completed in 2006, and an application made to the Commonwealth for funding under the Low Emission Technology Development Fund (LETDF) initiative.

The Project reached Financial Close in March 2008 with the execution of a LETDF Deed, execution of a Funding Agreement with the Australian Coal Association, and establishment of an Unincorporated Joint Venture.

The Callide Oxyfuel Project is being carried out in the following three stages:

Stage 1: Phase 1 - Refurbishment of the existing Callide A Unit No. 4 near Biloela in central Queensland (complete)
Phase 2 - Retrofit of oxy-firing technology and CO_2 capture (complete)
Phase 3 – Demonstration of oxy-combustion and CO_2 capture (in progress)

Stage 2: Transport and geological storage
Phase 1 – Appraisal of potential CO_2 storage sites (in progress)
Phase 2 – Facilitation of a CO_2 injection trial of several hundred to several thousand tonnes

Stage 3: Project conclusion and technology commercialisation

The Oxyfuel boiler and CO_2 capture plant were commissioned in May and December 2012 respectively, and the plant is intended to operate as an RD&D facility until December 2014.

An important element of the Callide Oxyfuel Project is to investigate storage options and industrial uses of the product CO2 now being produced at Callide A. Two main options have been investigated for a CO2 storage trial based on road transport of Liquid CO2; an injection quantity of up to 10,000 t/year for 1 or 2 years; and storage as a Chapter 5, Level 2 injection test in the context of the Greenhouse Gas Storage Act (QLD) 2009, Environmental Protection Act (QLD) 1994, and associated Regulations. These options have been as follows:

Option 1 – Northern Denison Trough (previously EPQ-2) located near Emerald;
Option 2 – North Surat Basin (EPQ 7 & 8) and South Surat Basin (EPQ 10, 12 & 14) Tenements or proposed Tenements located near Wandoan and Moonie respectively.

A broad comparison of the characteristics of the North Denison Trough and Surat Basins is summarised in Table (I) below. It may be noted that in the North Denison Trough, some Catherine sandstone zones may exhibit permeability greater than 10 mD. The Evergreen Formation contains sealing siltstones at its top and a number of intra-formational seals. It also contains some sandstone members. Some Precipice zones may exhibit permeability significantly greater than 200 mD.

Table (I) General Subsurface Characteristics of North Denison Trough versus Surat Basin CO2 storage reservoirs

No	Paramete	Units	North Denison Trough	Surat Basin
1	Basin	-	Bowen	Surat
2	Storage Reservoir	-	Catherine, Freitag,	Precipice
3	Regional Seal	-	Black Alley Shale	Evergreen
4	Reservoir Type	-	Saline Formations	Deep Saline Formations
5	Top Reservoir Depth	m	~850 (Catherine), ~1100 (Freitag), ~1200 (Aldebaran)	~1500-1700
6	Gross Thickness (Reservoir Formation)	m	~150 (Catherine), ~100	~70-110
7	Gross Thickness (Seal Formation)	m	~50 (Peawaddy), ~100 (Ingelara)	~200
8	Res. Absolute Permeability	mD	0.1-5	10-200
9	Res. Total Porosity (%)	%	8-13	10-18

1.2 Potential Learnings from CO_2 Storage Test

Schlumberger have determined a number of potential learnings from a proposed CO_2 storage test associated with the Callide Oxyfuel Project, as listed below:

1. *Understanding the integration process of CO_2 storage to capture technologies*

   The storage component represents the final ingredient for a comprehensive demonstration of an integrated CCS technology as a means of mitigating greenhouse gas emissions and realizing a low carbon future. The integration offers valuable opportunity for participants of different industrial background to understand overlapping requirements at each point of interaction as the project progresses from one phase to the next. A successful integration of the capture, transport, and storage components is a paramount confidence builder for future commercial-scale technology deployment in Queensland.

2. *Providing case study/reference point for maturing CO2 storage technology application*

   Given the limited number of CO_2 storage application to-date worldwide, the project would serve as a valuable reference point for best practices in storing CO_2 across saline formation, contributing to the worldwide effort of maturing the technology for commercial deployment, irrespective of location choice.

3. *Evaluating <u>technical viability</u> of CO_2 storage in Queensland's sedimentary basins*

The interpretation and evaluation of gathered engineering data allows assessments with regard to injection rate, capacity and containment performances to be made. Ultimately, technical viability of the reservoir-seal pairs as competent CO_2 sinks could be appraised or verified.

4. *Understanding <u>financial</u> scope and requirements for CO_2 transport and storage*

The collection of financial data allows understanding of overall financial requirements to transport CO_2 by land and store it permanently underground. Cost-benefit analyses may provide valuable insight on implementation approaches that make the most economical sense. Knowledge about storage economics is critical for supporting commercial viability assessment of a potential scaled- up deployment in a carbon-constrained future.

5. *Understanding CO_2 storage <u>project management</u>, implementation workflow, and timeline*

The storage test allows participants to obtain familiarity in CO_2 storage project management, implementation workflow, and timeline requirement for each project phase. Knowledge about project needs, related to front-end technical/operational studies, work breakdown structure, project execution plan, critical-path tasks, human resources, and time allocation, among others, is necessary to realize flawless project planning for future implementation.

6. *Defining/testing state/federal <u>regulatory</u> framework and environmental approval process*

In Australian context, the relevant regulatory framework is given by the following Acts:

- Offshore Petroleum and GHG Storage Act 2006 (Nov 2008), amended and published in January 2010
- Queensland GHG Storage Act 2009
- Victoria GHG Geological Sequestration Act 2008
- Environment Protection Act

In the Callide Oxyfuel proposed storage demonstration, the specific regulatory approvals/endorsements to be pursued include:

- Qualification of Callide's CO_2 as a GHG stream per GHG Storage Act 2009
- Qualification of the proposed injection as a test per GHG Storage Act 2009
- Environmental authority (EA) per Environmental to inject up to 20 ktonne of GHG stream

The project provides an opportunity for participants to fully understand the statutory requirement within the current regulatory framework through first-hand experience with authority approval process. Furthermore, participants may obtain clarity in regulatory requirements with respect to site rehabilitation/closure and long-term storage liability. This enables participants to provide informed feedback to regulators with respect to necessary modification and enhancement to existing regulatory regime to support higher scale of technology deployment.

7. *Developing appropriate equipment specifications for wells and surface facilities*

The storage project enables implementation of conceptual equipment designs in the field, allowing necessary refinement to achieve pre-defined transport, injection, and monitoring objectives.

Fit-for-purpose well construction requirements, comprising of tubular metallurgy, isolation cement system, casing/tubing configuration, completion, bottom-hole assembly, and others, would be defined for each injection and monitoring wells. Final well configuration would be devised according to necessary specifications to mitigate risk of wellbore leakage as well as to allow access for implementation of monitoring plan. Surface facility design and fabrication allows a safe implementation of injection and monitoring designs.

8. *Understanding CO_2 land- transport operational, regulatory, HSE, and financial requirements*

Trucking liquid CO2 from the plant to the injection site may provide useful insight on Australian land transport operational, regulatory, HSE, and financial requirements for CO2. Given the properties of the transported CO2 (purity, pressure, temperature), the trucking operations represents unique challenges and risks related to journey management, regulatory approval, equipment endurance, dry ice formation, operational venting and many others, warranting in-depth study and fine-tuning to establish a cost-effective operation.

9. *Selecting/validating efficacy of CO_2 monitoring, measurement, and verification (MMV) technologies*

The storage project provides opportunities to develop monitoring workflows for measurement, interpretation and modelling, to investigate appropriate intensity of monitoring, and to define the procedures for simultaneous deployment of a combination of monitoring technology. In addition, the project enables appropriate components of baseline measurement and environmental survey to be defined to adequately characterize the original state of the storage site. Operation monitoring would be implemented to measure conditions and amounts of CO2 being transported and injected. On the other hand, verification monitoring would be used to verify system integrity and CO2 fate underground. Finally, assurance monitoring is intended to detect potential leakage and investigate impact of such eventuality.

10. Defining standard operating procedures (<u>SOP</u>) for CO2 transport, injection, and monitoring.

Although CO_2 injection has been undertaken routinely for over 60 years in the oil and gas industry, in the context of CO_2 sequestration, injection experiments are still few. The number does not yet constitute a sufficient basis for deriving useful statistics or best practices to aid with planning, preparing, and executing such projects elsewhere. At present, any injection experiment properly documented will add to expanding the experience in this nascent field. The storage project provides an opportunity for the industry to define standard operating procedures for CO_2 land transport, injection and monitoring.

11. Gauging CO_2 storage <u>public acceptance</u> in Queensland

Being the first to implement CO_2 injection in Queensland at a considerable scale, this project may be utilized to gauge CO_2 storage public acceptance within the state boundaries as well as with the Australian public. This information is particularly useful in light of Queensland government current initiative to develop state-wide storage hub across Surat and Galilee basins.

12. Expanding <u>scientific understanding</u> about CO_2 storage in saline formation

The scientific studies to be undertaken could include the following:

- Forward (reservoir, wellbore, surface) modelling validation & refinement: "predictive capability to aid decision makings in future commercial deployment".
- MMV result interpretation & evaluation.
- Impacts of stream impurities (precipitation, corrosion, mineral leaching, trapping mode).
- Geochemical interaction between $_{CO2}$ and reservoir.
- Geochemical interaction between different capture compositions and reservoir and seal rock based on laboratory studies on cores
- Relative permeability behaviour between CO_2 and water by Special Core Analysis (SCAL) of cores in the laboratory (very few measurements worldwide)
- Near- wellbore damage (salting out, drying out, precipitation, impurities)
- Hardware corrosion
- CO2 plume fate & trapping mechanism (structural/stratigraphic, dissolution, residual saturation, mineralization).

1.3 Surat Basin Assessment

The main purpose and intention of this report is to present a high level assessment of the CO_2 storage potential of the Surat Basin. This work follows.

CoalBedEnergyConsultants.

Review of Surat Basin CO_2 Storage Options

for Oxyfuel Technologies Pty Limited

21st May 2013

CoalBedEnergyConsultants.

CoalBed Capability Statement

CoalBed Energy Consultants Pty Limited (CoalBed) has considerable experience in coal gas related activities. The company has long been involved in gas projects pertinent to mining, the technical evaluation phase of Australian CSG industry development, and has assisted major corporations with project management and reservoir assessment since 1998. CoalBed has project managed, and advised on a number of CSG and sequestration projects, surface and underground gas gathering and utilisation programs for mining, and fugitive emissions studies. The company has been involved in CSG technical due diligence for a range of clients in Australia and overseas, including major international corporations. In addition, CoalBed provides technical training in CSG to companies and institutions. For further information on the company, refer to http://www.coalbed.com.au.

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Oxyfuel Technologies Pty Limited

Surat Basin CO_2 Storage Options

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EXECUTIVE SUMMARY:

This report has been commissioned by Oxyfuel Technologies Pty Ltd (OTPL), with the prime objective of providing an independent assessment of the CO_2 storage potential of part of the Surat Basin, in particular regard to the suitability of existing GHG tenements, EPQ 7, 8, 10, 12, and 14. The report contained herein represents a small part of a much larger appraisal being undertaken by OPTL, to investigate the potential for future development and scale-up of oxyfuel technologies for large scale (>1Mtpa) CO_2 transport and geological storage, with a focus on Queensland and the Surat Basin. It is recognised that this report represents a view based on current data and that detailed geostorage volumes, trapping mechanisms, and potential impacts and resource conflicts still remain largely unknown until detailed site-specific characterisation takes place.

The Surat Basin is a very large sedimentary basin, more than 300,000km^2, and host to a number of potential reservoirs suitable for storage of CO_2, with appropriate seals. The Precipice Sandstone and the Hutton Sandstone are the most prospective in the areas covered by the GHG tenements, and the Evergreen Formation is likely to provide an excellent regional seal for sequestration activities. Work to date indicates that the porosity and permeability of the Precipice and Hutton Sandstones are favourable, and significant volumes of CO_2 may be stored in these formations.

The basin is stable tectonically and major faulting in the basin does not appear to progress through the regional seal, the Evergreen Formation, which is a positive in terms of CO_2 storage reservoir stability.

The five (5) EPQ's are situated along the structural axis and eastern limb of the Mimosa Syncline, the deepest part of the Surat Basin. This is probably the most attractive area in the Surat Basin for storing CO_2. The five (5) EPQ's have been ranked according to prospectivity, based on potential

storage capacity volume, geological character, depth, and the morphology of the reservoir and accompanying seals.

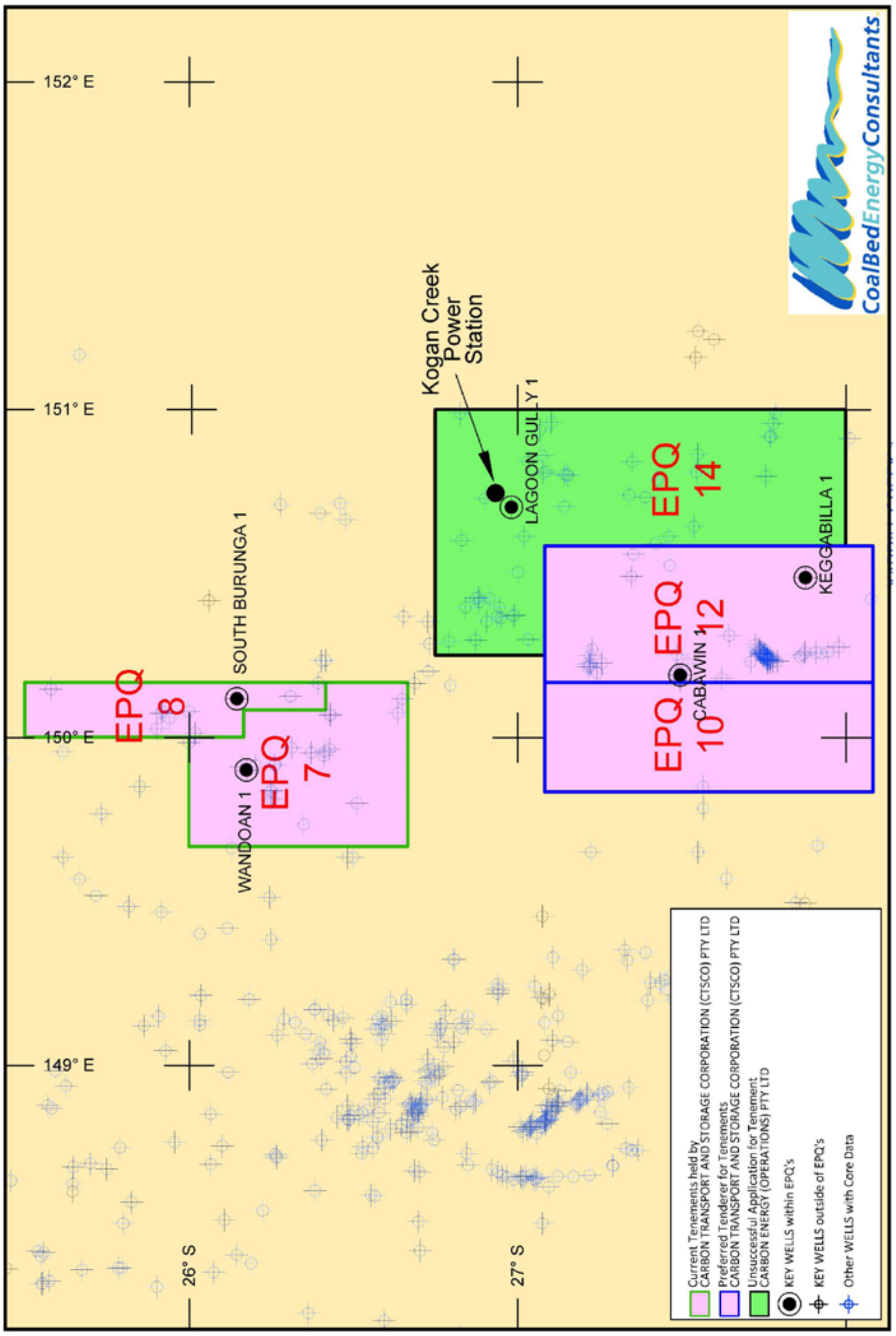
EPQ's 7, 10, 12 and 14 are all prospective for the storage of significant CO_2 in the Precipice Sandstone, and in the case of EPQ 10 and 12, also in the Hutton Sandstone. EPQ 8 is not attractive as a CO_2 storage site, due to depth and other geological constraints. More than 900 Mt of CO_2 can potentially be stored in the aforementioned GHG tenements. This figure is likely to be conservative, however further work is required to ascertain the thickness and extent of potential injection horizons in both the targeted reservoir horizons.

Further development of the key GHG tenements will require the drilling of dedicated CO_2 storage wells designed to provide detailed sedimentology from the key formations, and to investigate the porosity, permeability, and injection rate and capacity for the Precipice and Hutton Sandstones.

1. Introduction and Background

Oxyfuel Technologies Pty Ltd (OPTL), representing the Callide Oxyfuel Project near Biloela in central Queensland, is undertaking a number of studies and investigations into the prospects for future development and scale-up of oxyfuel technology and large scale (>1 Mtpa) CO_2 transport and geological storage.

CoalBed Energy Consultants Pty Limited (CoalBed) has been commissioned by OPTL to present an initial appraisal of a number of potential CO_2 storage reservoirs in the Surat Basin based on currently proposed Exploration Permit Queensland (EPQ's) in the Northern (EPQ 7 & 8) and Southern (EPQ 10, 12, 14) Surat Basin areas (Figure 1).



<u>Figure 1:</u> Location of GHG tenements and potential CO_2 storage sites in relation to Kogan Creek Power Station. Key regional historical stratigraphic boreholes are shown (black circle) and other bores (blue).

2. Methodology for Assessment of Resource Storage Potential

The estimation of CO_2 storage capacity for any given basin is not a simple and straightforward process (Bradshaw et al, 2007 and Bunch, 2013) and prone to errors of significant magnitude, largely due to the variable and difficult to predict nature of the geological inputs that a quantitative outcome is derived from.

A suitable target for geosequestration of CO_2 must have a suitable seal (to inhibit cross-measure migration) and exhibit appropriate porosity and permeability characteristics. Identifying such units has been a clear priority in this study. On a regional scale, these properties need to be generalised, and similar to many other geological processes, these properties are prone to variance associated with local reservoir parameters and local changes to the trapping and storage mechanisms within the target unit.

Storage capacity is a simple formula on the basis that it simply represents the pore volume available, that is the volume of rock (area x thickness) multiplied by the pore space (percentage of rock represented by the space between grains filled with liquid, usually water). However, this is a volumetric calculation only of pore space, whereas storage capacity depends on the injectivity and integrity of the geological formation to be a valid site for storage of CO_2. A further important factor is the dynamic nature of the reservoir – what changes to permeability and injectivity behaviour can be expected over a long period of time? This is a complex issue that is not easily resolved via high level assessments such as this one.

This study represents a view of likely storage capacity, pertinent to the area covered by five (5) separate GHG tenements in the Surat Basin. As no CO_2 storage specific drilling and testing has been undertaken at these sites the inferences contained herein are derived from publications pertinent to GHG storage, prior knowledge of the Surat Basin and general geological understanding of the process. Due to the history of resource development in the Surat Basin the general geological morphology is reasonably well understood, nevertheless, the Mimosa syncline (which broadly underlies the GHG tenements) is one of the least explored parts of the basin.

The approach taken herein is necessarily a conservative one, and is an attempt to determine a *'realistic capacity'* (as per Bradshaw et al, 2007). The methodology is as follows:

1. Identify the regional geological formations relevant to each GHG tenement and determine individual suitability for CO_2 storage. This data has been obtained from deep stratigraphic boreholes drilled in the area and regional analysis. The QLD CO_2 Storage Atlas (Bradshaw et al, 2009) and public domain boreholes have been the primary source of information used in this study.
2. Establish CO_2 storage capacity of key target horizons based on knowledge of porosity, permeability and thickness of each unit. Calculate storage capacity based on a multiple of areal extent, unit thickness and porosity. Unit thickness is a key input, and estimates are based on a conservative view, given the known variable character of sandstone formations.

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3. Discount those potential targets that do not appear to have a regional seal.
4. Discount those potential targets that are of insufficient depth for supercritical storage (<~800m below ground level).
5. Discount those potential targets that are likely to be adversely affected by the development of CSG industry wells.

Many of the boreholes available for use in assessing CO_2 storage capacity have been drilled for other purposes (usually petroleum related exploration). As a consequence, many have cores not taken in appropriate locations, production testing undertaken only in hydrocarbon intervals (and not saline water intervals), a general overreliance on log derived assumptions rather than specific core derived results, no data from areas away from the top of structural traps, and seismic data focussed on petroleum target zones not saline reservoir intervals, etc. Many boreholes are simply too shallow to be of use in assessing CO_2 storage capacity.

There are five (5) key historical wells in the vicinity of the GHG tenements (see Figure 1). These boreholes have been drilled for hydrocarbon exploration (Cabawin 1, Keggabilla 1, Wandoan 1 and South Burunga 1), and as a water source for the Kogan Creek power station (Lagoon Gully No. 1).   A summary of the findings from these bores is contained in Appendix I and Well Completion Reports in Appendix II.

The applicability of the available dataset is of particular importance for geological modelling studies where quality assurance processes will be needed to validate the various datasets that have been used. In addition to this, the modelling methodologies themselves must be assessed in an appropriate context for geostorage investigations (for further discussion on these requirements, see Hodgkinson and Grigorescu, 2012).

It is suggested that future work (see Section 7) will result in an upgrade of this assessment and the determination of the intrinsically more accurate *'viable capacity'* (Bradshaw et al, 2007). This is not possible without drilling CO_2 storage specific exploration boreholes.

3. The Surat Basin

3.1 Geological Setting

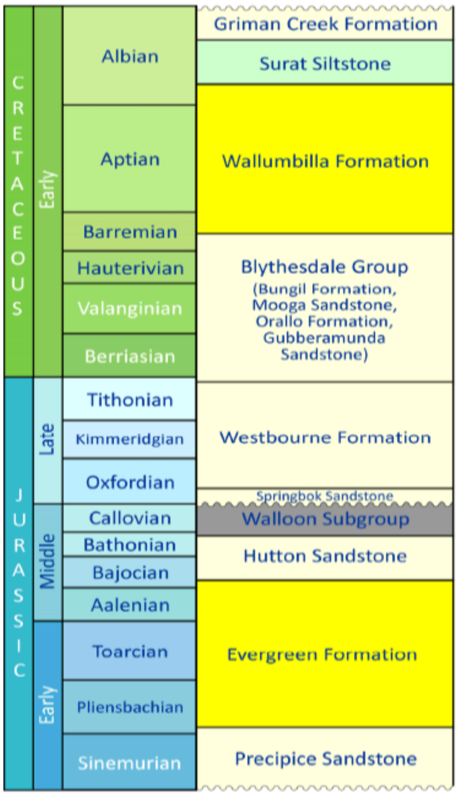
The Surat Basin is an asymmetric, north-south trending, intracratonic basin that occupies more than 300,000 km^2 of central southern Queensland and central northern New South Wales. The basin forms part of the larger Great Artesian Basin, and interfingers westward across the Nebine Ridge with the Eromanga Basin, and eastward across the Kumbarilla Ridge with the Clarence-Moreton Basin. Basement blocks consisting of the Central West Fold Belt and the New England Fold Belt limit the basin to the south, while in the north the basin has been eroded and unconformably overlies Triassic and Permian sediments of the Bowen Basin.

The Surat Basin has a maximum sediment thickness of 2,500 metres and deposition was relatively continuous and widespread. Deposition commenced in the Early Jurassic with the onset of a period of passive thermal subsidence across much of eastern Australia and continued until the early Cretaceous. A summary stratigraphic column is presented in Figure 2.

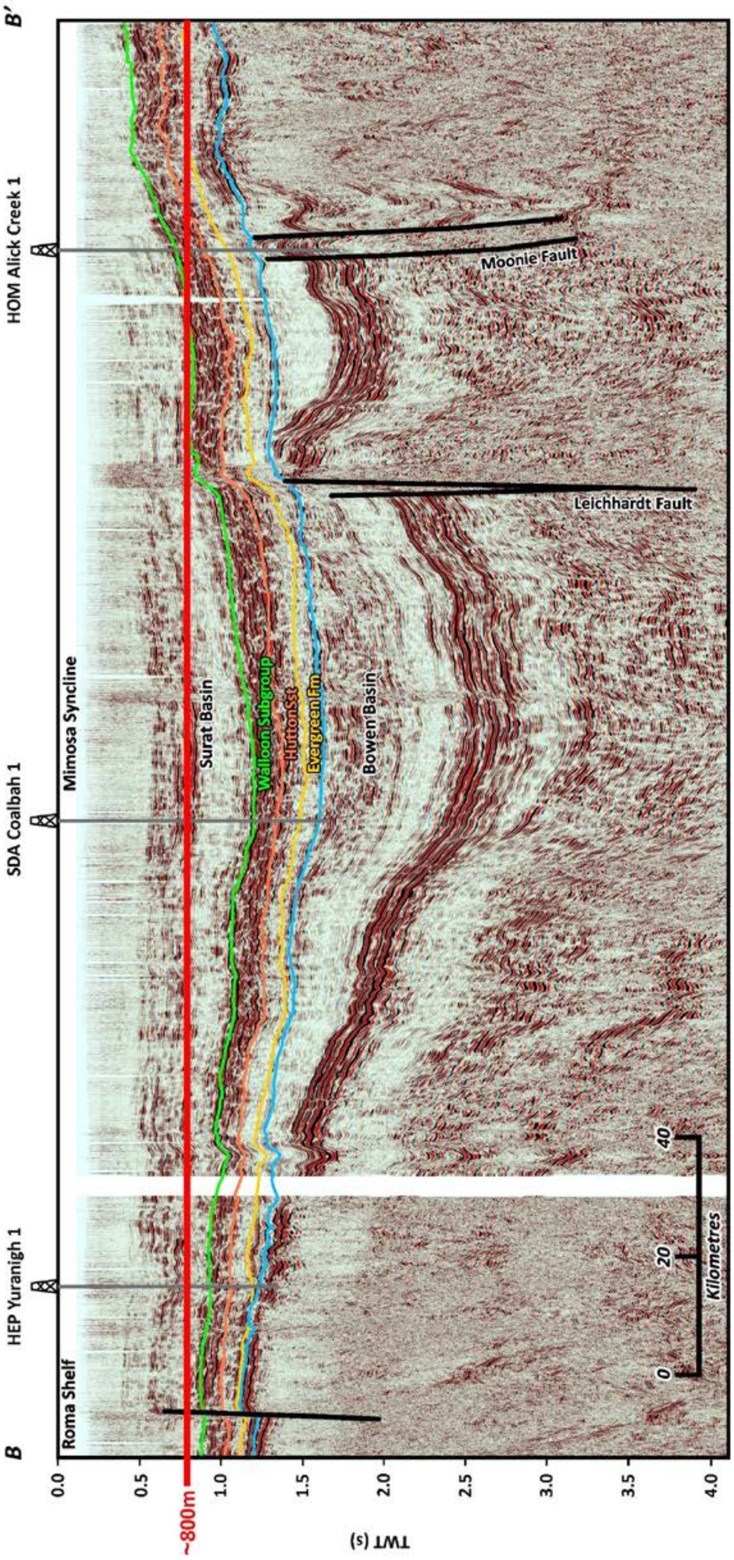
The succession consists of six (fining-upwards) sedimentary cycles dominated by fluvio-lacustrine deposits. The lower part of each cycle typically comprises coarse-grained mature sandstone, grading up into more labile sandstone and siltstone, with mostly siltstone, mudstone and coal in the upper part. In the Cretaceous, inundation of the land through an increase in sea level led to deposition of predominantly coastal plain and shallow marine sediments in two cycles.

In the late Middle Jurassic, coal swamp environments predominated over much of the basin, except in the north where fluvial sedimentation continued. This part of the succession includes the Walloon Coal Measures which are known to host coal seam gas deposits.

Structurally, the Surat Basin is relatively simple, with the area of maximum deposition, the Mimosa Syncline, overlying the thickest Permian-Triassic rocks in the Taroom Trough of the underlying Bowen Basin (Figure 3). Major faulting within the basin predominantly mirrors basinal boundary faults of the underlying Bowen Basin. There is substantial folding across the basin, which is due to compaction and draping, as well as some rejuvenation of older pre-Jurassic structures and faults. Formations outcrop along the northern erosion boundary and dip gently to the south and southwest at less than 5°.



<u>Figure 2:</u> Stratigraphic column for the Surat Basin (from Queensland CO_2 Storage Atlas, 2009).



<u>Figure 3:</u> Cross section through the Surat Basin showing the unconfomable relationship with the underlying Bowen Basin, and the key formations of interest for CO_2 storage (from Queensland CO_2 Storage Atlas, 2009). The cross-section is orientated broadly W-E (from south of Roma to slightly west of Dalby).

3.2 Current status of CO_2 storage tenements in the Surat Basin

The Surat Basin is considered to be a 'high prospectivity basin' according to the Queensland CO_2 Storage Atlas (2009). Consequently, the Surat is of interest not only for its geological virtues, but proximity to active CO_2 emission sources. It is likely that the Eromanga Basin has better storage potential (based on regional assessment of prospective storage capacity), but that basin is located a long way from emitters. The current position in the Surat Basin is that there are five (5) exploration permits of potential interest in terms of CO_2 storage sites, namely EPQ's 7, 8, 10, 12 and 14 (Table 1). Only one of these (EPQ 7) has been formally granted.

Table 1: Status of Surat Basin EPQ's (from QLD government website, see http://mines.industry.qld.gov.au/).

EPQ 7	
Status	Granted
Lodged	15 June 2010
Granted	20 January 2012
Expires	19 January 2024
Principal Holder	CARBON TRANSPORT AND STORAGE CORPORATION (CTSCO) PTY LIMITED

EPQ 8	
Status	Application
Comments	Preferred Tenderer
Lodged	15 June 2010
Granted	
Expires	
Principal Holder	CARBON TRANSPORT AND STORAGE CORPORATION (CTSCO) PTY LIMITED

EPQ 10	
Status	Application
Comments	Preferred Tenderer
Lodged	15 June 2010
Granted	
Expires	
Principal Holder	CARBON TRANSPORT AND STORAGE CORPORATION (CTSCO) PTY LIMITED

EPQ 12	
Status	Application
Comments	Preferred Tenderer
Lodged	15 June 2010
Granted	
Expires	
Principal Holder	CARBON TRANSPORT AND STORAGE CORPORATION (CTSCO) PTY LIMITED

EPQ 14	
Status	Application
Comments	Unsuccessful Application
Lodged	15 June 2010
Granted	
Expires	
Principal Holder	CARBON ENERGY (OPERATIONS) PTY LTD

EPQ 7 is currently held by Carbon Transport and Storage Corporation (CTSCo) Pty Ltd., which is a 100% owned subsidiary of Xstrata. The stated objectives of CTSCo include:

- To determine the viability of up to 75 million tonnes of CO_2 storage in the Surat Basin;
- Link to a large scale demonstration capture project (the Wandoan Power Project); and
- To assess suitability of the Surat Basin as a potential CCS Hub in Australia based on the preliminary work of the Queensland Geological Survey CO_2 Storage Atlas and the National CCS Taskforce Report.

To date, it appears that only limited work has been carried out on EPQ 7. A Level 2 environmental authority was granted on the 22nd November 2011. This included authorisation to conduct seismic work and to drill up to four (4) wells for geotechnical evaluation. This authority specifically excluded CO_2 injection testing as part of the approval.

Initial desktop studies indicate that EPQ 7 covers the Precipice Sandstone at appropriate depths for CO_2 storage. It appears to have favourable characteristics, albeit typical of the Precipice Sandstone in the Surat Basin, namely, very high permeability, and good seal rock coverage and structure that would appear to be suitable to support a large scale CO_2 storage project (in excess of 100 Mt, see Section 5).

3.3 Position of EPQ's in relation to regional structure

The five (5) EPQ's are all located on the eastern side of the Surat Basin and close to the deepest part of the basin, expressed by the axis of the Mimosa Syncline. The Mimosa Syncline is a north-south trending down warp (see Figure 4 and Figure 5). The position of the EPQ's relative to major structural features is presented in Figure 4, and relative to the deepest parts of the Surat Basin in Figure 5. EPQ's 7, 8 and 10 are located in the very deepest part of the basin (particularly EPQ 10), with 12 and 14 slightly shallower on the eastern limb of the Mimosa Syncline.

Major north-south trending faults occur on the eastern limb of the Mimosa Syncline. These structures do not appear to penetrate the Evergreen Formation (which is recognised as the primary seal pertinent to these leases) (see Figures 3 and 4).

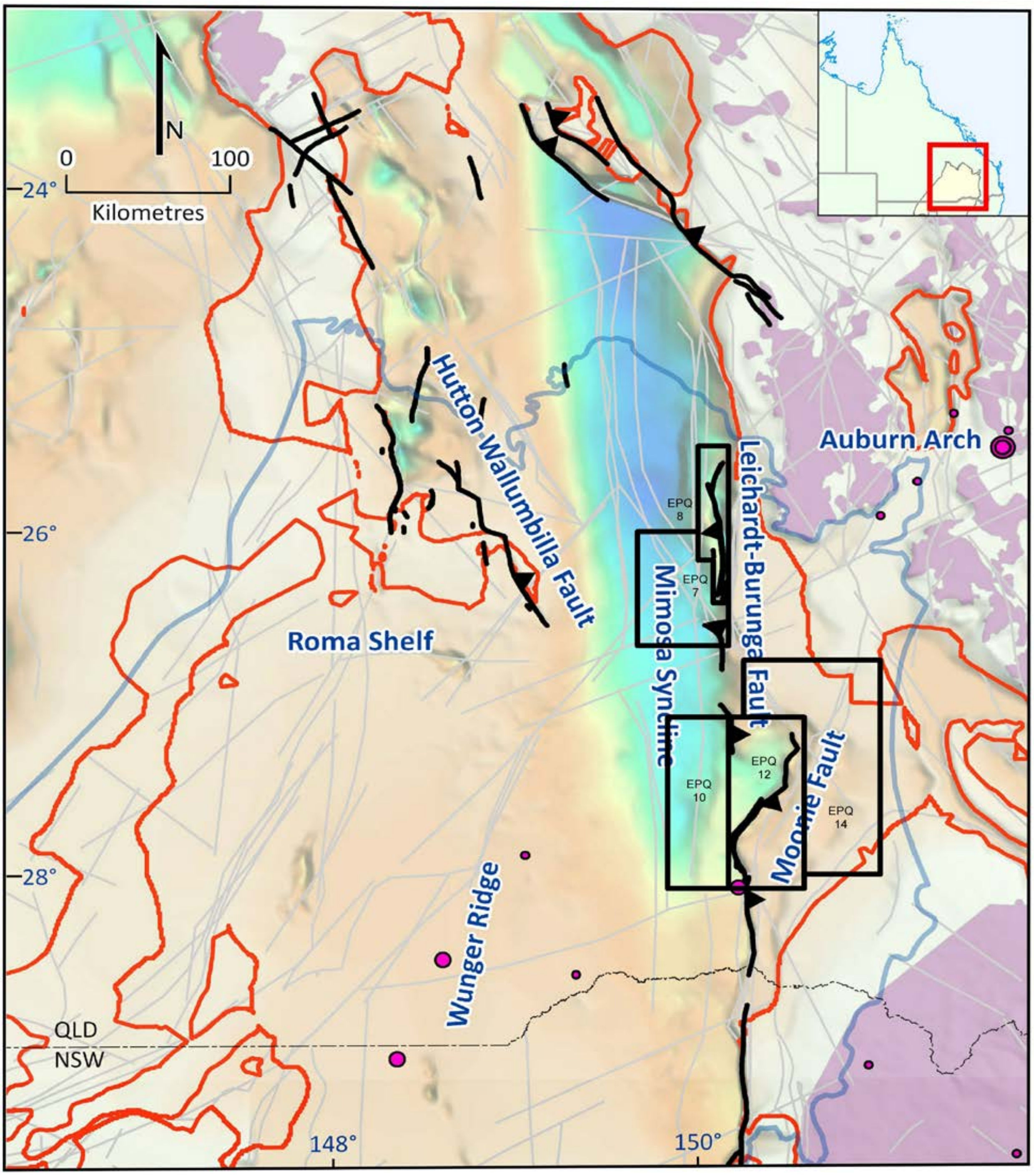


Figure 4: The location of the EPQ's relative to the Surat Basin major structural features. Cool colours represent the extent of the Mimosa Syncline. Major N-S faults occur on the eastern limb of the syncline.

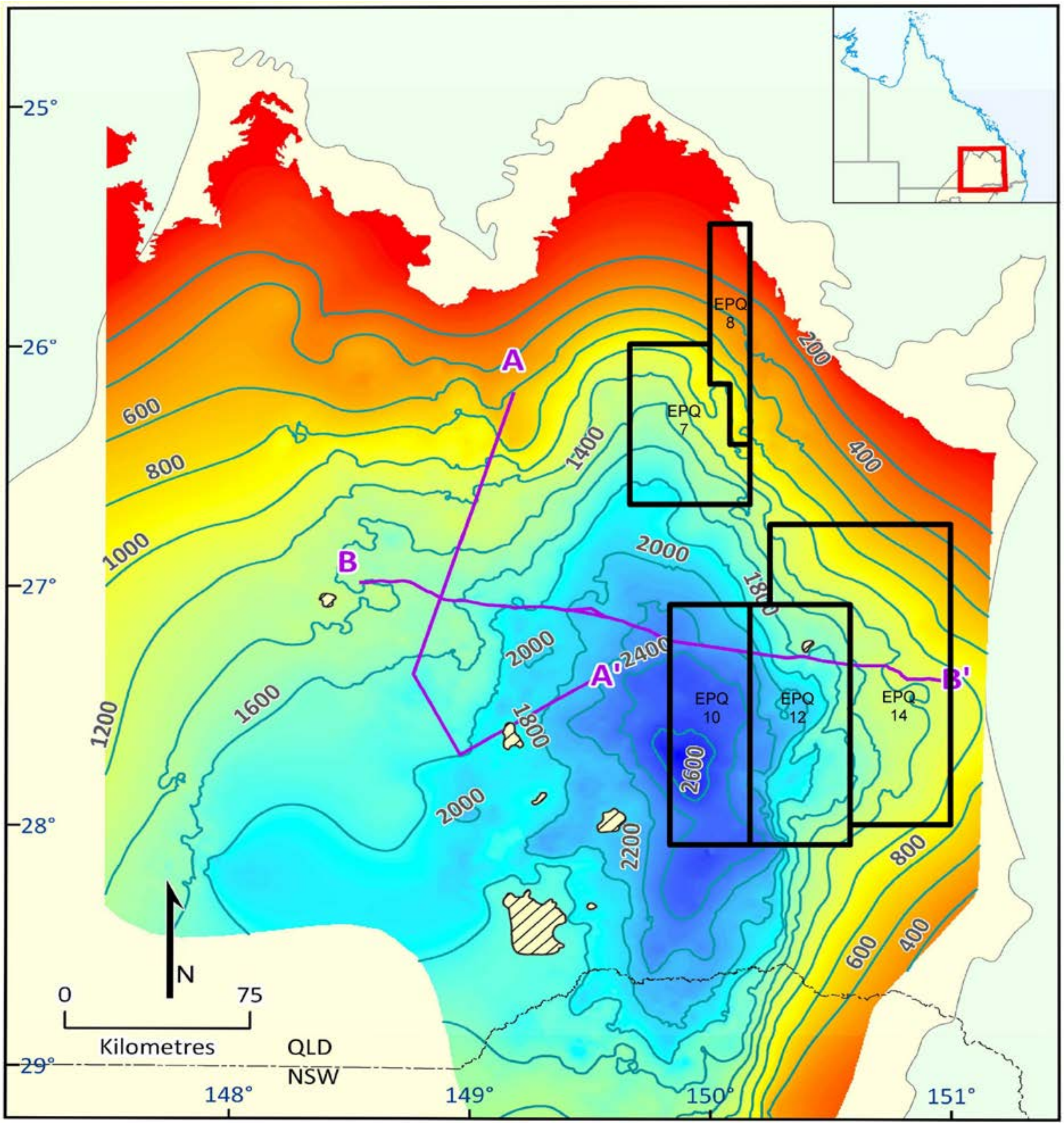


Figure 5: Structure contours to top of Evergreen Formation regional seal (using datum 450mASL[1]) showing the position of the EPQ's relative to the deepest parts of the Surat Basin.

4. Key Characteristics of Sedimentary Basins for CO_2 Storage

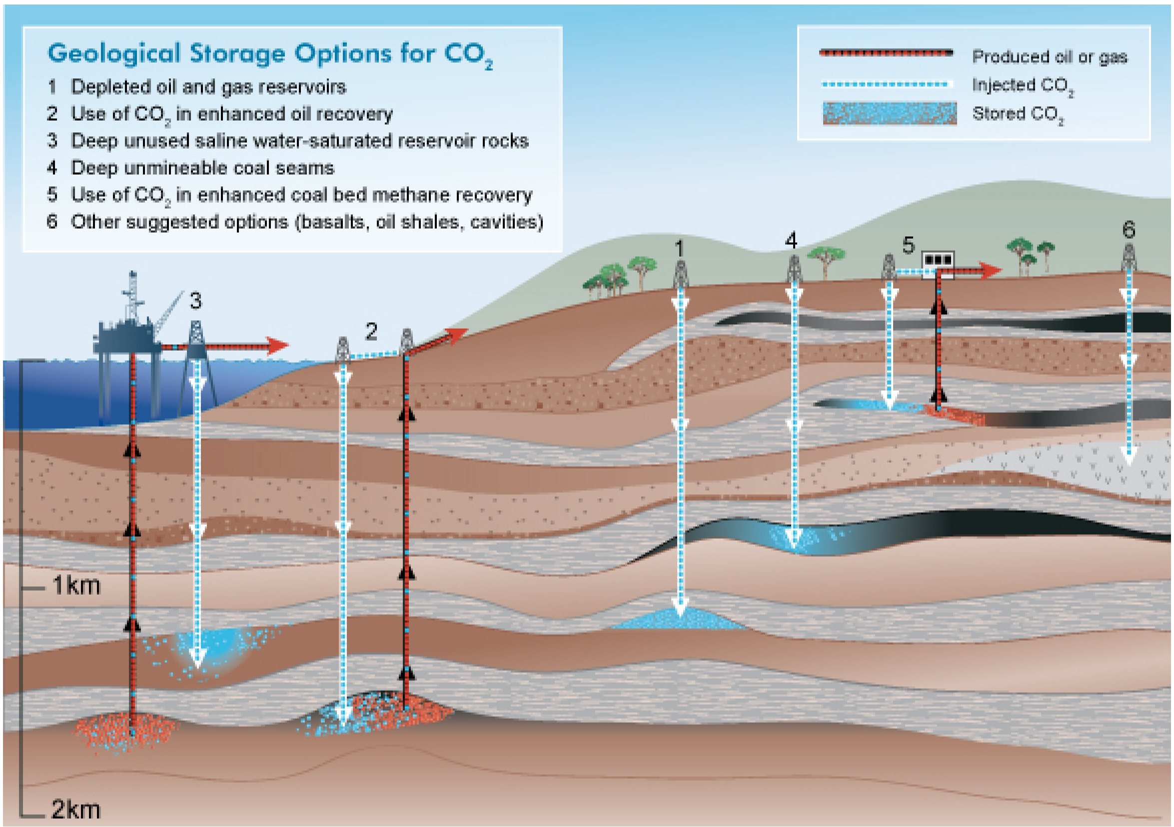
4.1 General tenets

The Australian government has supported the development of CO_2 capture and storage facilities via the establishment of a Co-operative Research Centre (CRC) for Greenhouse Gas Technologies (CRC

[1] mASL pertains to 'Metres Above Sea Level'.

for CO_2), which has a useful web site explaining the centre's activities and providing information on related matters (see http://www.co2crc.com.au).

In essence, the principal that CO_2 emitted from various sources (including coal fired power plants) can be stored is simple. Providing the gas can be captured and transported at economic rates, gas can be theoretically stored deep in the Earth's subsurface in suitable formations. The various conceptual circumstances pertinent to CO_2 storage is illustrated in Figure 6. Although the concept is simple, finding and securing appropriate reservoirs, proximal to emission generating activities remains a challenge.



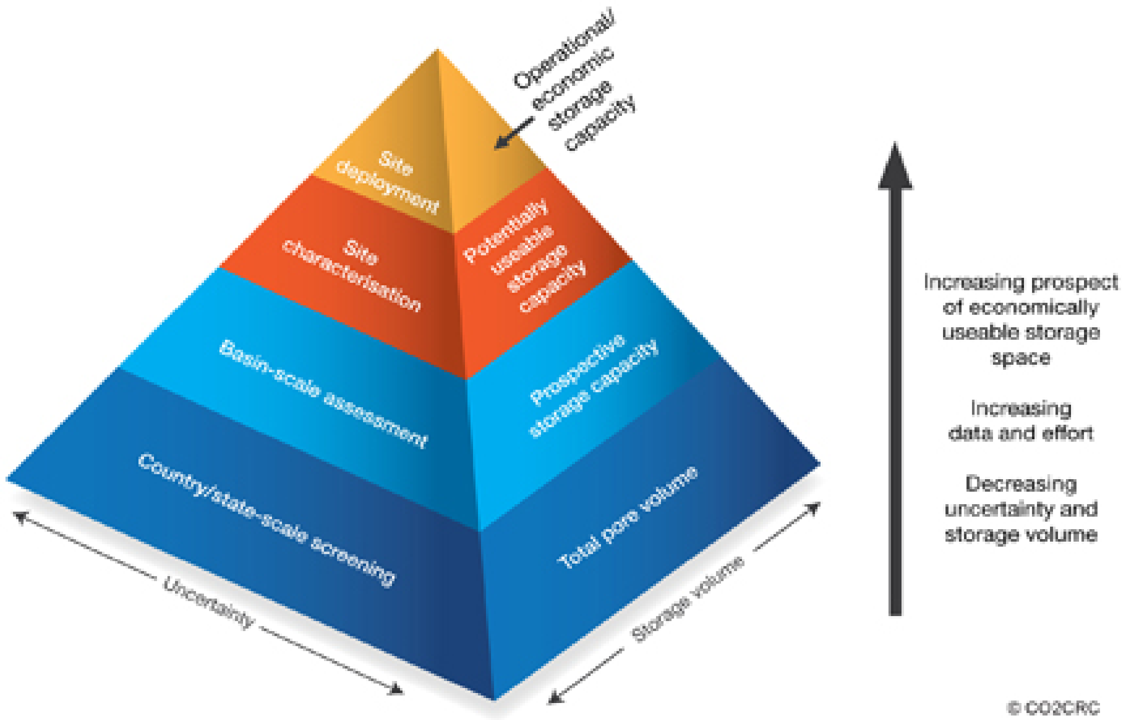
<u>Figure 6:</u> Geological storage options for CO_2 (from CRC CO_2 website).

The key reservoir characteristics pertinent to storage of CO_2 generally, and with particular reference to the Surat Basin include:

- The storage of the CO_2 needs to be at depths greater than 800m where the pressures are sufficient to maintain CO_2 in its supercritical state. This does not apply if the proposed mechanism is for the gas to be adsorbed to shallow coals (in which case the CO_2 stays in a sub-critical gas state). The latter is theoretically possible in the Surat Basin (via the Walloon coals) but is technically challenging (see Section 5.8). From a practical perspective it is the deep (>800m) sandstone reservoir targets that are of most relevance to any proposed storage of CO_2 but it is generally accepted that the large volume storage required can only be satisfied by aquifer geostorage (Bachu 2000; Michael et al. 2009).

- Reservoir rock which is porous and permeable. The latter is important to ensure the dissipation of the fluid in the rock, and the former is important because it provides the volume of pore space in which the liquid can be stored.
- A suitable trapping mechanism that ensures the CO_2 remains in the host formation and does not cross formation boundaries. It is important that the cap (or seal) rock (the rock immediately above the target formation) is impermeable.
- Saline reservoirs are particularly suitable for storage of CO_2 in that the CO_2 may dissolve in the saline formation water, and additionally, they are unlikely to be of interest as a long term groundwater resource. The key Surat Basin reservoirs (e.g. Precipice, Hutton Sandstones) are all sources of good quality groundwater (not saline), and are accessed by the agricultural community throughout the Great Artesian Basin.

Finding a storage site with large volumes of space, and the potential to accept the injected CO_2 is relatively straightforward on a theoretical basis. The complexity lies in the detail, and in particular the rate at which the CO_2 can be injected (and adsorbed) and the rate at which it dissipates through the reservoir, and how this changes with time (relative permeability effects). This concept is illustrated in Figure 7 (from CRC CO_2 web site) whereby countrywide screening can provide a large storage space (base of pyramid) but the usable capacity is vastly reduced (apex of pyramid) after the site characteristics are comprehensively assessed (see also Bunch, 2013).



<u>Figure 7:</u> CO_2 storage capacity pyramid (from CRC CO_2 web site).

In undertaking a regional or basin wide study of potential sequestration targets, other less critical, but notable characteristics includes the following:

- The basin should be tectonically stable, as the Surat Basin undoubtedly is. Basins that have high levels of seismicity are potentially prone to leakage of stored CO_2 (e.g. it would be difficult to store CO_2 with confidence in the Gondwanan coal bearing basins in the foothill of the Himalayas, or anywhere along the Pacific Rim).
- Suitable formations need to be 'just right' for depth. Too deep and they incur increased drilling costs (and experience likely lower permeability), too shallow and they breach the supercritical threshold.
- Suitable formations must have large storage capacity at the right depths (in other words a suitable target formation that dips steeply, or lenses out, will reduce its economic attractiveness). The 'shape' or morphology of the target horizon needs to be understood during the appraisal phase.
- The basin must not be overly faulted. If multiple geological structures are present the risk of losing control of the ultimate path of the injected CO_2 is greater. Again, the Surat Basin would not be considered a highly faulted basin by international standards (the Himalayan foothill example proves the opposite case). In the Surat Basin there appears to be little possibility of CO_2 migrating to the surface via faults, as no major fault systems have been mapped at the level of the regional seal (namely, the Evergreen Formation, see Section 4.2 and Section 5).
- The hydrology of the target formation must be properly understood. Although permeability is important with regard to the rates of injection (and high permeability is advantageous), the target formation needs a slow flow rate and/or a long migration pathway in order to keep the CO_2 'in the system'. An additional consideration is the long term dynamic effect of injection on target formation permeability (permeability may actually decline in the later stages of injection).
- The geothermal gradient (the rate at which the temperature increases in the subsurface) has a bearing on CO_2 storage rates. The colder the rocks, the more CO_2 can be stored at a given pressure. The CSIRO has determined that the Surat Basin has a geothermal gradient of 28° per km depth (Figure 8, from CO_2 Storage Atlas, 2009), which is definitely cooler than parts of the Sydney and Bowen basins (for example, the Sydney Basin has a predicted geothermal gradient of up to 70° per km close to basin margins, see Harrington et al, 1989). The Surat Basin would be considered moderately 'cool' in comparison.
- It is desirable that the area has not been substantially drilled for oil and gas targets. A large number of drill holes increases the risk of leakage of CO_2 into formations other than the target horizon as most wells have not been completed to withstand the impact of acidic waters and pressures associated with supercritical CO_2. This is a genuine issue for the Surat Basin which has been extensively drilled on the Roma Shelf (for oil and gas) and on the east limb of the Mimosa Syncline for CSG.

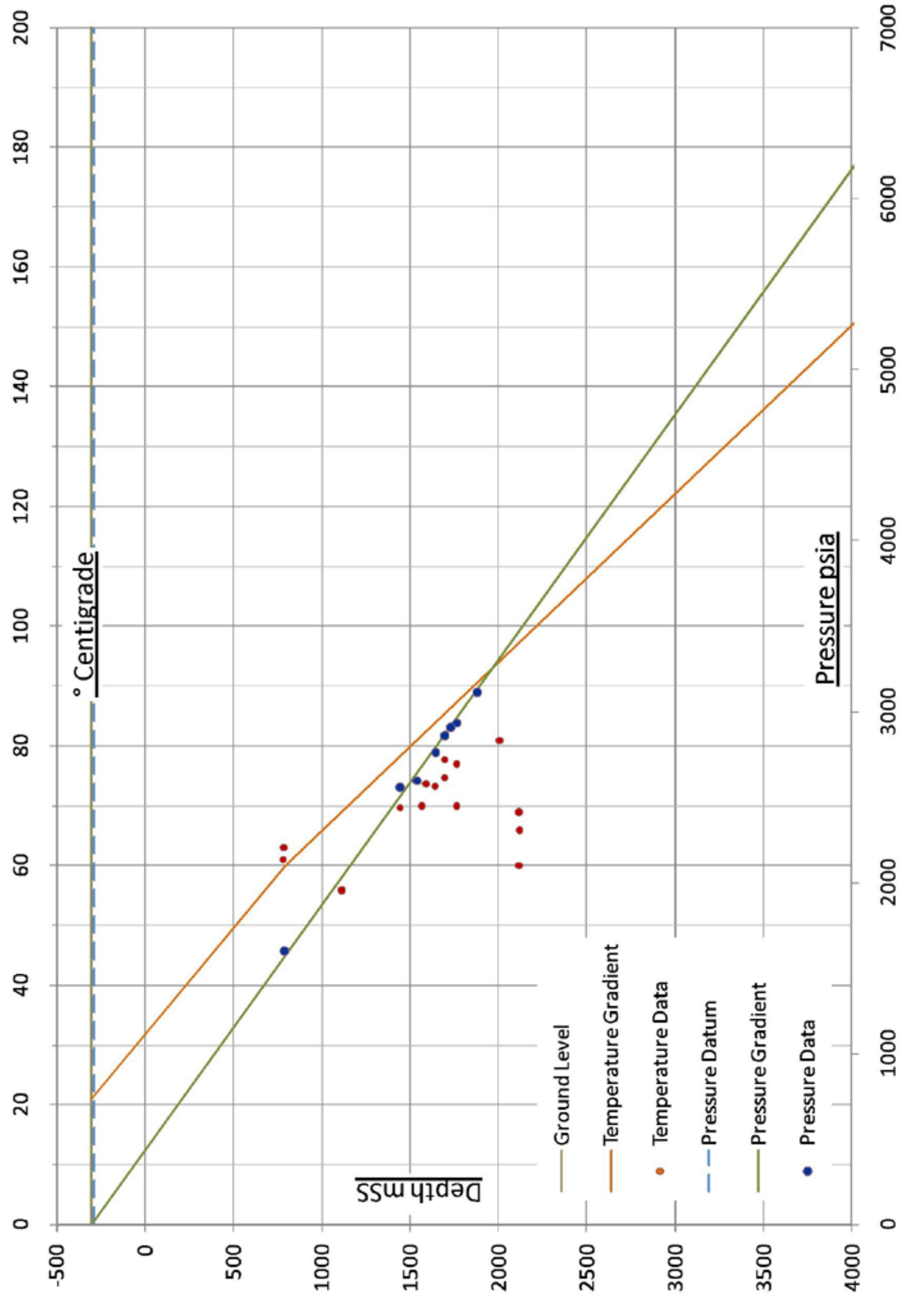


Figure 8: Geothermal gradient for Surat Basin, indicating an average increase in temperature of 28° per km (from Bradshaw et al, 2009). Note: 1000 psia = ~7000 kPa (70 bar).

A summary of these key features and their bearing on basin attractiveness for storage of CO_2 is presented in Table 2 (Surat Basin position annotated in **bold**).

Table 2: Summary table of criteria for screening sedimentary basins (from CRC CO_2 website). The Surat Basin status relative to key criterion is presented in bold.

	Criterion	Increasing CO_2 Storage Potential →				
		Classes				
		1	2	3	4	5
1	Seismicity (tectonic setting)	Very high (e.g. subduction)	High (e.g. syn-rift, strike-slip)	Intermediate (e.g. foreland)	Low (e.g. passive margin)	**Very low (e.g. cratonic)** [2]
2	Size	Very small (<1000 km2)	Small (1000–5000 km^2)	Medium (5000 – 25000 km^2)	Large (25000–50000 km^2)	**Very large (>50000 km^2)**
3	Depth	Very shallow (<300 m)	Shallow (300–800 m)		Deep (>3500 m)	**Intermediate (800–3500 m)**
4	Faulting intensity	Extensive		Moderate		**Limited**
5	Hydrogeology	Shallow, short flow systems, or compaction flow		Intermediate flow systems		**Regional, long-range flow systems[3]; topography or erosional flow**
6	Geothermal	Warm basin (>40°C/km)		**Moderate (30–40°C/km)**		Cold basin (<30°C/km)
7	Reservoir–seal pairs	Poor		**Intermediate**		Excellent
8	Coal seams	None	Very shallow (<300 m)		Deep (>800 m)	**Shallow (300–800 m)**[4]
9	Coal rank	Anthracite	Lignite		Sub-bituminous	**Bituminous**
10	Evaporites	**None**		Domes		Beds
11	Hydrocarbon potential	None	Small	Medium	**Large**	Giant
12	Maturity	Unexplored	Exploration	Developing	**Mature**	Super-mature
13	Onshore/ offshore	Deep offshore		Shallow offshore		**Onshore**
14	Climate	Arctic	Sub-arctic	Desert	Tropical	**Temperate**
15	Accessibility	Inaccessible	Difficult		Acceptable	**Easy**
16	Infrastructure	None	Minor		**Moderate**	Extensive

[2] The Surat Basin is an intracratonic basin, was formed through passive thermal subsidence, and is currently non-seismically active.
[3] The Surat Basin is part of the Great Artesian Basin.
[4] The Wallloon Coal Measures, an active CSG producing formation.

4.2 Suitability of the Surat Basin for CO_2 Storage

The Queensland Carbon Dioxide Geological Storage Atlas (Bradshaw, 2009), which currently is the definitive document on CO_2 sequestration in Queensland, has identified the Surat Basin as a suitable target for GHG storage. It cites a number of prospective sedimentary units that have promising reservoir qualities in the Surat Basin, including:

- The Precipice Sandstone – Estimated 1289 Mt of storage capacity
- The 'Basal Evergreen' Formation – Estimated 21 Mt of storage capacity
- The Boxvale Sandstone (part of the Evergreen Formation) – 454 Mt
- The Hutton Sandstone – 1198 Mt

The above named formations exhibit favourable porosity and permeability that suggest they would be excellent targets for CO_2 storage. The Precipice Sandstone in particular is a prime target, because it has favourable properties and is capped by an appropriate regional seal (the Evergreen Formation). The Precipice Sandstone exists at depths favourable for CO_2 storage in the Surat Basin GHG tenement areas. The 'Basal Evergreen' and Boxvale units are limited in exposure at suitable depths in the subsurface of the GHG tenements. The Hutton Sandstone has significant potential in the southern areas.

Geological data in the Precipice Sandstone in the GHG Tenements is heavily concentrated to the west of the north-south trending fold line of the Leichhardt Fault, south and east of Condamine and also southeast of Tara. Whilst there are extensive data sets on geology, groundwater quality and inferred porosity and permeability, there is limited hydrodynamic (i.e. groundwater head versus time) data for the Precipice Sandstone in the exploration areas.

Over the exploration areas, the thickness of Precipice Sandstone varies from in excess of 120m to the west of the Burunga-Leichhardt Fault and is over 100m thick to the west of the Moonie-Goondiwindi Fault. Much of the Precipice Sandstone lies below 800m depth.

The permeability (hydraulic conductivity) of the Precipice Sandstone in general is very high, with values typical in the range of 30 – 2500 mD and as high as 4000 mD as for example with CS Energy's Lagoon Gully No. 1 bore near Kogan Creek Power Station (regional values tend to be closer to 60mD). The Precipice Sandstone appears to be the prime target for geosequestration.

5. Assessment of the GHG Tenements in the Surat Basin

5.1 General observations

The assessment of CO_2 storage sites in the Surat Basin has been based on the comparative geological qualities of the specific EPQ's available (namely the northern Surat, EPQ 7 and EPQ 8, and the southern Surat, EPQ 10, EPQ 12, EPQ 14). Each of the EPQ's have been assessed and ranked based on compatibility with the key elements presented in Section 4.1 and 4.2.

Key parameters that influence the assessment of reservoir potential for large-scale injection and storage of CO_2 in the Surat Basin is reservoir quality (i.e. porosity ≥10 % and permeability ≥5 mD at depths ≥ 800m), and thickness and areal distribution of sandstone units where effective seals are present. The presence of an appropriate seal is paramount.

In the parts of the Surat Basin that are covered by EPQ's 7, 8, 10, 12, and 14 the obvious reservoir target is the Precipice Sandstone, and the appropriate seal is provided by the Evergreen Formation. All other potential reservoirs and seals in the Surat Basin fail one or more key criterion in the EPQ's under investigation, with the exception of the Hutton Sandstone in the southern tenements.

The Precipice Sandstone is a thick, laterally extensive reservoir and major aquifer with good porosity and permeability. The reservoir quality varies significantly from east to west. In the east, proximal to the EPQ's of interest (and the Mimosa Syncline) the maximum thickness of the formation is ~139 m with very good porosity (maximum = 37 %, median = 18 %, n = 8,002) and permeability (maximum = 2,000 mD, median = 59.5 mD, n = 730). The Precipice Sandstone thins to the west and permeability appears to decline (Bradshaw, 2009).

The upper part of the Evergreen Formation is a thick, extensive sequence of shale and siltstone with minor sandstone deposited under shallow marine to lacustrine environments that seals hydrocarbons in the underlying Early Jurassic Boxvale, basal Evergreen and Precipice sandstones. Sand units within the Evergreen Formation are minor and are interpreted to be laterally discontinuous. In the east, in addition to the Evergreen top seal, the Precipice Sandstone contains a shale unit that divides the formation into lower and upper reservoir units and forms an intraformational seal (Bradshaw, 2009).

5.2 The Northern Surat - EPQ 7

EPQ 7 (see Figure 1) is the only active current greenhouse gas tenement. Key questions that need to be asked in order to assess the suitability of the tenement for CO_2 storage include:

- **Does a suitable reservoir exist, at the right depths?**

Yes, the Precipice Sandstone is present, at appropriate depths, particularly to the southwest of the tenement (Figure 9).

- **Is the quantum of storage space suitable for CO_2 storage from Kogan?**

Yes, there is likely to be sufficient space. Our estimate is at least 88.6 Mt in the Precipice Formation (see Section 5.7).

- **Is the regional seal (the Evergreen Formation) present at appropriate depths?**

Yes, the Evergreen is present at the right depth, and is moderately thick (~200m +, Figure 10).

- **Are there any other suitable reservoirs present?**

No, not really. Only the Walloon coals and these are considered a difficult proposition for CO_2 storage (see discussion, Section 5.8).

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Conclusion: EPQ 7 is a suitable tenement for at least some storage from Kogan Creek Power Station.

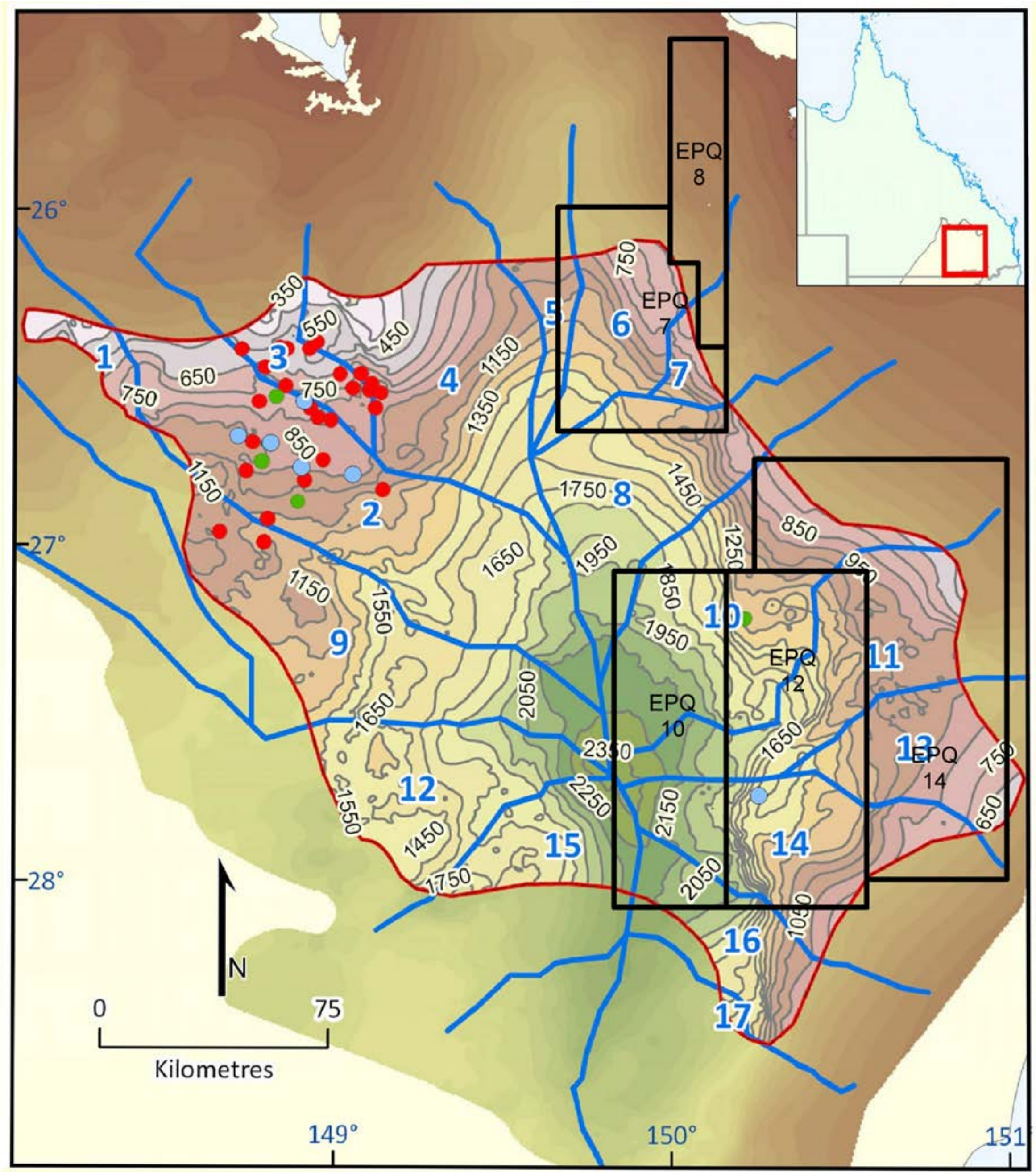

Figure 9: Depth to the top of the Precipice Sandstone (structure contours relative to mSS datum[5]). The red outline represents the 800m depth of cover limit for the Precipice Sandstone. Red, green and blue dots relate to Roma Shelf oil and gas intersections in the formation.

[5] mSS stands for "Metres Sub-Sea" and is equivalent to 'metres below sea level'.

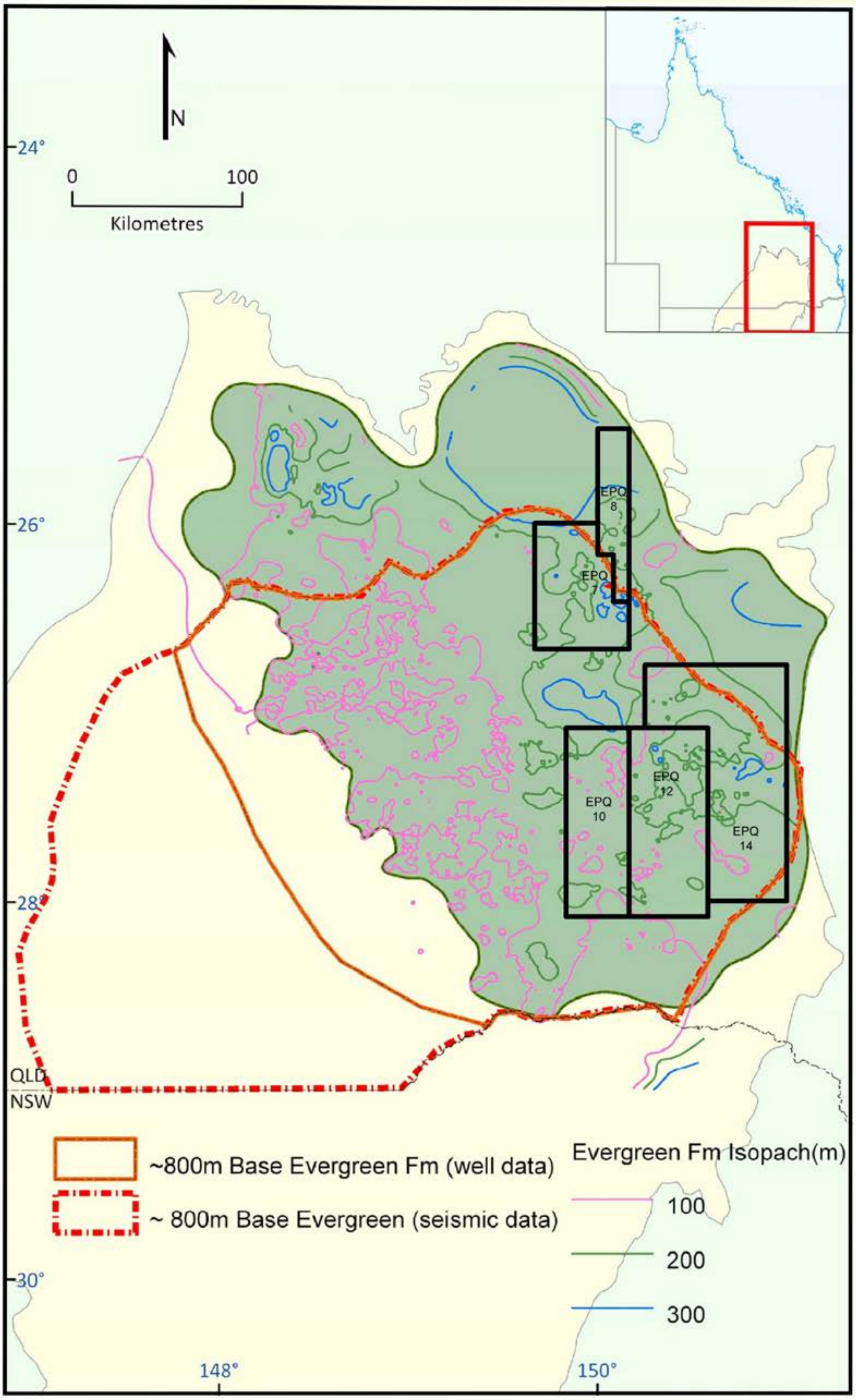

Figure 10: **Depth to the top of the Evergreen Formation (structure contours relative to mSS datum), and isopachs of seal thickness (pink, green and blue lines).**

5.3 The Northern Surat - EPQ 8

EPQ 8 (see Figure 1) is currently under application as a greenhouse gas tenement. Key questions that need to be asked in order to assess the suitability of the tenement for CO_2 storage include:

- **Does a suitable reservoir exist, at the right depths?**

No, the Precipice Sandstone is not present at the appropriate depths, it is too shallow (see Figure 9).

- **Is the quantum of storage space suitable for CO_2 storage from Kogan?**

No, there is insufficient storage capacity unless the coals are used. Approximately 0.1 Mt CO_2 storage space may exist in the Precipice Sandstone.

- **Is the regional seal (the Evergreen Formation) present at appropriate depths?**

No, the Evergreen is not present at the right depths (Figure 10).

- **Are there any other suitable reservoirs present?**

No, not really. Only the Walloon coals and these are considered a difficult proposition for CO_2 storage.

Conclusion: EPQ 8 is **not** a suitable tenement for CO_2 storage from Kogan Creek Power Station.

5.4 The Southern Surat - EPQ 10

EPQ 10 (see Figure 1) is currently under application as a greenhouse gas tenement. It is located along the axis of the Mimosa Syncline, and the Surat Basin is at its deepest.

Key questions:

- **Does a suitable reservoir exist, at the right depths?**

Yes, the Precipice Sandstone is present, however at considerable depths, and this will add considerably to the cost of storage and the depth may also affect permeability and injection rate (Figure 9). Also note that no significant increase in CO_2 density occurs below ~1800m depth, so therefore only a marginal increase in storage capacity ameliorates the cost of drilling deeper. The optimum injection interval remains to be resolved for this formation, and should be the subject of further investigations.

- **Is the quantum of storage space suitable for CO_2 storage from Kogan?**

Yes, there is plenty of space; at least 127.5 Mt of CO_2 storage is available.

- **Is the regional seal (the Evergreen Formation) present at appropriate depths?**

Yes, the Evergreen is present, also at considerable depths, but is thinner (~100m) than in the northern tenements (Figure 10). It is still likely to provide a suitable seal.

- **Are there any other suitable reservoirs present?**

Yes, the Hutton Sandstone is present, and although theoretically at appropriate depths for CO_2 storage (Figure 11), it is still very deep. It may be the optimal target in this tenement due to depth considerations, with the proviso and warning that the overlying Walloon Coal Measures are unlikely to provide as good a seal as compared to the Evergreen Formation, which overlies the Precipice Sandstone (particularly with massive depressurisation up-dip associated with CSG developments). The properties of the Hutton Sandstone appear to be favourable for CO_2 storage, and in fact porosity and permeability actually appear to be more favourable than the Precipice Sandstone in this area. We estimate that up to 183.0 Mt of CO_2 storage capability is available in the Hutton Sandstone.

Conclusion: EPQ 10 may be a suitable tenement for CO_2 storage from Kogan Creek Power Station; however depth / cost limitations will be paramount.

5.5 The Southern Surat - EPQ 12

EPQ 12 (see Figure 1) is currently under application as a greenhouse gas tenement. It is immediately to the east of EPQ 10.

Key questions:

- **Does a suitable reservoir exist, at the right depths?**

Yes, the Precipice Sandstone is present, however at considerable depths, this will add considerably to the cost of storage and the depth may also affect permeability (Figure 9).

- **Is the quantum of storage space suitable for CO_2 storage from Kogan?**

Yes, there is plenty of space. We estimate a minimum of 160.6 Mt of CO_2 storage capability available in the Precipice Sandstone.

- **Is the regional seal (the Evergreen Formation) present at appropriate depths?**

Yes, the Evergreen is present, and of moderate thickness (~150m +) (Figure 10).

- **Are there any other suitable reservoirs present?**

Yes, the Hutton Sandstone is also present, at what are likely to be appropriate depths for CO_2 storage (Figure 11). We estimate that up to 229.1 Mt of CO_2 storage capability is available in the Hutton Sandstone. The properties of the Hutton Sandstone appear to be favourable for CO_2 storage. The Hutton Sandstone is overlain by the Walloon Coal Measures which is likely to provide a suitable seal, again with the proviso that the impact of the impending massive depressurisation of the coals via CSG extraction would add a level of uncertainty to the consideration.

Conclusion: EPQ 12 may be a suitable tenement for CO_2 storage from Kogan Creek Power Station, however depth / cost limitations will be paramount.

5.6 The Southern Surat - EPQ 14

EPQ 14 (see Figure 1) is currently under application as a greenhouse gas tenement, but at time of writing the application has been unsuccessful. It is immediately to the east of EPQ 12. This is the only tenement under application from Carbon Energy (Operations) Pty Limited (all others are CTSCo).

Key questions:

- **Does a suitable reservoir exist, at the right depths?**

Yes, the Precipice Sandstone is present, and at appropriate depths, but in some parts of the lease is too shallow (Figure 9).

- **Is the quantum of storage space suitable for CO_2 storage from Kogan?**

Yes, we estimate that at least 137.9 Mt is available in the Precipice Sandstone.

- **Is the regional seal (the Evergreen Formation) present at appropriate depths?**

Yes, the Evergreen is present, and of moderate thickness (~200m +) (Figure 10).

- **Are there any other suitable reservoirs present?**

No, the Hutton Sandstone is not present in any meaningful way (Figure 11).

Conclusion: EPQ 14 may be a suitable tenement for CO_2 storage from Kogan Creek Power Station. An additional social constraint may be the extent of CSG activity in the same area.

5.7 Storage Capacity for EPQ's

The CO_2 storage capacity of the respective EPQ's and ranking of the prospectivity of the GHG tenements, is presented in Table 3. The areal extent of each EPQ's exposure to the key reservoirs is presented in Figures 13 and 14.

Table 3: Summary table showing CO2 storage capacity of each EPQ and individual ranking.

EPQ	CO2 Storage Capacity (Mt)				
	Precipice Sandstone	Hutton Sandstone	Total storage capacity	Ranking	Comments
7	88.6		88.6	4	Moderate reservoir, relatively shallow
8	0.1		0.1	5	Not attractive, too shallow
10	127.5	183	310.5	2	Large reservoir, appropriate seal, but very deep
12	160.6	229.1	389.7	1	Largest reservoir, appropriate seal, and depths are encouraging
14	137.9	1.4	139.3	3	Moderate reservoir, relatively shallow

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5.8 The Walloon Coal Measures as a Storage Option

In principle, CO_2 can be stored in the Walloon coals in its gassy state, at depths less than 800m, and the coals are present in all of the GHG tenements (Figure 12). However, it is a difficult proposition to store significant quantities of CO_2 in coals due to their very low injection rates. In addition, the currently massive CSG developments on the eastern limb of the Mimosa Syncline also implies that finding suitable areas to inject CO_2 will be hampered by scheduling conflicts with CSG operators (a CSG operator would be unlikely to support CO_2 injection prior to production of CSG). We suggest that the Walloon coals are not a serious option for CO_2 storage for the reasons already mentioned, plus the following:

- Walloon coals are discontinuous and of poor quality, this lenticular nature is unlikely to be favourable for long term migration of CO_2.
- The sheer volume of completed CSG boreholes is likely to compromise the sealing properties of the non-coal sections in the Walloon Coal Measures.
- The extent of depressurisation through CSG activities will certainly have a major impact upon regional hydrology and may result in unexpected outcomes in terms of migration pathways.
- The non-coal sections of the Walloon Coal Measures may prove an inadequate seal to prevent CO_2 migration into the overlying Springbok Sandstone aquifer.

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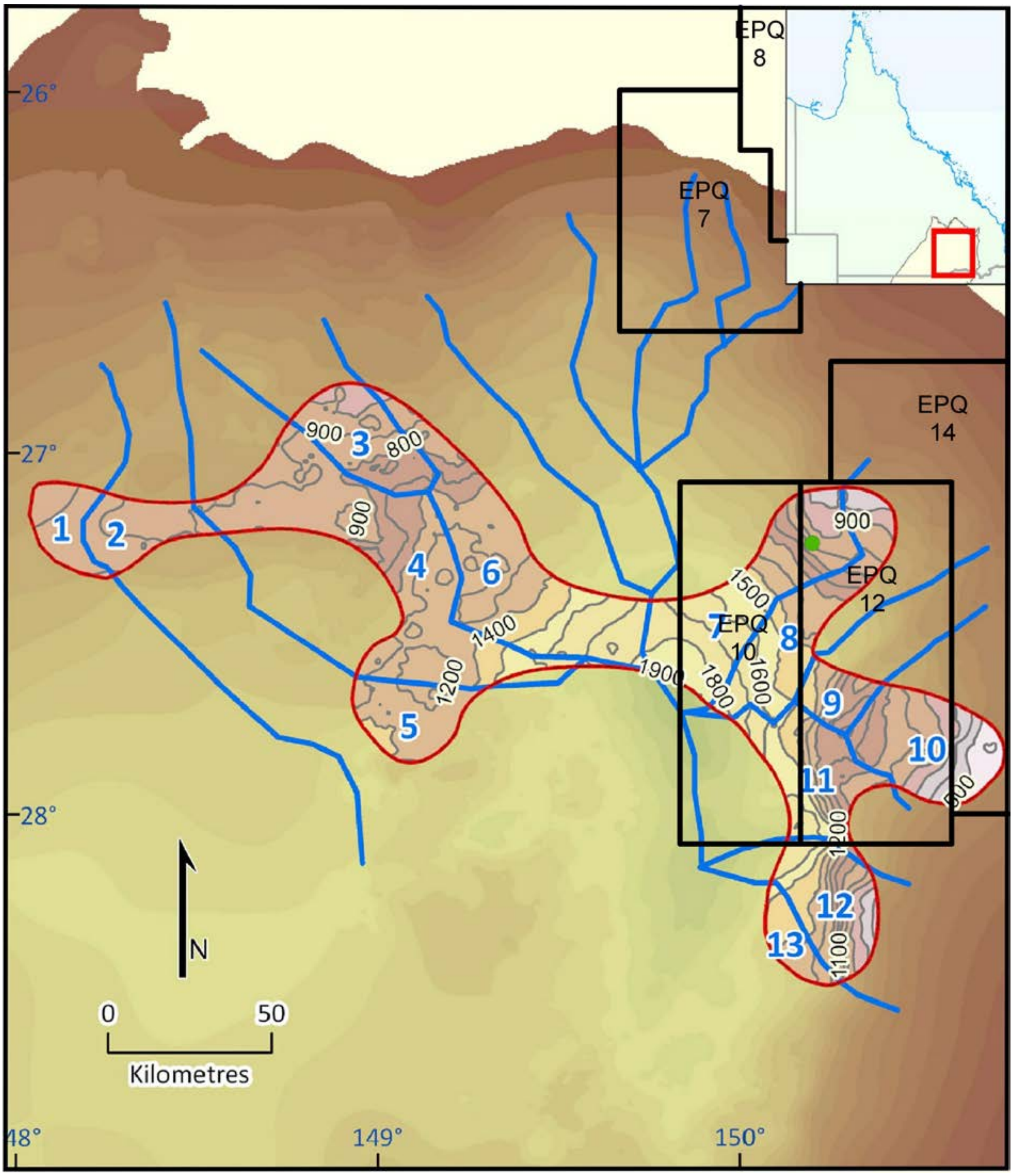


Figure 11: **Depth to the top of the Hutton Sandstone (structure contours relative to mSS datum), the red line represents the extent of sub-800m Hutton reservoir available for sequestration.**

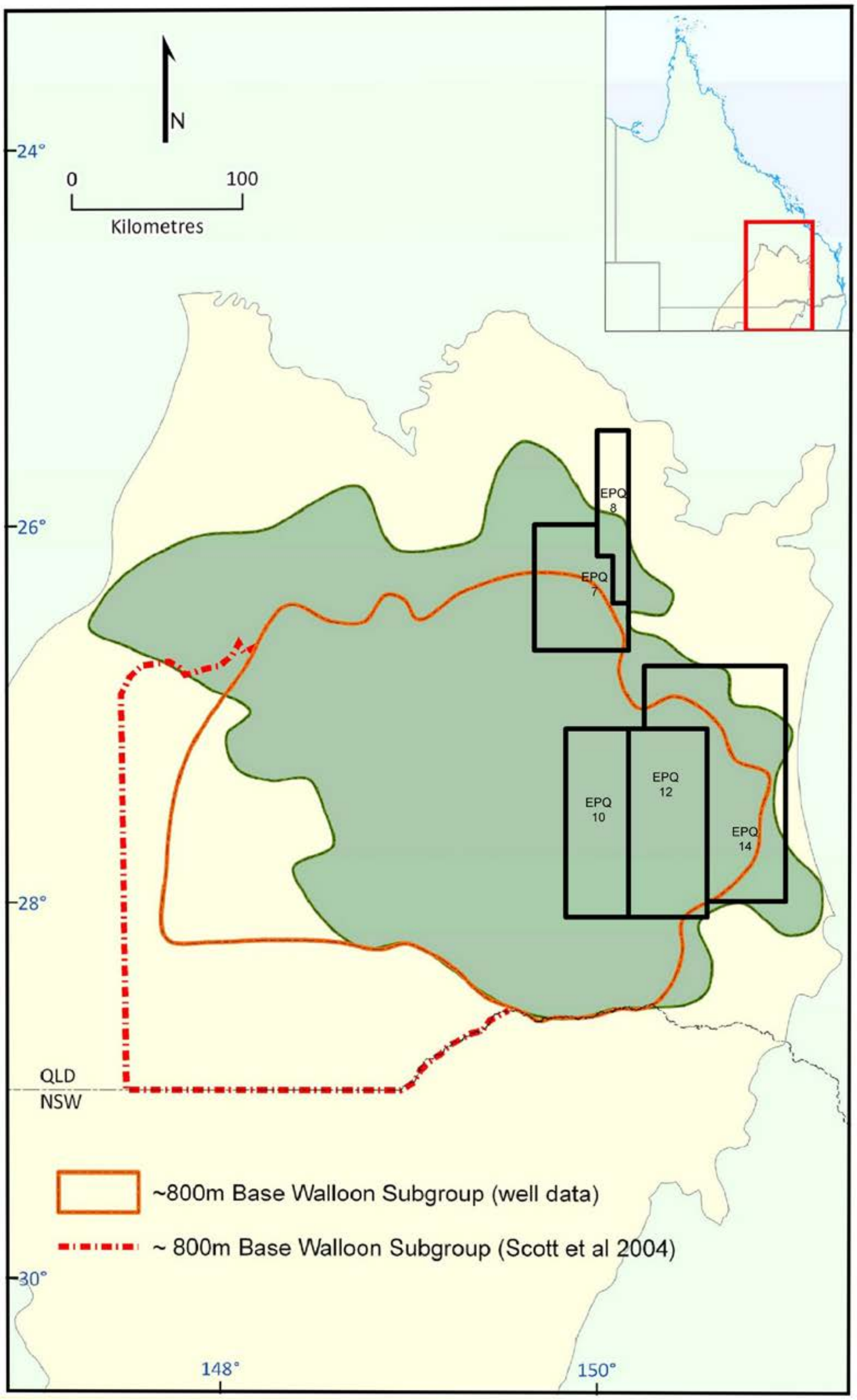
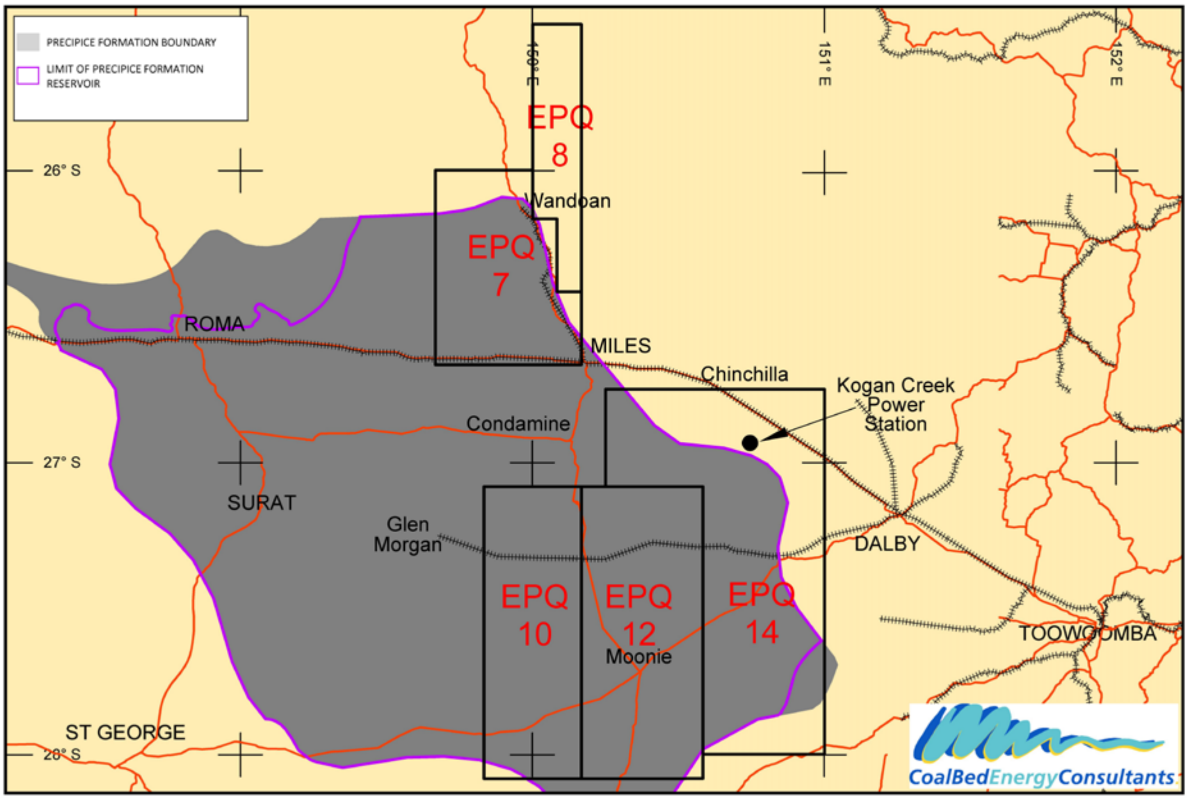
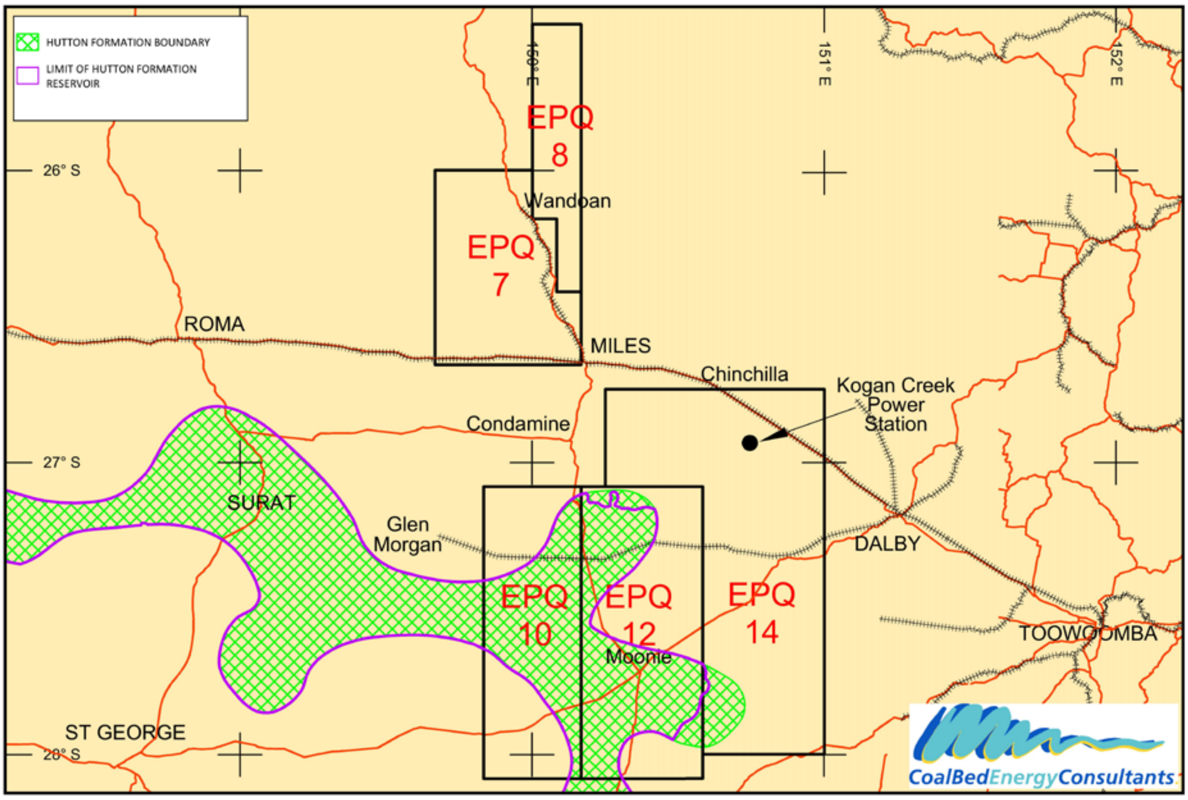


Figure 12: Extent of the Walloon Coal Measures relative to the GHG tenements.



<u>Figure 13:</u> Position of the various GHG tenements relative to the subsurface distribution of the Precipice Sandstone reservoir.



<u>Figure 14:</u> Position of the various GHG tenements relative to the subsurface distribution of the Hutton Sandstone reservoir.

6. Social and Environmental Factors

The GHG tenements are all located in the Western Downs region of the Surat Basin. The Western Downs region dominates Queensland's Surat Basin, which is one of the nation's fastest growing regions. The Western Downs Regional LGA experienced a 17.4% increase in Gross Regional Product and a 400% growth in the mining sector during 2008-09 (Western Downs Regional Council website, http://www.wdrc.qld.gov.au/business-industry . The unemployment rate in the Western Downs Regional LGA was 4.4% in the September Quarter 2011, which was lower than the averages for both Queensland (5.5%) and Australia (5.1%). These positive indicators would have only improved since these statistics were gathered.

Traditionally, these areas are characterised by a range of agricultural activities including grazing, cropping and rural lifestyle properties. In more recent times, the CSG industry has established a very strong presence in the area, and there has been considerable opposition to CSG, mainly built on concerns relating to various aspects of groundwater management. The challenge for the area is to capitalise on the benefits of the resources boom without adversely impacting upon prime agricultural land, and to manage the conflict between protagonists representing both sides of the debate. Most of the prime agricultural land (based around the subcrop of the Condamine alluvium) occurs east of the GHG tenements. There is a significant socio-economic constituency, located around Tara, which hosts alternate lifestyle inhabitants, many of whom are 'off the grid' (i.e. have no power, water, phones etc.). This group is strongly opposed to development of any kind.

To the west of the GHG tenements, the Roma area is one of the oldest oil and gas regions in Australia, with strong local ties to the petroleum industry. This has not been the case in the east of the Surat, and in the areas of the GHG tenements, and any positive perspectives on the resource industry that may occur in the Roma area do not appear to translate to support in the east.

A summary of the social, land access and stakeholder characteristics of each of the GHG tenements is presented in Table 4.

Table 4: A summary table showing key land access, infrastructure and stakeholder issues for the GHG tenements.

EPQ	Towns	Land access and infrastructure	Land use	Community issues	Stakeholder issues
7	Wandoan	Significant infrastructure expansion in the area as part of the LNG projects, and proposed coal mining. Intersected by export pipeline.	Grazing. Mod-high value agricultural land. CSG and open cut mining	Housing shortages, impact of CSG & mining on services.	Anti- coal. Heartland of agriculture vs. mining dispute.
8	Wandoan	Significant infrastructure expansion in the area as part of the LNG projects, and proposed coal mining. Intersected by export pipeline.	Grazing. Mod-high value agricultural land. CSG and open cut mining	Housing shortages, impact of CSG & mining on services.	Anti- coal. Heartland of agriculture vs. mining dispute.
10	Wieambilla, Tara	Significant infrastructure developed for gas fields, trunklines and major infrastructure corridors.	Mixed; grazing and rural lifestyle blocks. Full field CSG development. Land of low agricultural value.	Housing shortages, impact of CSG & mining on services.	Anti-CSG , lower socio-economic area.
12	Wieambilla, Tara	Significant infrastructure developed for gas fields, trunklines and major infrastructure corridors.	Mixed; grazing and rural lifestyle blocks. Full field CSG development. Land of low agricultural value.	Housing shortages, impact of CSG & mining on services.	Anti-CSG , lower socio-economic area.
14	Kumbarilla, Kogan	Significant infrastructure developed for gas fields, trunklines and major infrastructure corridors.	Grazing and cropping. Kogan Creek Mine & Coal Fired power station.	Housing shortages, impact of CSG & mining on services.	Anti-CSG , lower socio-economic area.

It does not appear that any of the GHG tenements have an advantage over the others in terms of access and infrastructure, community or stakeholder issues. All are affected by the CSG developments and their impact upon community perception of resource based activities. The presence of the CSG operators has ensured that the area is traversed by roads of reasonable quality and infrastructure, facilities are available, and suitable contractors are all nearby.

Groundwater issues remain a key area of debate and controversy surrounding CSG developments, in conflict with landowners, many of which already operate water bores drilled into Surat Basin formations relevant to potential sequestration (including the Walloon Coal Measures, the Hutton Sandstone and the Precipice Sandstone). The most important aquifers in the Surat Basin are the Precipice, Boxvale, Hutton, Springbok, Gubberamunda, and Mooga sandstones. The Precipice Sandstone yields water of very good domestic quality, whereas the Hutton tends to more variable (Quarantotto 1989).

There are approximately 5,300 groundwater bores drilled in the Surat Basin, 900 of which exhibit artesian flow conditions (Hodgkinson and Grigorescu, 2012). Bores exploiting the lower to middle Jurassic succession are mainly restricted to the northern and eastern margins of the basin, where the principal aquifers of the Hutton Sandstone and the Precipice Sandstone are relatively shallow (200–300m depth).

The key issues surrounding groundwater in the Surat Basin include:

- Long term impact of CSG extraction on the Great Artesian Basin (which the Surat Basin is part of), and more specifically on individual farmer's bores.
- Possibility of groundwater contamination via CSG activities (e.g. hydraulic fracturing, dumping of waste water after drilling, salt residues left behind after CSG water processing, etc.).
- The impact of CSG on the high-value agricultural land associated with the Condamine alluvium (part of the Murray-Darling Basin). The Condamine alluvium is mainly located to the east and north of EPQ's 10, 12 and 14 and is not of direct concern to sequestration activities (which will target deep formations in the Surat Basin).

The main sequestration targets in the EPQ's include the Hutton and Precipice Sandstones. Both units have been commonly targeted for groundwater extraction by farmers, but not at the depths they are encountered in the GHG tenements. Nevertheless, sequestration activities are likely to be perceived as a potential threat to farmer's bores located up dip of sequestration activities. It will be essential to undertake a comprehensive hydrological study prior to the initiation of storage of CO_2 in the Hutton and Precipice Sandstones, and it will also be necessary to undertake water quality analysis, and pressure monitoring of the key formations. A considerable body of work is currently being undertaken in conjunction with CSG activities, and much of this will be directly relevant to groundwater assessment pertinent to CO_2 storage (for example, see Queensland Water Commission Report, 2012).

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The single biggest issue for CO_2 storage in the area will be managing competing land use issues. Negotiating access with CSG licence holders will be an additional non-technical challenge and a potential barrier. A considerable effort will be required to deal with the competing interests of farmers, rural lifestyle owners, gas companies in full-field development mode, and coal miners.

It will help that the location of single (or widely spaced) storage facilities is unlikely to be considered overly intrusive in an area already affected by CSG wells, spaced (in many cases) nominally 750m apart on a rectangular grid. The depth of CO_2 injection activities may also ameliorate local landowner concerns with regard to impact upon their water bores. The depths at which CO_2 remains in the supercritical phase (>800 m) are typically much greater than the regions where groundwater is abstracted for irrigation, stock watering and municipal supply.

It is unknown how the anti-CSG lobby will respond to CO_2 storage – it may be perceived as a positive due to its 'green' credentials, but if the 'Lock the Gate' Alliance and others oppose the development, this is sure to lead to delays and adverse publicity.

7. Conclusions and Recommendations

The best potential geological storage area in the Surat Basin is the broad structural depression of the Mimosa Syncline, where the structural architecture of the basin provides long-range migration for any stored CO_2, and maximises the potential for residual gas saturation storage. EPQ 7, 10 and 12 are particularly well situated with respect to the structural morphology of the Mimosa Syncline.

Within the Mimosa Syncline, numerous structures with mapped closures are present in which shale and mudstone units (Upper Evergreen, Walloon Subgroup) have acted as conventional and intraformational seals for fluvial quartzose sandstone reservoirs (Precipice Sandstone and the Hutton Sandstone in particular). No major fault systems have been mapped at the level of the regional seals.

The Precipice Sandstone is the most favourable target for CO_2 storage in the GHG tenements of the Surat Basin, due to its favourable reservoir properties, appropriate depths, and the presence of a regional seal, namely the Evergreen Formation. The Precipice Sandstone is also at its thickest (up to 139m) in the east of the Surat Basin in the general area covered by the GHG tenements.

EPQ's 7, 10, 12 and 14 are all prospective for the storage of significant CO_2 in the Precipice Sandstone, and in the case of EPQ 10 and 12, also in the Hutton Sandstone. More than 900 Mt of CO_2 can potentially be stored in these GHG tenements. This figure is likely to be conservative, and further work is required to ascertain the thickness and extent of potential injection horizons in both the targeted reservoir horizons.

Further development of the key GHG tenements in the Surat Basin will require the drilling of dedicated CO_2 storage wells designed to provide detailed sedimentology from the key formations, and to investigate the porosity, permeability and injection capacity of the Precipice and Hutton

Sandstones. True storage effectiveness, the presence (or otherwise) of trapping mechanisms, potential impacts and resource conflicts at this stage remain unknown until detailed site-specific characterisation takes place.

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APPENDIX I – SUMMARY OF DATA FROM KEY REGIONAL BOREHOLES

Borehole	Drilled by	Spud date	TD	Purpose	Data available	Key findings pertinent to CO2 storage
Cabawin 1	Union Oil	Oct 6, 1960	12,035' (3,668.2m)	Oil & gas exploration borehole - test petroleum potential of domed structure & unconformity	Geophysical logs, cutting logs, some conventional cores, sidewall samples, gas detection on rig, short production test	Hydrocarbon shows, and flows of salt water, stratigraphic relationships
Keggabilla 1	Hartogen Energy	Oct 10, 1987	4,853' (1,479.1m)	Oil & gas exploration borehole - test petroleum potential of Precipice Sandstone	Geophysical logs, cutting logs, gas detection on rig, velocity survey, no well testing	Showed no hydrocarbons in Precipice, 100% gas saturated, stratigraphic relationships
Wandoan 1	Union Oil	Apr 22, 1962	3,278' (999.1m)	Wildcat oil & gas exploration borehole - test petroleum potential of north plunging anticline	Geophysical logs, cutting logs, some conventional cores, sidewall samples, gas detection on rig, short production test	Showed only trace hydrocarbon shows, and flows of fresh water, stratigraphic relationships
South Burunga 1	Union Oil	May 1, 1966	8,524' (2,598.1m)	Oil & gas exploration borehole - test petroleum potential of 'southern lobe of Burunga anticline'	Geophysical logs, cutting logs, some conventional cores, sidewall samples, gas detection on rig, short production test	Showed only trace hydrocarbon shows, and flows of fresh water, stratigraphic relationships
Lagoon Gully 1	CS Energy	Oct 8, 2007	1,122m	To monitor the impact of pumping from the Lagoon Gully No. 1 bore on the piezometric surface of the Precipice Sandstone aquifer	Chip logs, hydrology reports	Hydrology information, stratigraphic relationships

APPENDIX II – WELL COMPLETION REPORTS FROM KEY REGIONAL BOREHOLES