Unconventional Gas SELGA Forum

South Australian Regulatory Provisions

By

Michael Malavazos
Director Engineering Operations Branch
Energy Resources Division

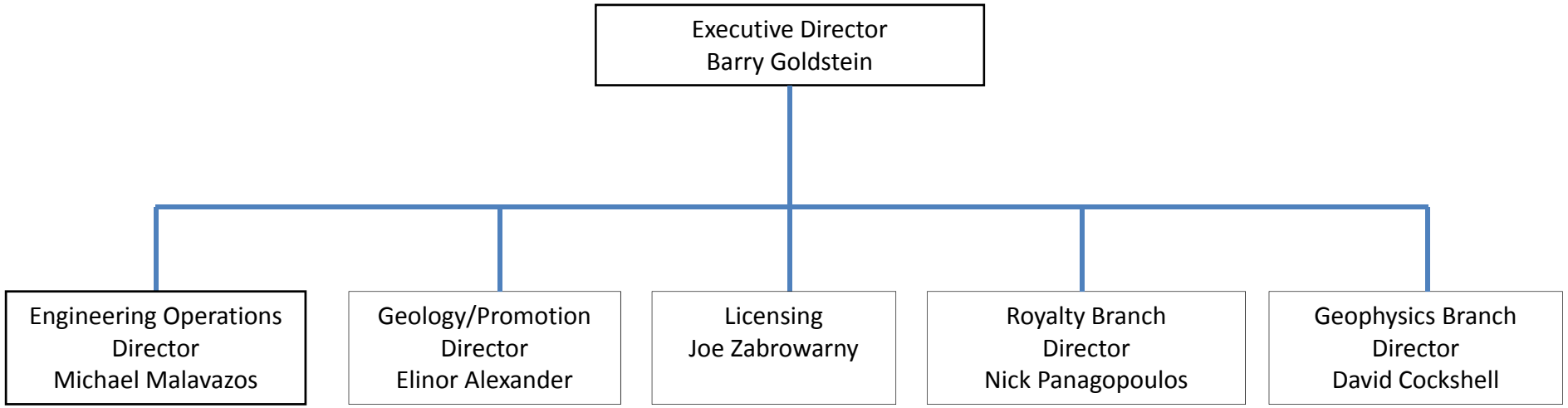
Purpose of Briefing

1) Who am I?

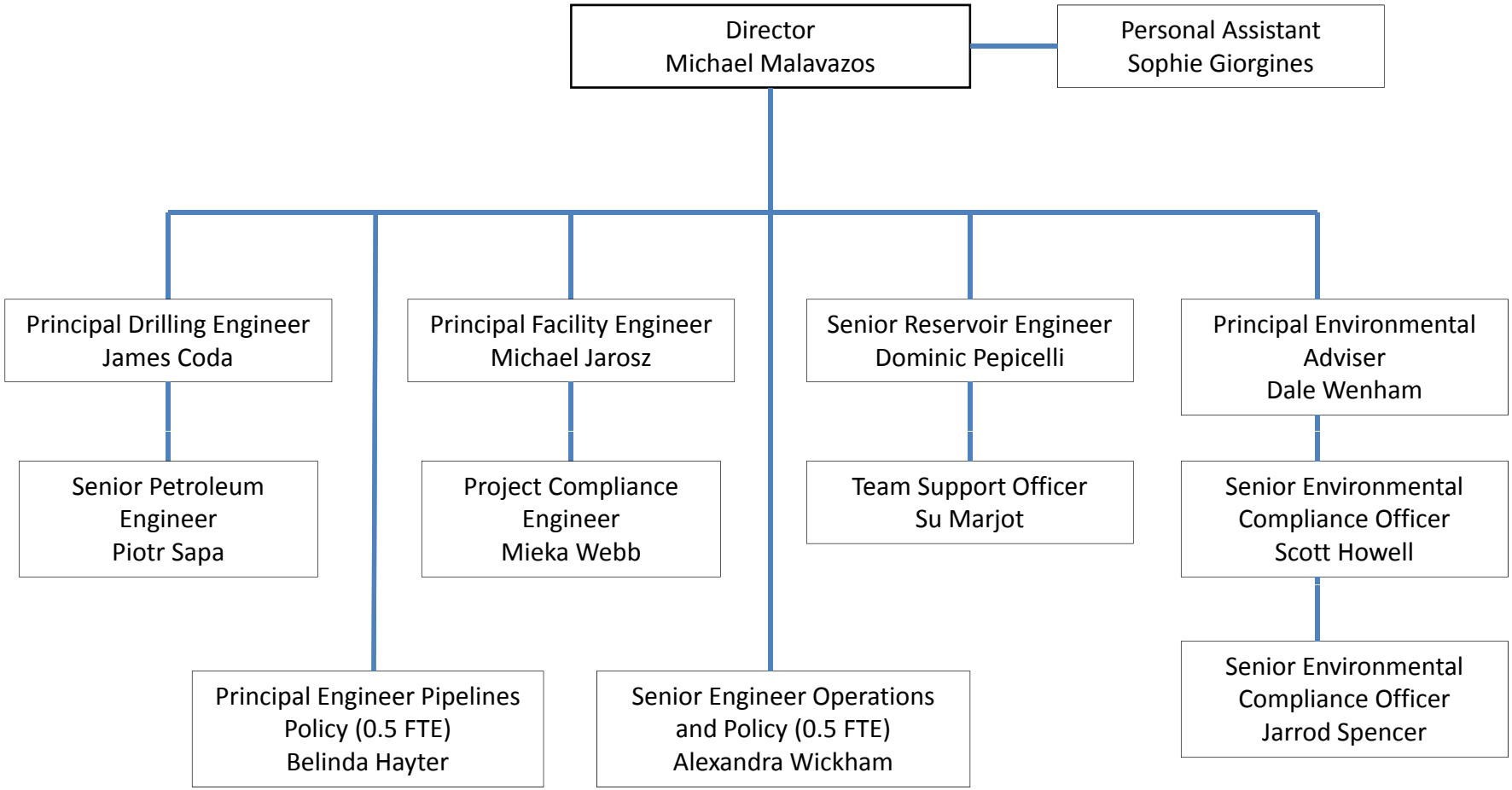
2) Part 1
- What is unconventional gas?
  - What is hydraulic fracturing?
- Background and history of gas extraction and drilling in SE
- State Government approval and regulatory processes, including the information requirements and local consultation

3) Part 2
- What are the Risks associated with unconventional gas exploration, drilling and related activities

Energy Resources Division



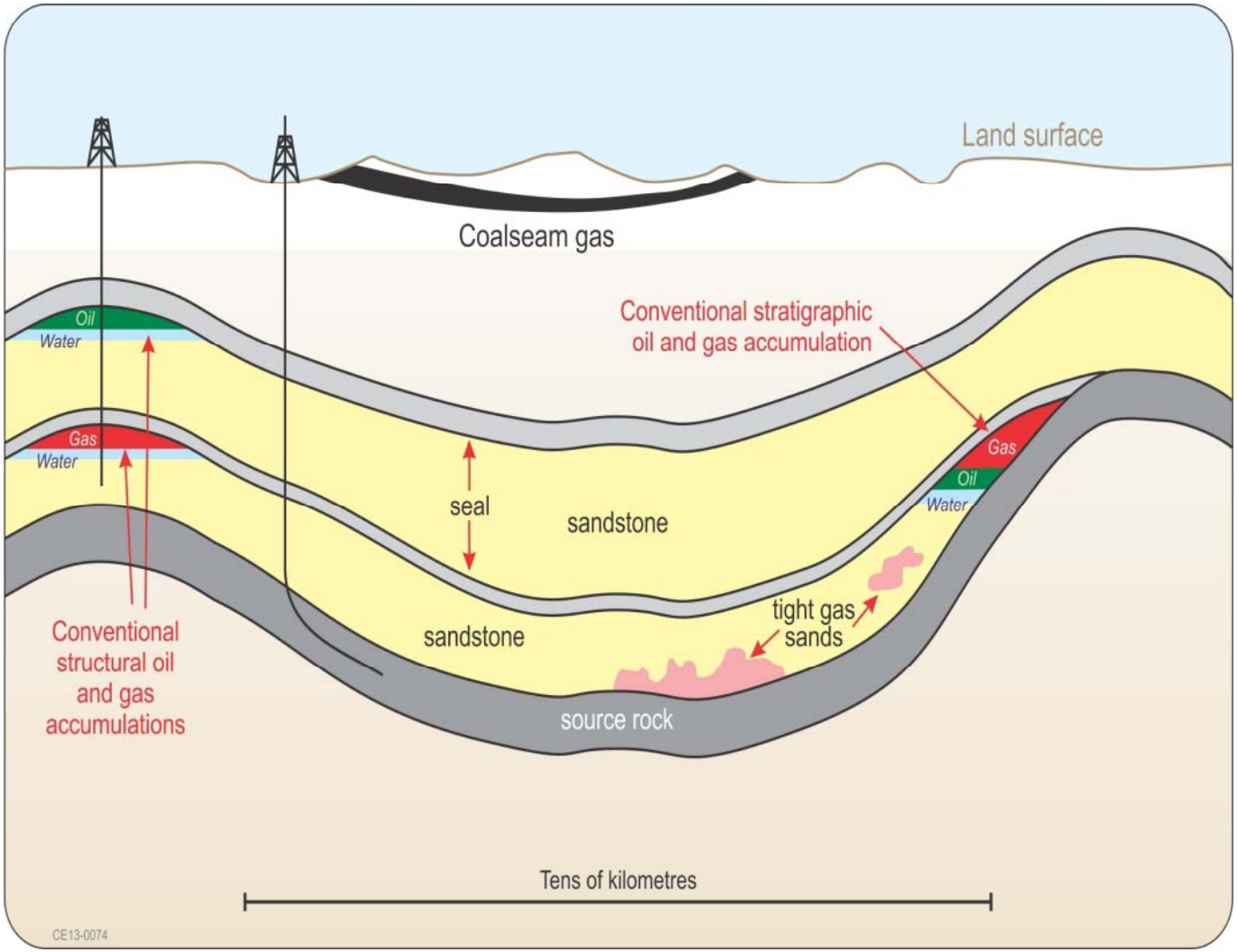
Engineering Operations Branch



Part 1

What is unconventional gas and oil?

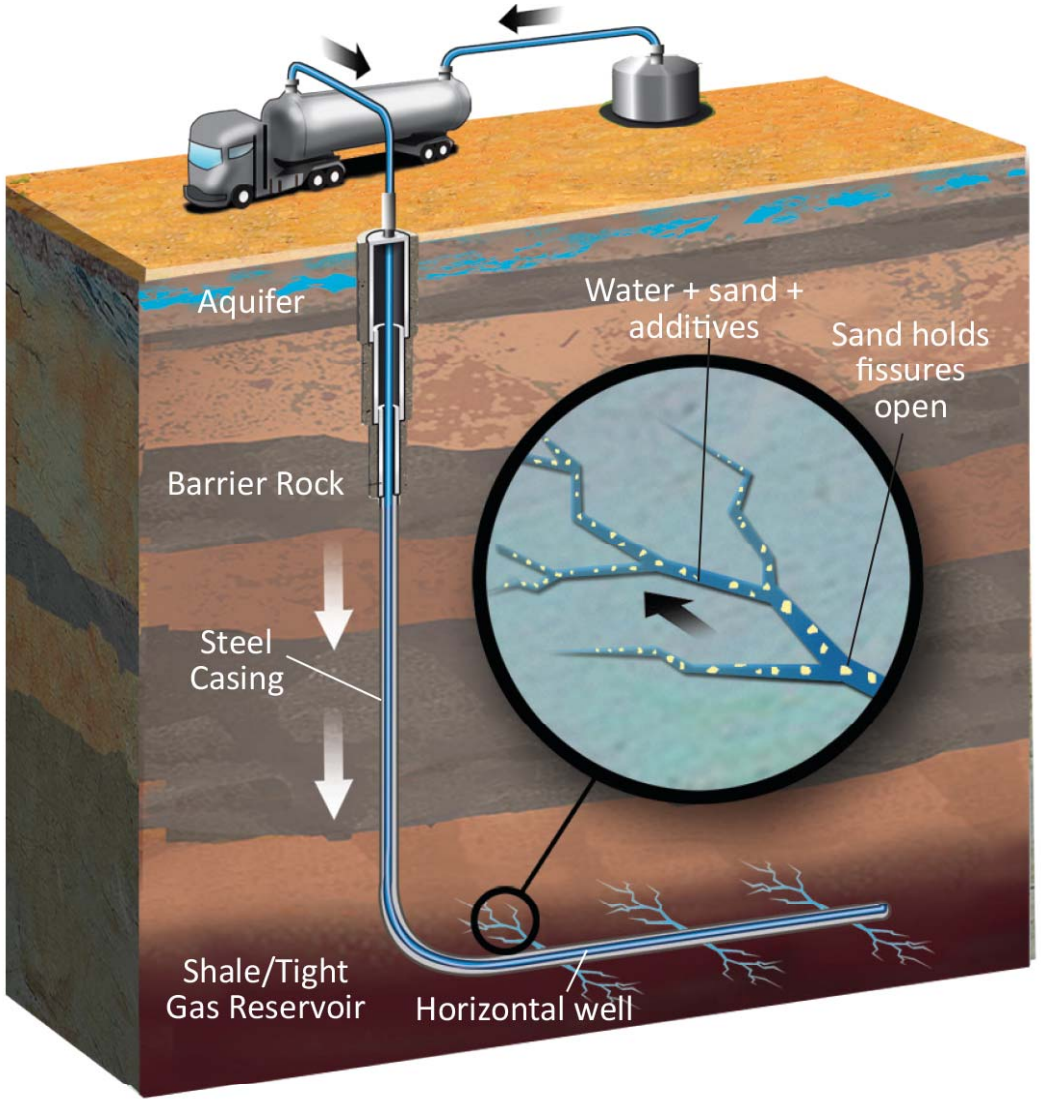
Oil and Gas
Conventional and Unconventional

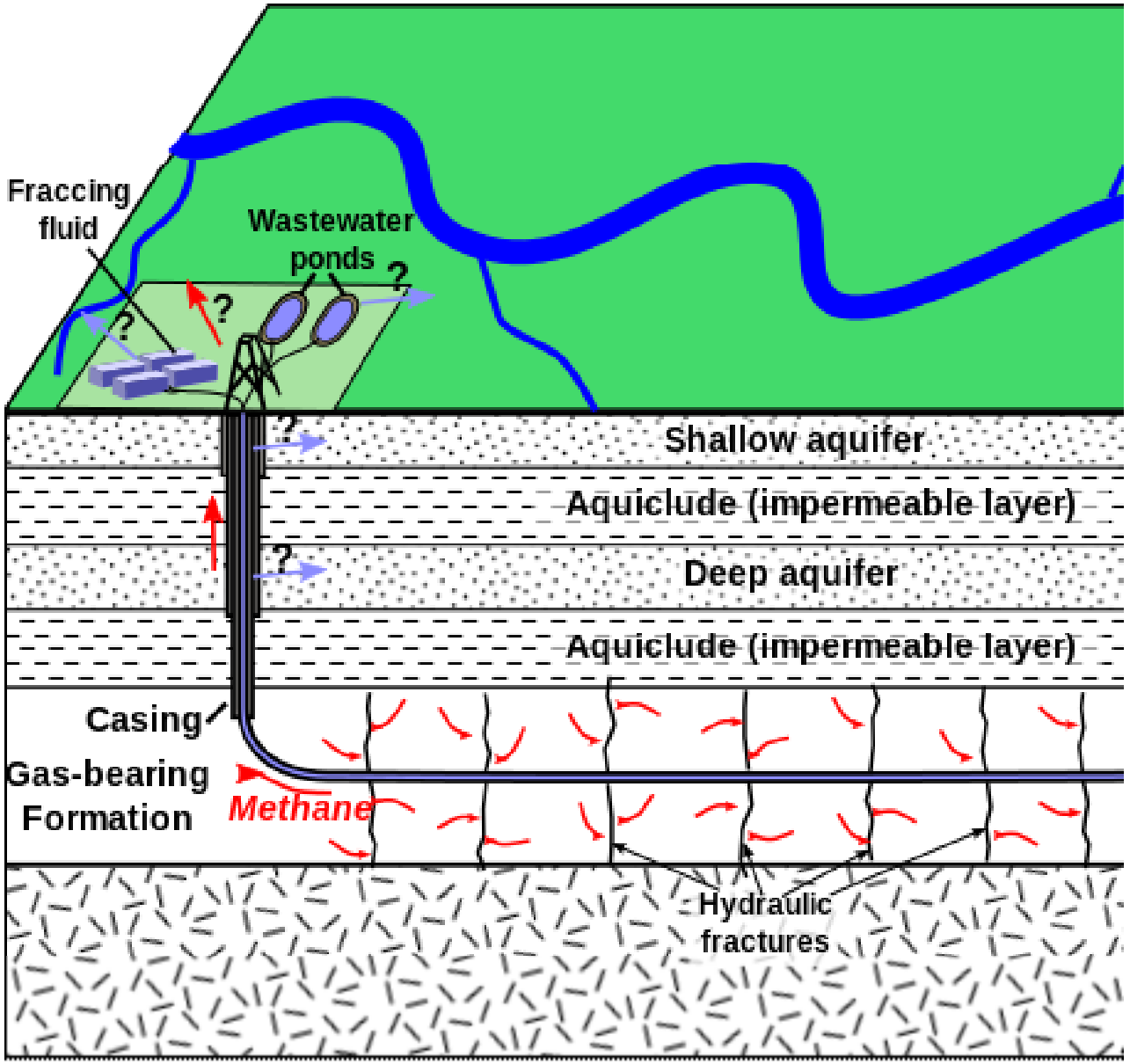


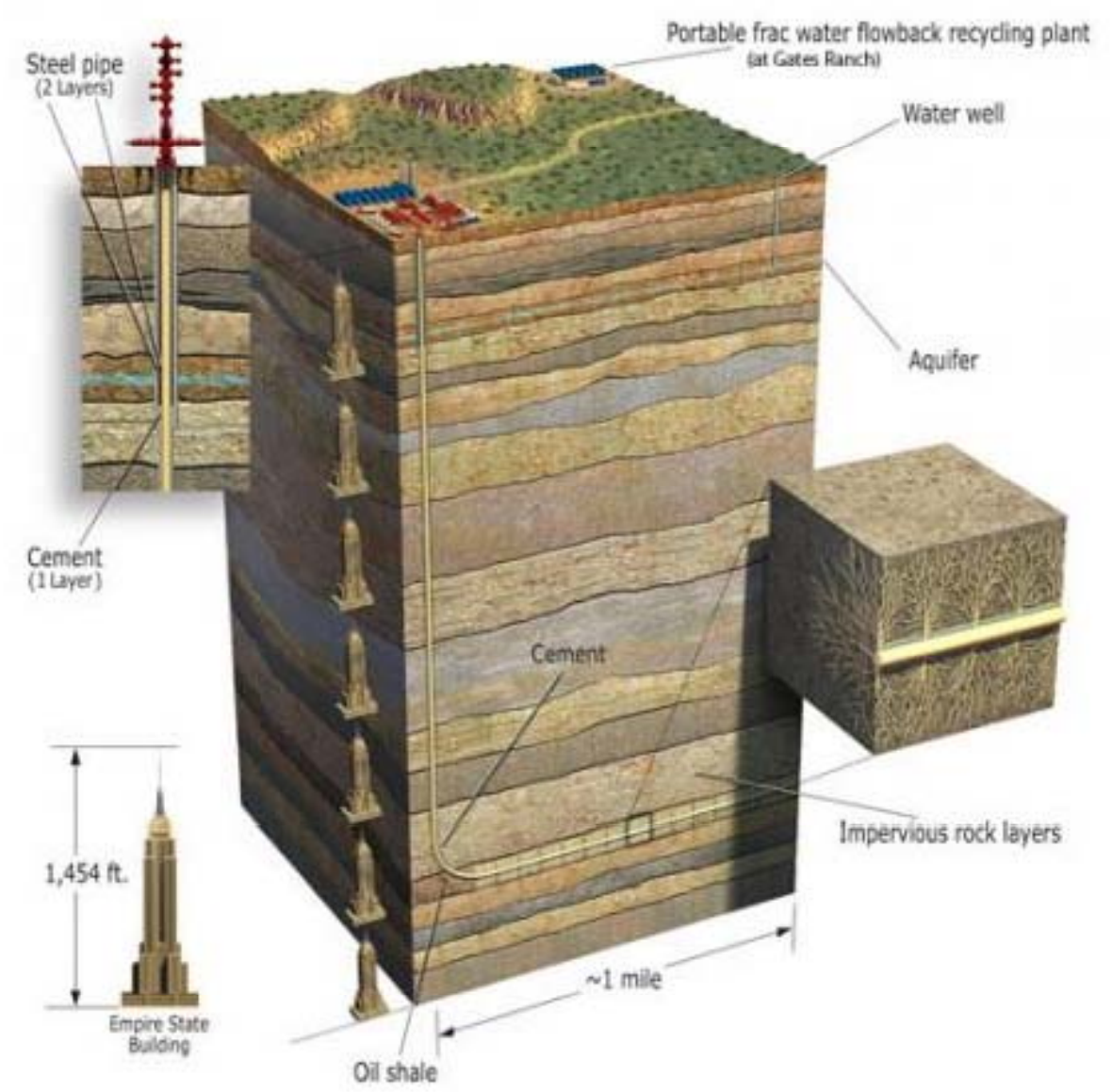
What is Hydraulic Fracturing

"..is a technique in which a mixture of mainly water mixed with sand (99.5% vol.) and chemicals (0.5% vol.) is injected at high pressure into a well to create small fractures (typically less than 1-2 mm), along which fluids such as gas and oil may migrate to the well."

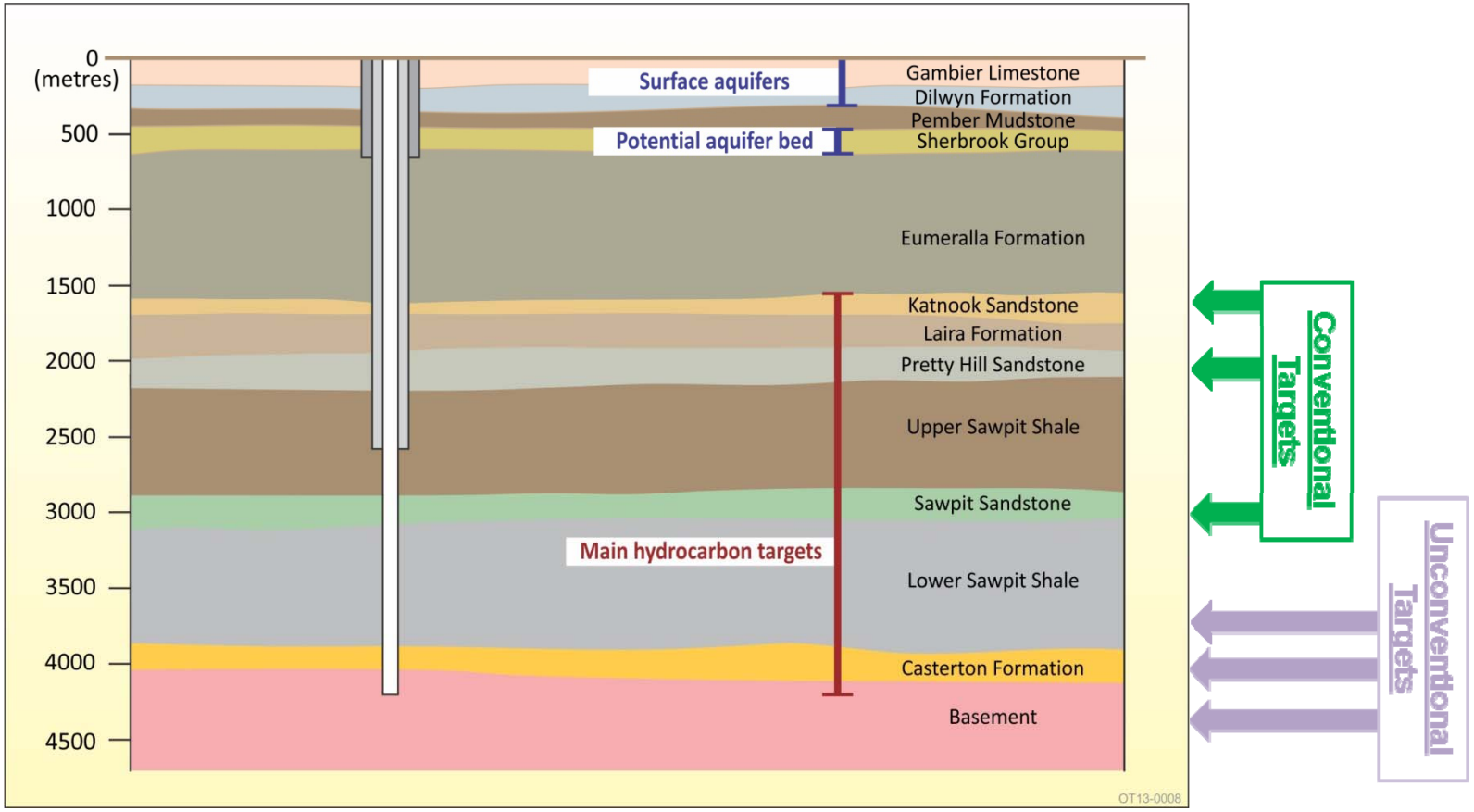
In SA Cooper Basin over 700 wells (circa 1400 stages) have been fracture stimulated


Aquifer
Water + sand + additives
Sand holds fissures open
Barrier Rock
Steel Casing
Shale/Tight Gas Reservoir
Horizontal well

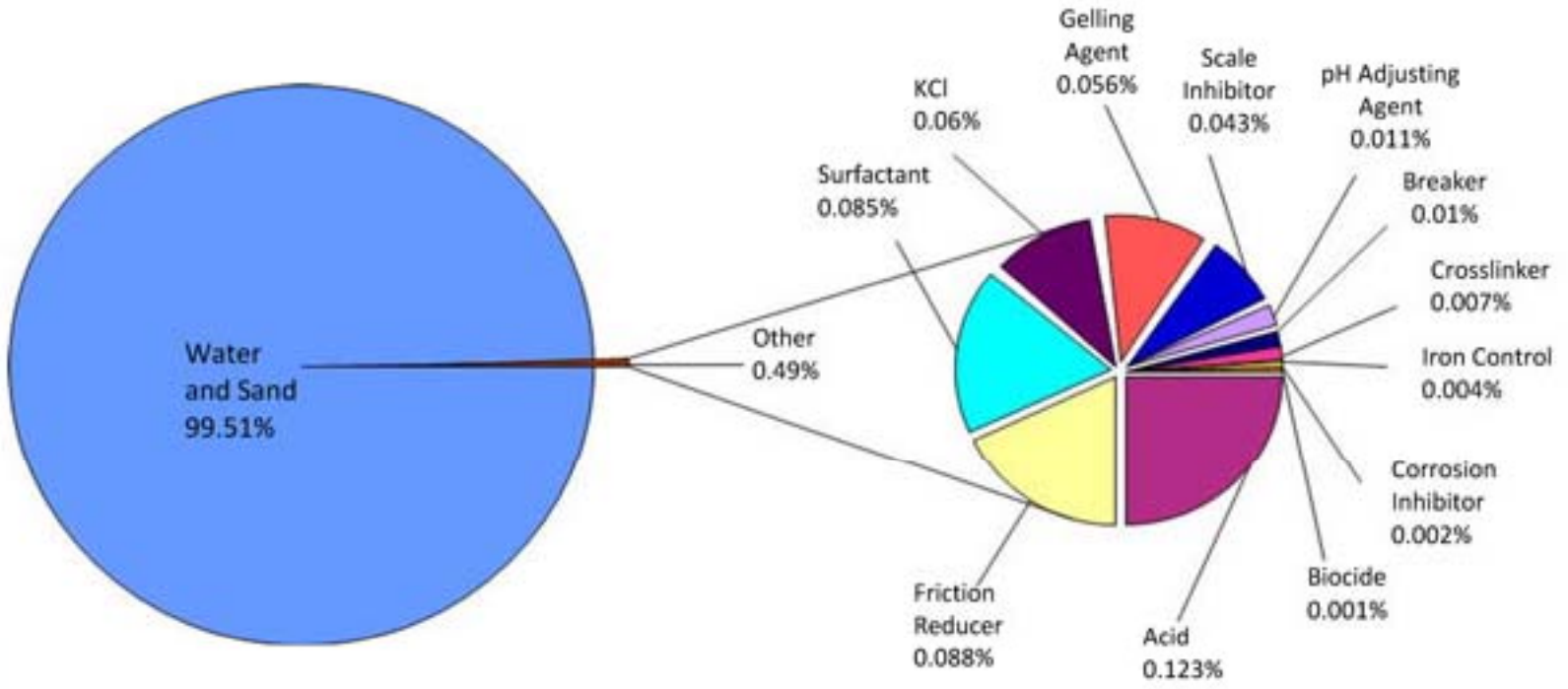

Fraccing fluid
Wastewater ponds
?
?
?
?
?
Shallow aquifer
Aquiclude (impermeable layer)
Deep aquifer
Aquiclude (impermeable layer)
Casing
Gas-bearing Formation
Methane
Hydraulic fractures


Portable frac water flowback recycling plant
(at Gates Ranch)
Steel pipe
(2 Layers)
Water well
Aquifer
Cement
(1 Layer)
Cement
Impervious rock layers
1,454 ft.
Empire State
Building
~1 mile
Oil shale

South East Source of Gas



Hydraulic Fracturing Animation


Water
and Sand
99.51%
Other
0.49%
KCl
0.06%
Gelling
Agent
0.056%
Scale
Inhibitor
0.043%
pH Adjusting
Agent
0.011%
Surfactant
0.085%
Breaker
0.01%
Crosslinker
0.007%
Iron Control
0.004%
Corrosion
Inhibitor
0.002%
Biocide
0.001%
Acid
0.123%
Friction
Reducer
0.088%

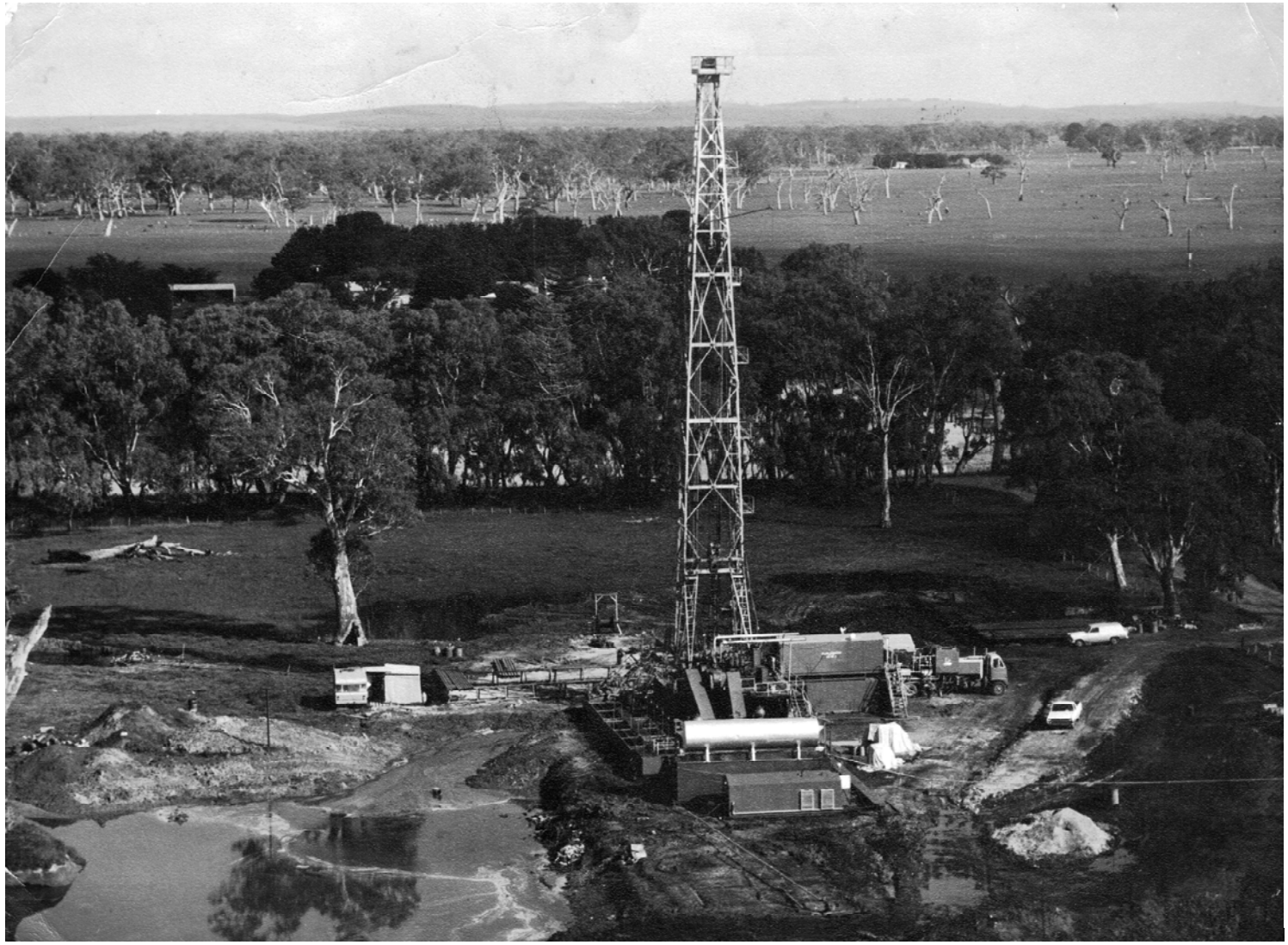
Additive Type	Main Compound(s)	Purpose	Common Use of Main Compound
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant; sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion inhibitor	N, n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, Acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, and cosmetics
Friction reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make up remover, laxatives, candy
Gel	Guar gum or hydroxyethyl	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice cream
Iron control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavouring in food and beverages; lemon juice ~7% Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, and de-icing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color

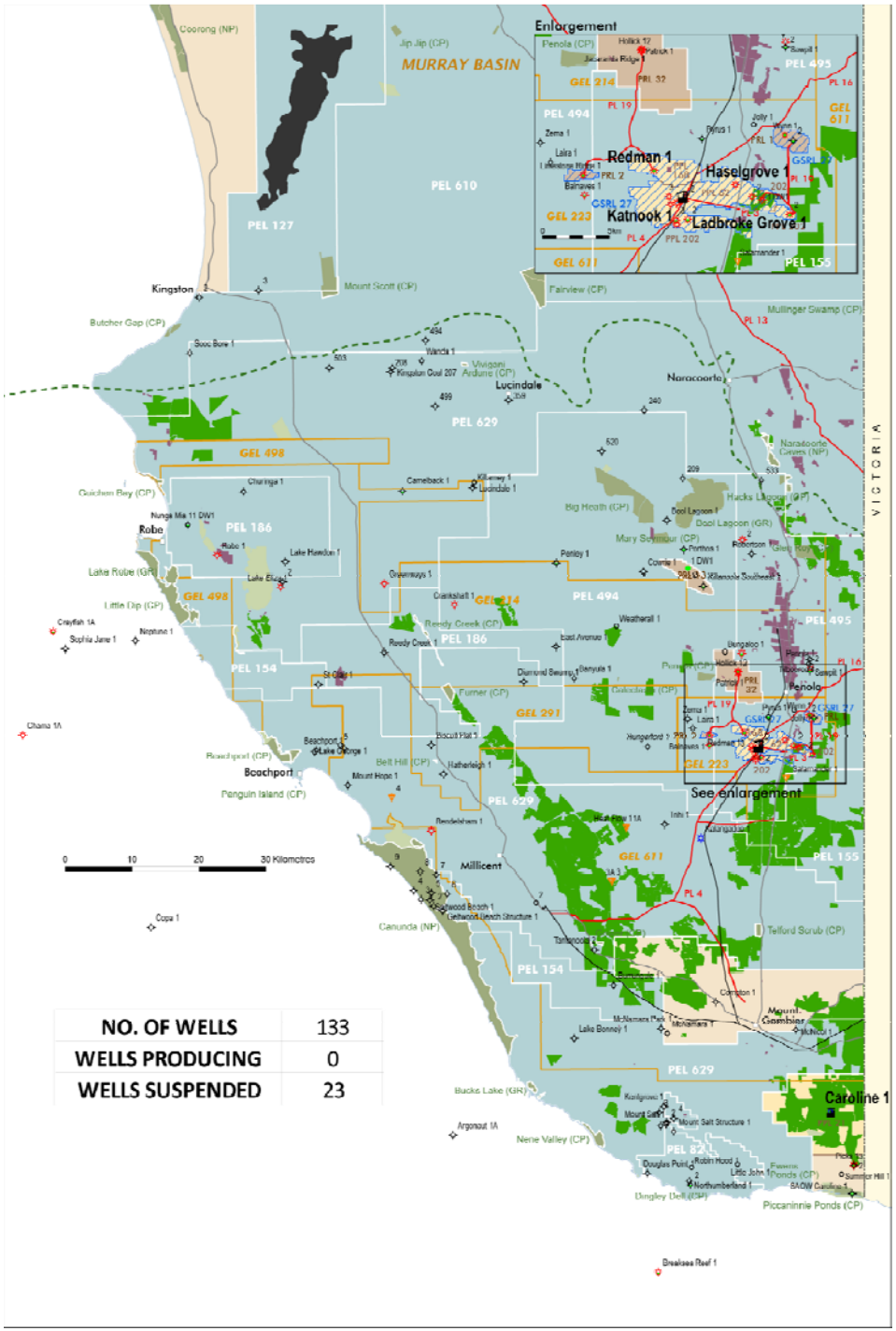
Source: Engineering Energy: Unconventional Gas Production, ACOLA, 2013

History of Gas Extraction in SE

Otway Basin

Kalangadoo #1 1964





NO. OF WELLS	133
WELLS PRODUCING	0
WELLS SUSPENDED	23

Petroleum wells
- CO_2 well
- CO_2 well with oil shows
- Dry hole
- Dry hole with oil shows
- Gas shows
- Gas well
- Gas well with oil shows
- Oil and gas well
- Oil and gas shows
- Oil well
- Proposed or currently drilling

Geothermal wells
- Abandoned well
- Suspended well

Infrastructure
- Processing plant
- Town
- Principal road
- Railway

Petroleum tenements
- Gas pipeline
- Petroleum Exploration Licence (PEL)
- Petroleum Production Licence (PPL)
- Petroleum Retention Licence (PRL)

Geothermal tenements
- Geothermal Exploration Licence (GEL)

Gas storage tenements
- Gas Storage Retention Licence (GSRL)

Land use
- Coal deposit
- Vines
- Forest Reserves
- National Parks and Reserves - with petroleum access
- National Parks and Reserves - no petroleum access

Conventional Oil and Gas Exploration Nothing New

YEAR SPUDDED	NO. OF WELLS DRILLED
1910 to 1919	2
1920 to 1929	5
1930 to 1939	1
1960 to 1969	28
1970 to 1979	12
1980 to 1989	20
1990 to 1999	37
2000 to present	12

Key History Milestones

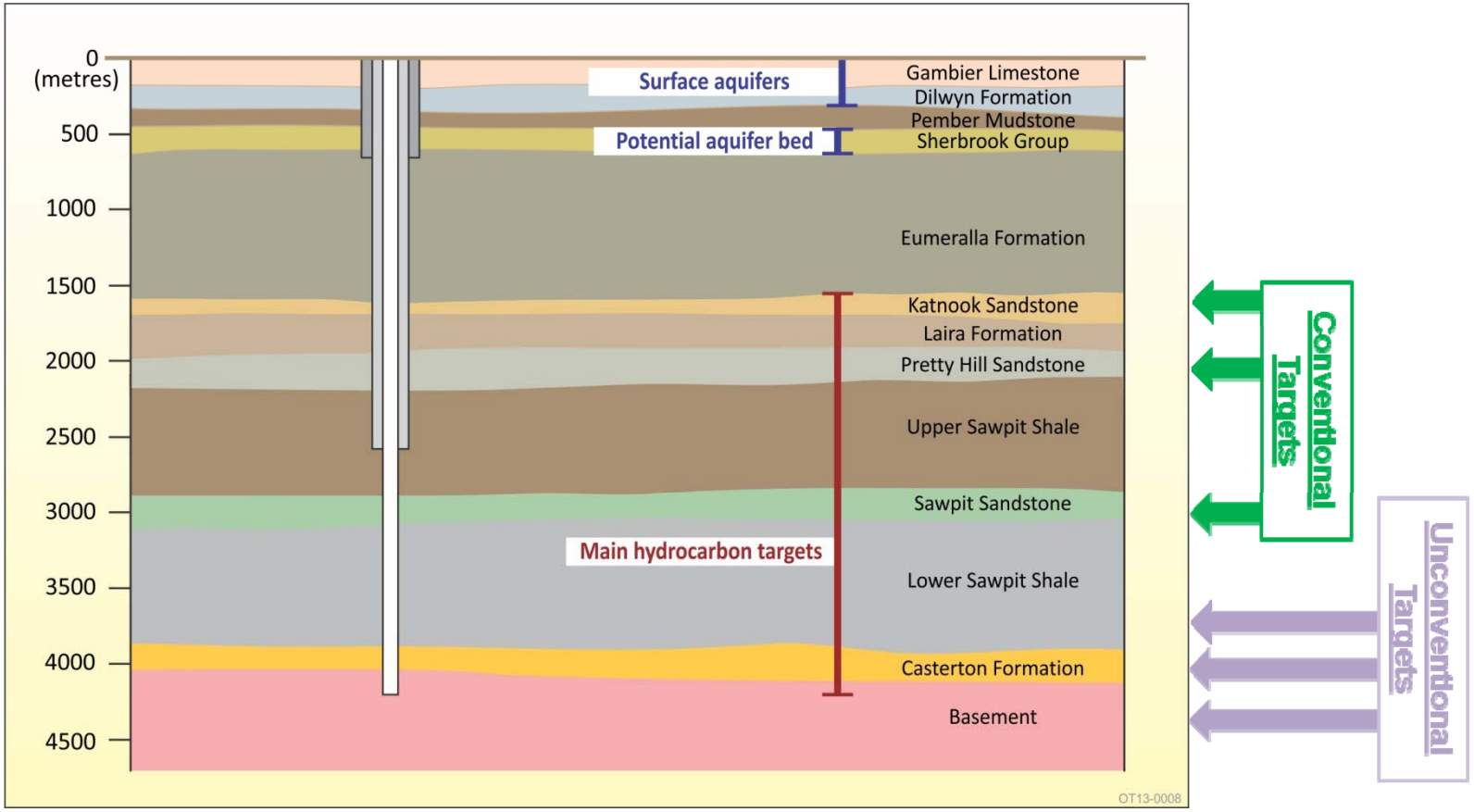
- Exploration commenced in 1866 in the South East with a well drilled near Salt Creek
- First flow at Kalangadoo-1 in 1965 and Caroline-1 in 1966 – both CO2
- First commercial flow of hydrocarbons in 1987 at Katnook-1
- Katnook Plant built and commissioned in 1991 – now mothballed
- Oil recovered from Sawpit-1 in 1992, flowed from Wynn-1 in 1994 – neither well commercial

Gas Supply

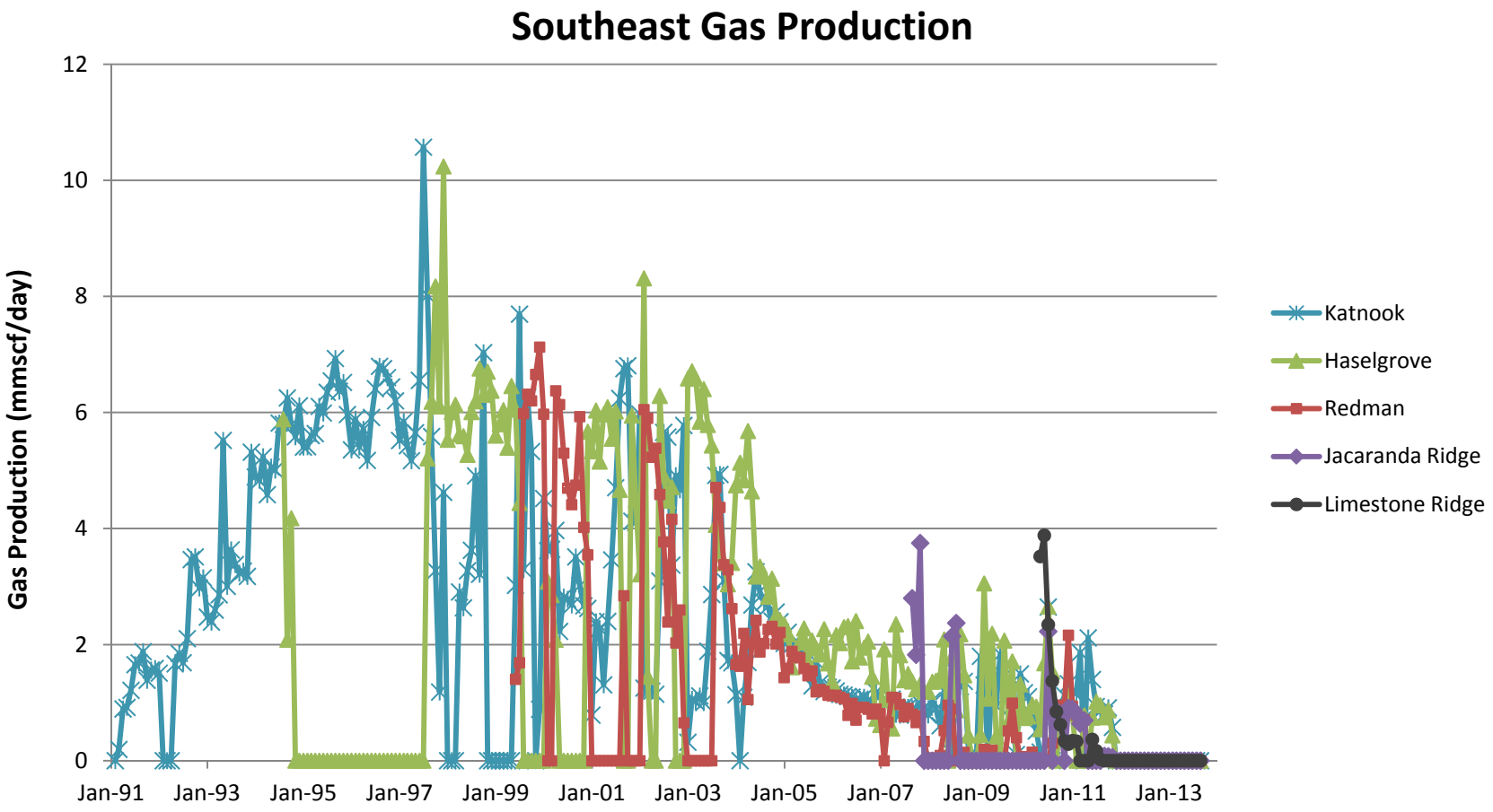
SOUTH EAST PIPELINE SYSTEM - 2003

PROJECT: PROPOSED OLYMPIC DAM PIPELINE							
DESCRIPTION: PROPOSED GAS PIPELINE FROM COMPRESSOR STATION 2 TO OLYMPIC DAM							
DRAWN BY: PJF		A	25/2/2002	Issued for Information	PJF		
DATE: 25/2/2002	SCALE: NTS	Rev	Date	Issue Description	By	Chk	Appr

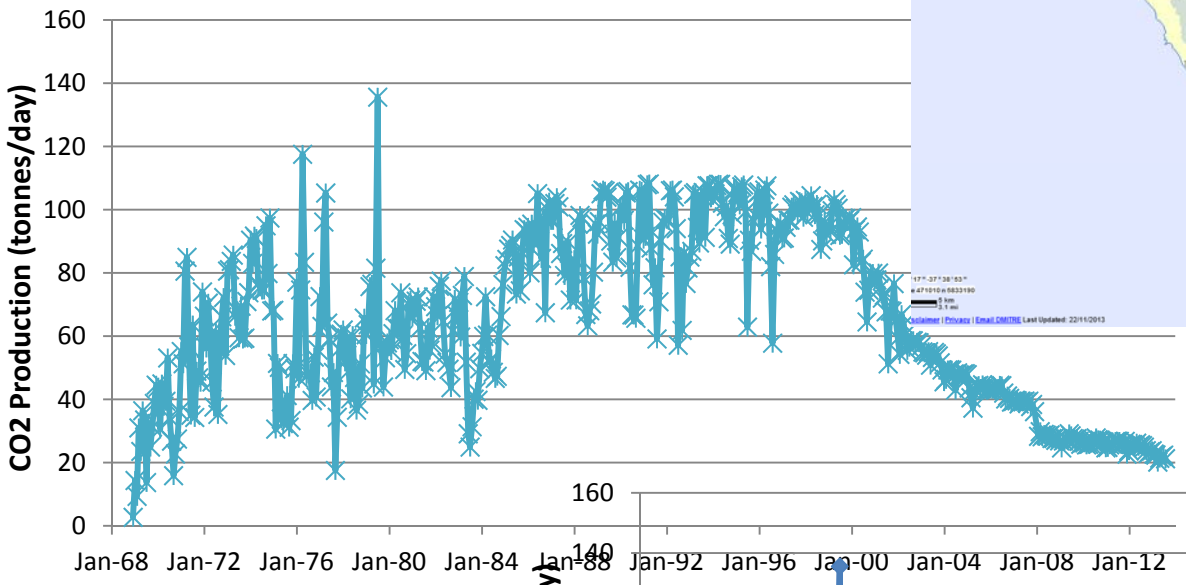
Source of Gas

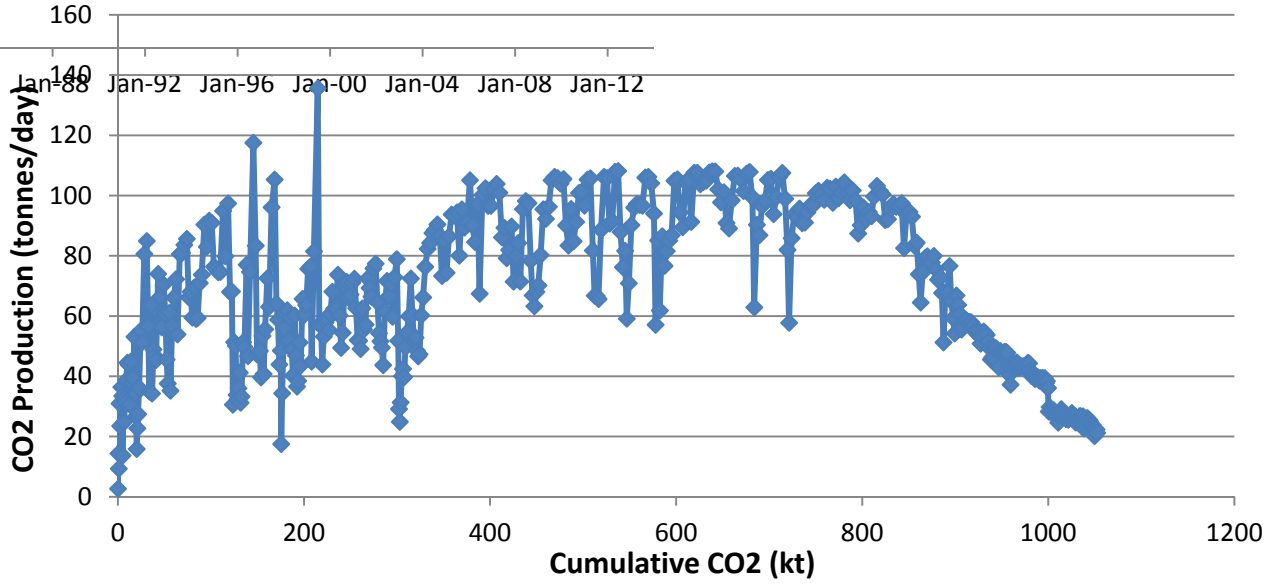


Historical Gas Production

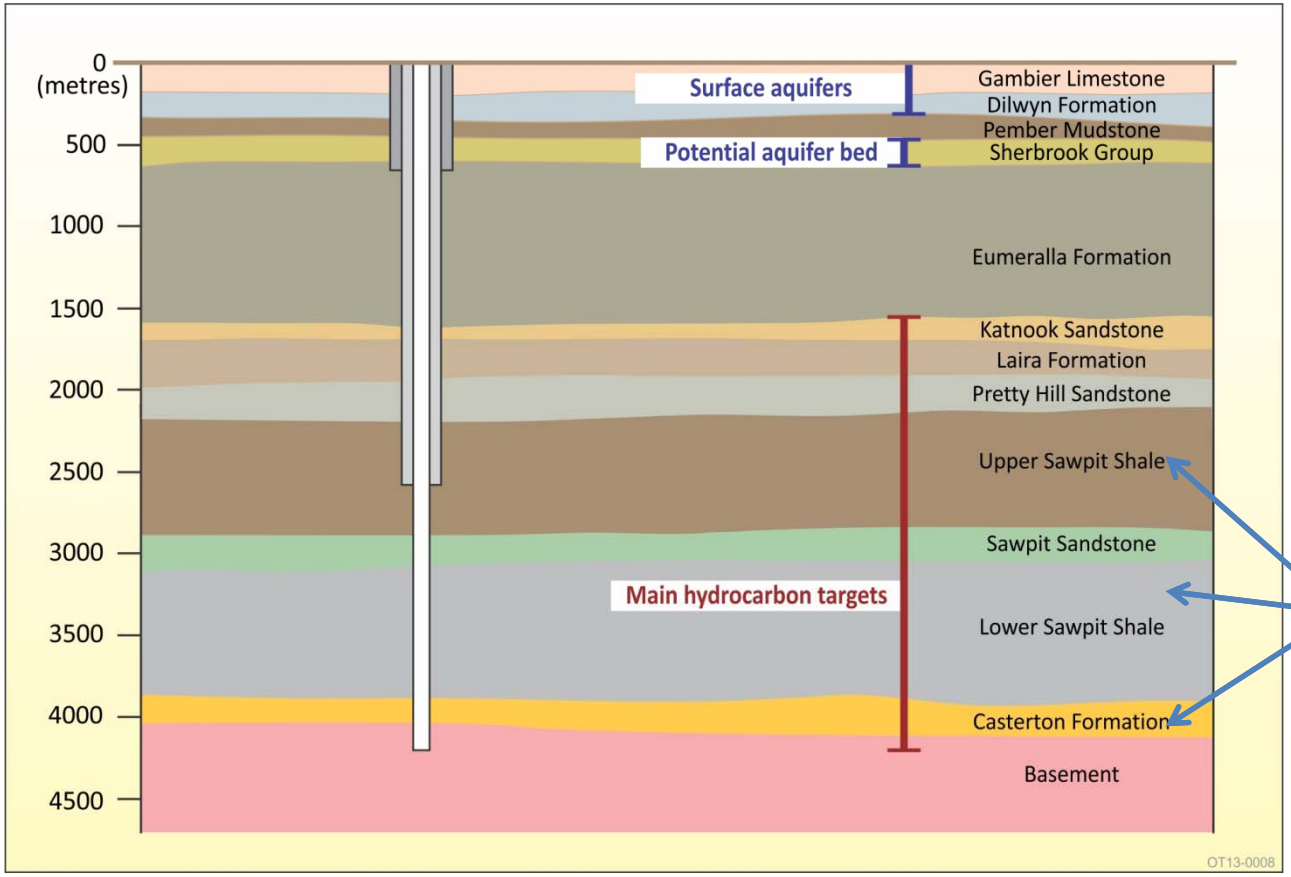


Caroline#1 CO2 Production

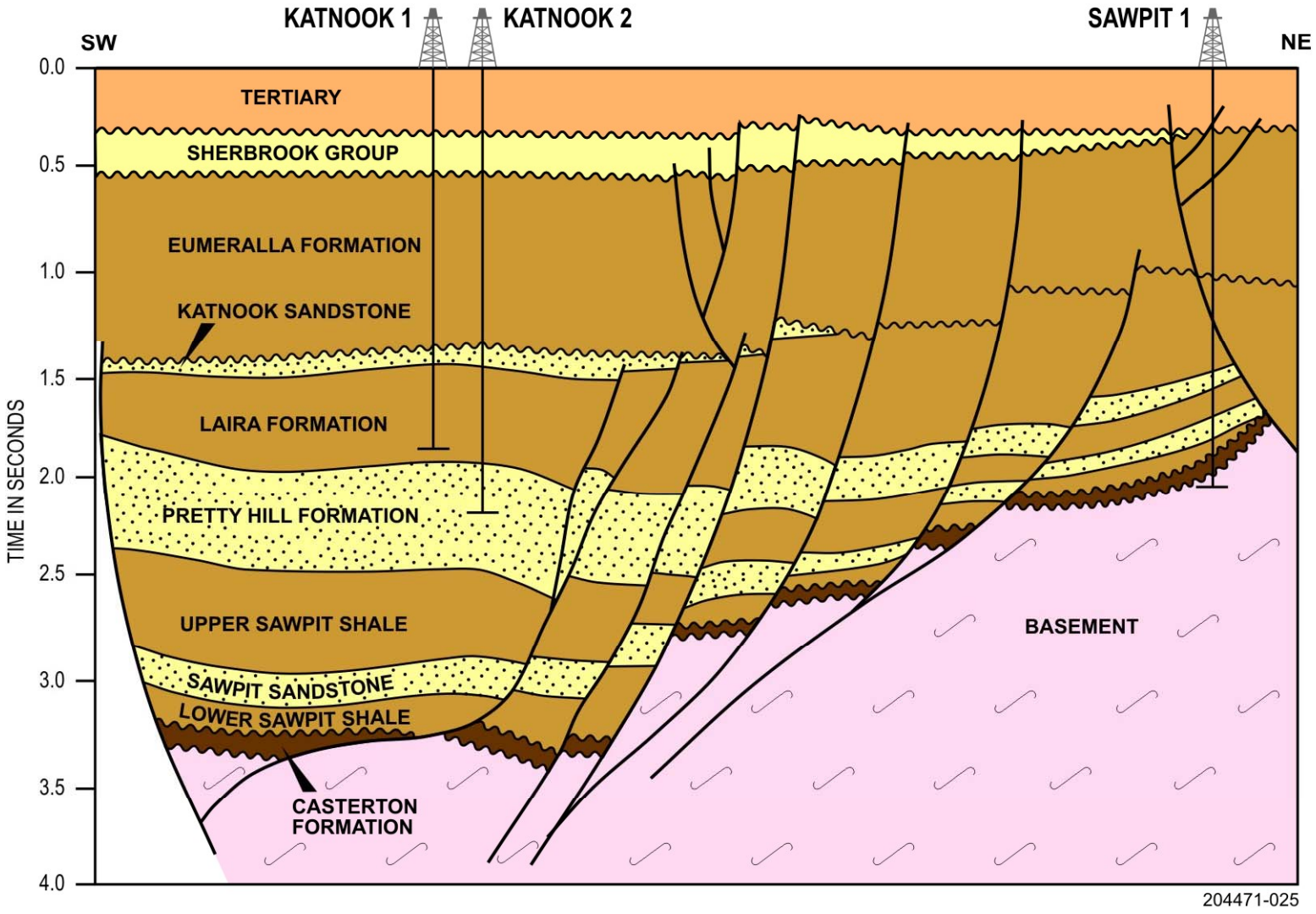




Where to Next?



South East Geology



South East Geology

SPE
Society of Petroleum Engineers

SPE 23009

Pressure-Transient Response in Compartmentalised Gas Reservoirs: A South Australian Field Example

M. Malavazos and R.C.M. McDonough, South Australia Dept. of Mines & Energy
SPE Members

This paper was prepared for presentation at the SPE Asia-Pacific Conference held in Perth, Western Australia, 4–7 November 1991.

Abstract

The long-term, production tests of the Katnook gas field in the South-East of South Australia are analysed to enable a better understanding of the reservoir geometry.

The pressure-transient responses are interpreted to indicate a compartmentalised reservoir, comprising a series of high-permeability sand bodies in relatively poor communication. This is consistent with the geological model, which describes the stacked-channel reservoirs having been formed in a low- sinuousity, braided-stream palaeo-environment.

Estimates of channel width and reservoir

The initial discovery was made in the Windermere Sandstone of the basal Eumeralla Formation. The subsequent drilling of Katnook #2 and #3 discovered and confirmed that the major gas reserves are located in a faulted anticlinal structure of the Pretty Hill Sandstone, covering an area of about 4 km^2.

A drill stem test gas flow of 16.4 MMscfd (462,000 m^3/d) on a half inch (12.7 mm) choke was measured during DST #12 in Katnook #2. This is a record for a well drilled onshore in South Australia.

Delivery of natural gas from Katnook to the industrial, commercial and domestic markets in the South-East of South Australia commenced in March 1991. Under the terms of the contract the producers will supply 22.5 PJ over a 15 year period.

South East Geology

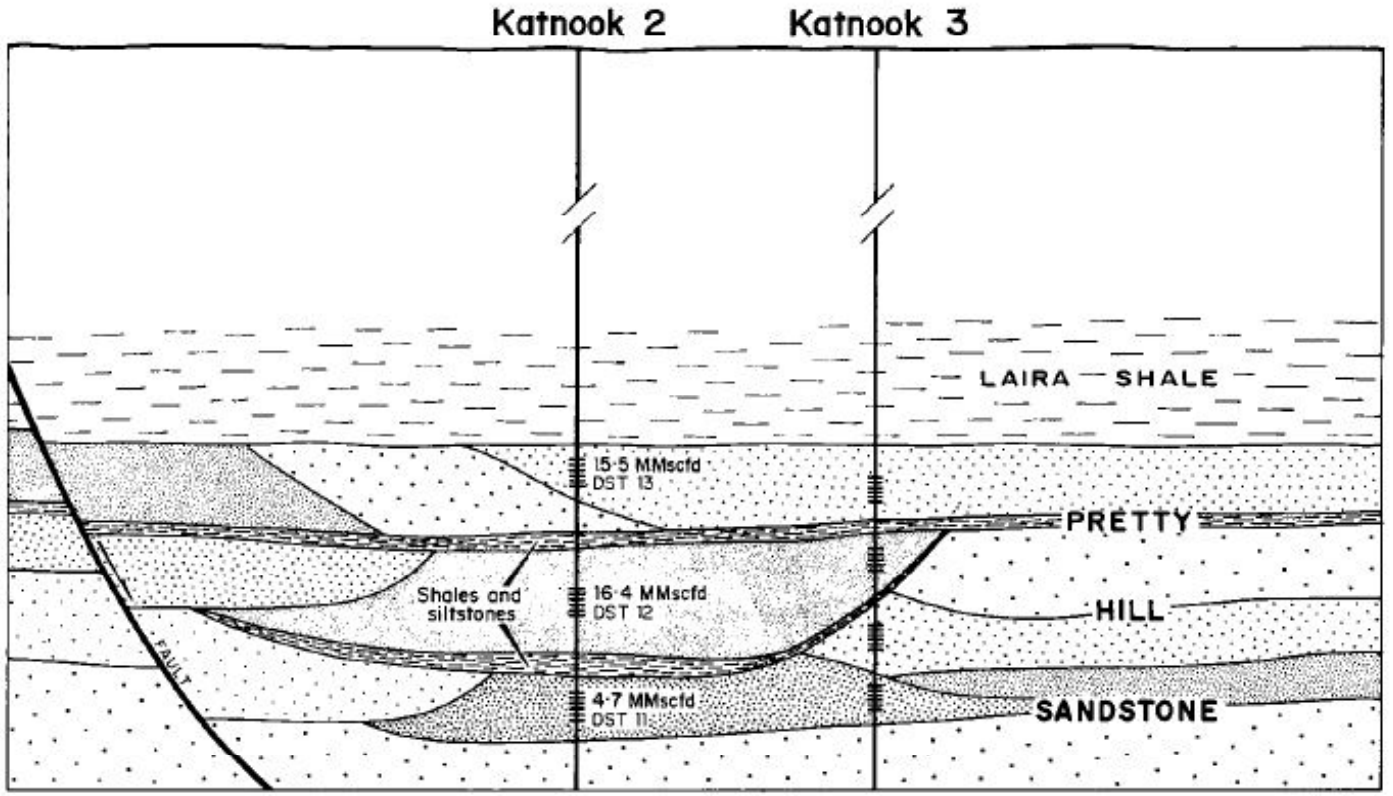


Fig. 2 Schematic section of the Katnook field (Pretty Hill Sandstone reservoir).

South East Geology

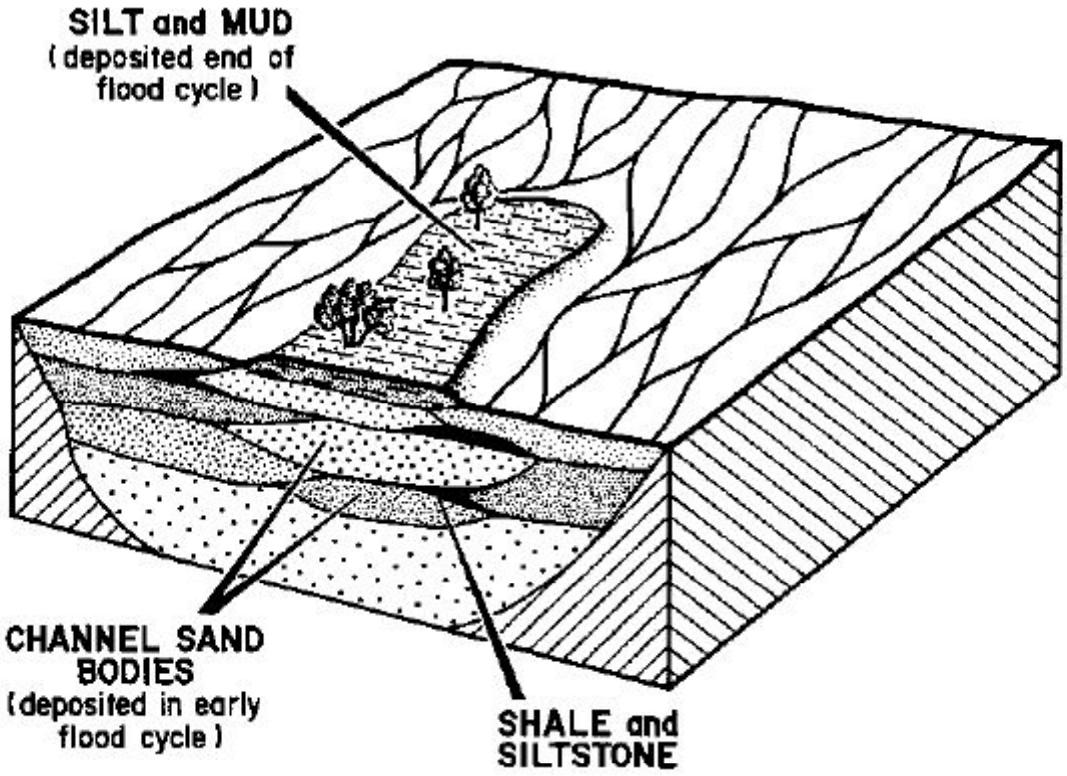


Fig. 3 Block diagram of channel sands in a braided fluvial environment (Scholle and Spearing[1]).

Legislative Controls

VISION: Deep unconventional gas delivering decades of safe, secure and competitive gas

To reach this vision

- **Must demonstrate:** Potential risks to social, natural and economic environments are *reduced to as low as reasonably practical* (**ALARP**); and meet community expectations;
- Stakeholders get timely information describing risks to enable informed opinions/decisions

Regulatory Objectives/Conditions

Avoid:

- Contamination of aquifers
- Adversely impacting other land users and uses
- Contamination of soil
- Disturbance of heritage sites
- Adversely impacting vegetation
- etc

Aim of regulatory processes is to have licensees demonstrate that they can and are achieving these objectives

Regulatory Framework

In South Australia

Petroleum Exploration and Production Activities regulated under:

- *Petroleum and Geothermal Energy Act 2000 (PGE Act);*
- *Environment Protection Act 1993;*
- *Natural Resources Management Act 2004;*
- *National Parks and Wildlife Act 1972;*
- *Aboriginal Heritage Act, 1988;*
- *Development Act, 1993;*
- *Work Health* and *Safety Act 2012;*
- *Public and Environmental Health (Waste Control) Regulations 2010;*
- *EPBC Act 1999*

Interaction between PGE Act and other South Australian Acts administered through Administrative Arrangements with respective agencies

Petroleum and Geothermal Act 2000

PGE Act defines the ***environment*** as:

- land, air, water, soil;
- plants & animals;
- social, cultural & heritage features;
- visual amenity;
- economic & other land uses.

Statements of Environmental Objectives (SEO)

- Regulated Activities cannot be carried out unless there is an approved SEO in place.
- SEO's set approval conditions for regulated activities e.g. seismic, well operations, production, processing, pipelines, gas storage, etc.
- Activity notifications – licensee demonstrates how it will achieve SEO before approval granted

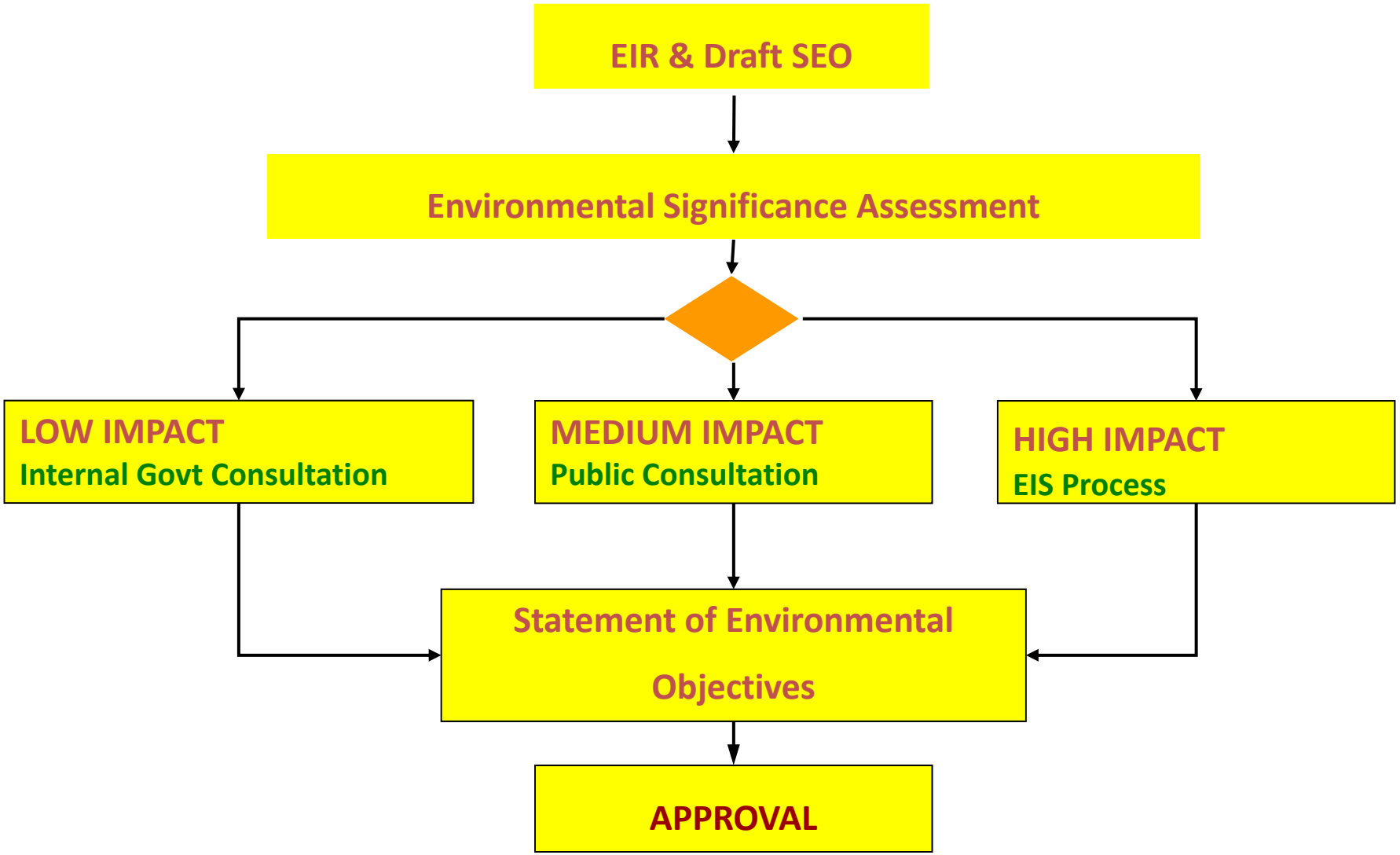
Approval Process

PGE Act Approval Processes

Two approval stages – Petroleum & Geothermal Act:

1. Licence approvals
   - Exploration, Retention
   - Production, Gas Storage, Pipeline, Special Facility Licences

2. Activity approvals
   - SEO Approval Process
     - what they must achieve
   - Activity Notification Process
     - demonstrate how they will achieve


EIR & Draft SEO
Environmental Significance Assessment
LOW IMPACT
Internal Govt Consultation
MEDIUM IMPACT
Public Consultation
HIGH IMPACT
EIS Process
Statement of Environmental Objectives
APPROVAL

Significance Criteria

PREDICTABILITY

Level of confidence that for each impact and consequence these issues have been addressed:

- Size
- Scope
- Duration
- Likelihood/Frequency
- Stakeholder Concerns

MANAGEABILITY

Extent to which consequences can be managed:

- Avoidance
- Probability
- Duration
- Size
- Scope
- Cumulative Effects
- Stakeholder concerns

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MANAGEABILITY

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SEO Objectives Include:

Avoid:

- Contamination of aquifers
- Adverse impacts on other land users and uses
- Contamination of soil
- Disturbance to heritage sites
- Adverse impacts on vegetation
- etc

Breaching these objectives is a PGE Act offence

Notices of Entry (NoEs)

- **Owners of land** means all persons and enterprises potentially directly affected by regulated activities,
- **NoEs** must provide timely information to enable potentially affected people and enterprises to reach informed views regarding impacts on their interests.
- **Owners of land** must be given **NoEs** at least 21 days in advance of the start of any activities – and have 14 days to lodge objections
- All potentially directly affected people and enterprises have **rights to object** to the approval of land access for regulated activities, and **all such objections are a show-stopper** until objections are resolved.

Notices of Entry (NoEs)

- These **Owner of Land** rights are sustained without support for vexatious objections.
- **Owners of land** are due compensation from relevant PGE Act licence holders for reasonable costs of assessing NoEs (including the cost of legal advice) and for any loss or deprivation that might result from activities regulated pursuant to the PGE Act.
- The **dispute resolution process** for objections to NoEs
  - starts with **engagement** between the concerned stakeholder and the relevant PGE Act Licence holder;
  - can escalate to **mediation** stewarded by the Minister; but
  - **court proceedings** are the ultimate dispute resolution process.

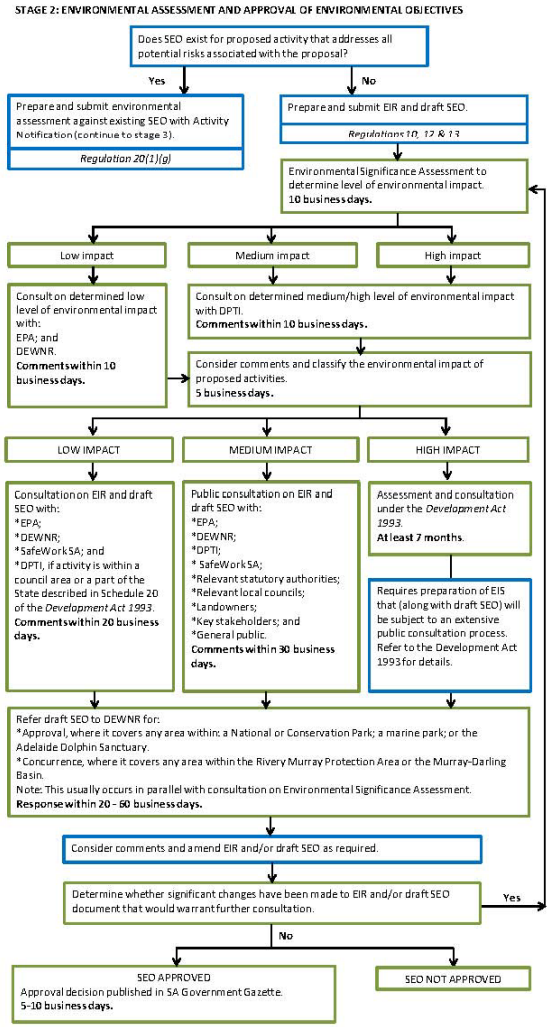
Best Practice Regulatory Principles

Delivering Regulatory Best Practice through 6 Principles:

1) Certainty
2) Openness
3) Transparency
4) Practicality
5) Flexibility
6) Efficiency

Openness

- Inclusive stakeholder consultation in establishing regulatory objectives, broad community engagement on addressing potential environmental, economic and social/cultural impacts.



Transparency

Public Access to regulatory decision making.

- Criteria for classifying the level of Environmental Impact
- All Environmental Impact Reports, assessments and Statements of Environmental Objectives (Approval Conditions) are online

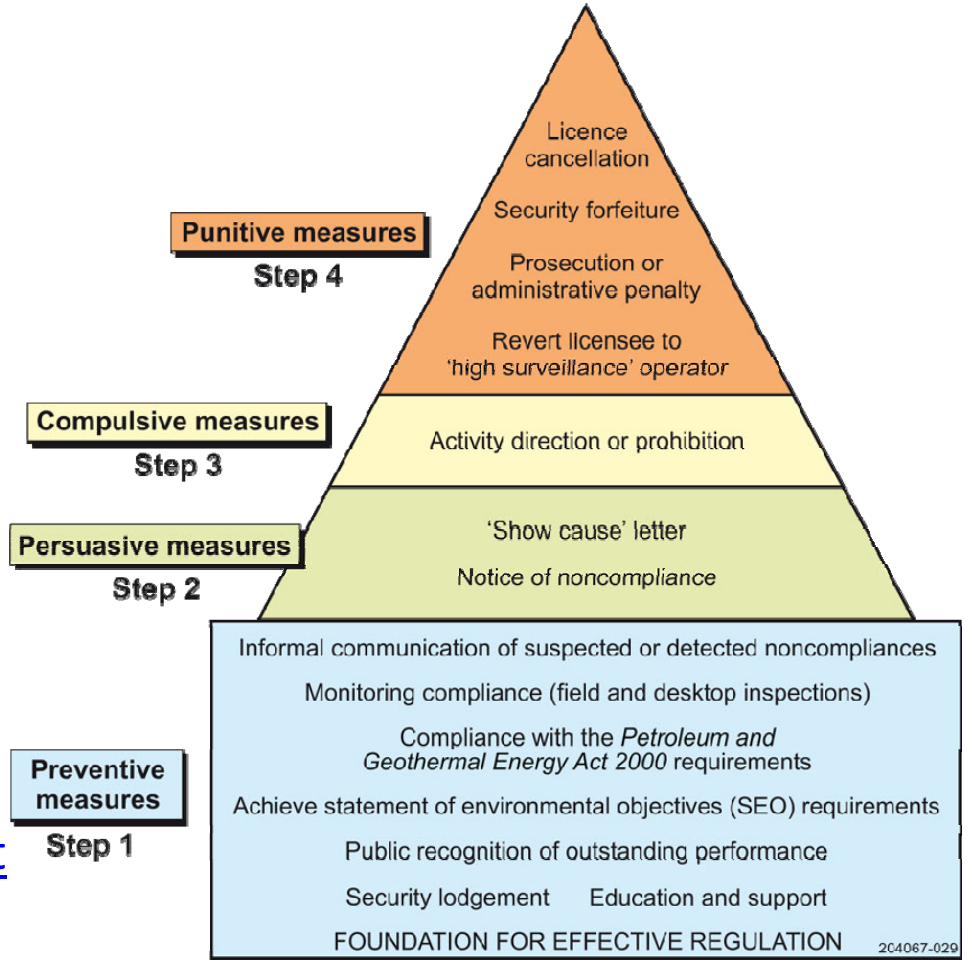
Community access to industry performance information:

- environmental performance
- regulatory enforcement actions
- surveillance activity information

- Licensee Annual Compliance Reports
- PGE Act compliance policy
- PGE Act Annual Compliance report

Appropriate range of regulatory enforcement tools to elicit compliant behaviour.

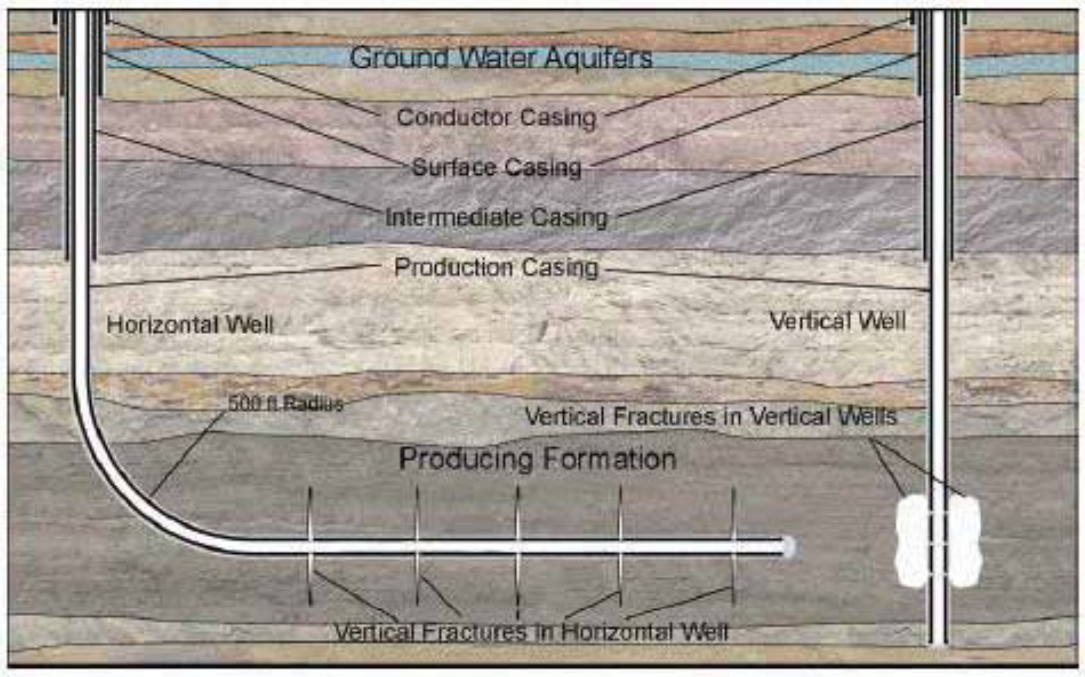
- PGE Act compliance policy
- PGE Act Annual Compliance report



Part 2

What are the risks?

How do we identify and manage the risks?



Beach Energy Shale Gas Fraccing - EIR

Beach Energy Shale Gas Fraccing - SEO

EIR Summary

HAZARDOUS EVENTS	POTENTIAL CONSEQUENCES	MITIGATION MEASURES
Access & pad construction, vehicle & people movement.	Intrusion or physical damage to areas of Aboriginal heritage significance.	Scouting for such sites to be undertaken ahead of activity.
Crossflow from hydrocarbon zones or lesser quality aquifers.	Contamination of aquifers.	Identified aquifers isolated behind casing.
Drilling through fresh water aquifers.	Pollute water source of other users	Use of non-toxic muds.
Fraccing into adjacent and overlying aquifers		Non-toxic frac fluid. Monitor frac through micro seismic and control pump pressures accordingly

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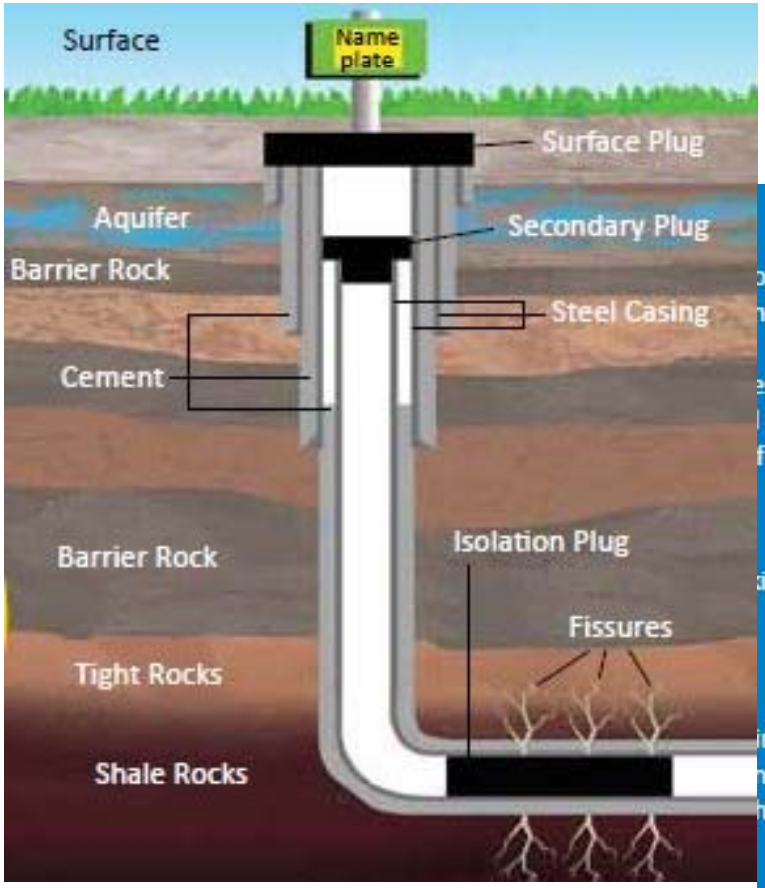
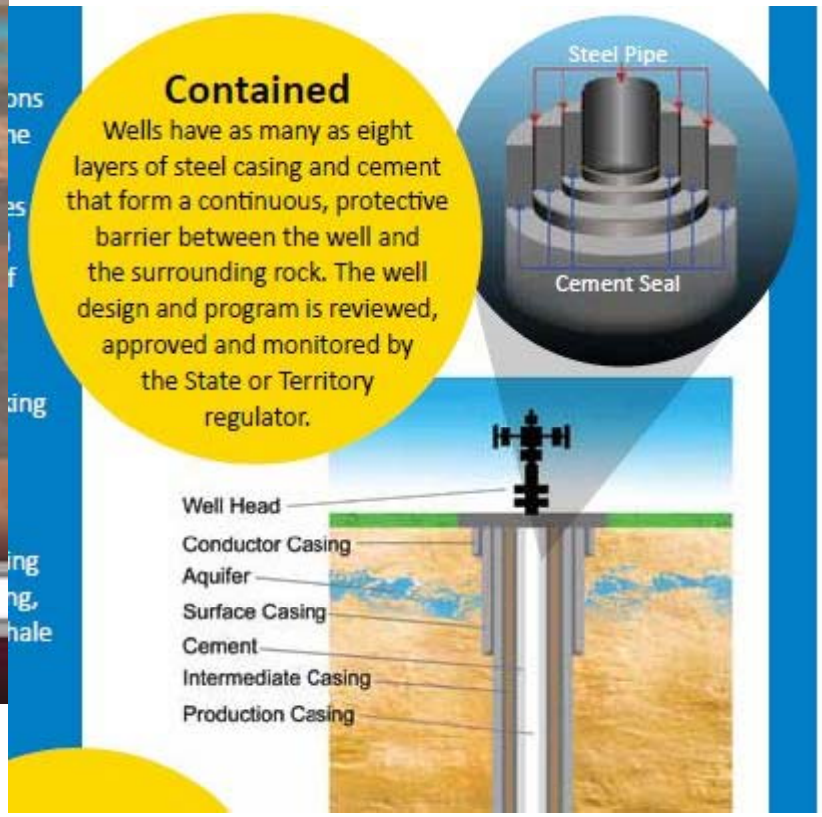
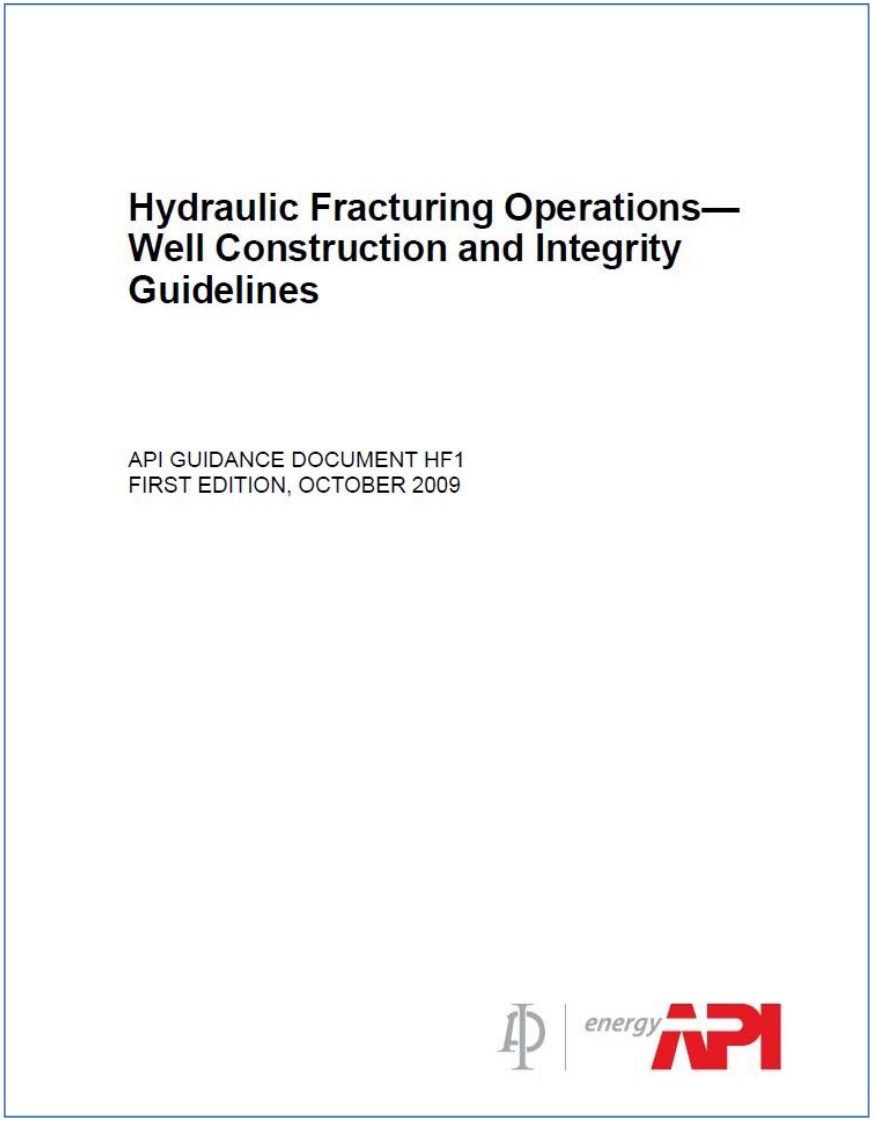




Courtesy: APPEA Natural Gas Revolution Brochure, 2013

Best Practice Industry Standards

http://www.shalegas.energy.gov/resources/HF1.pdf



Recommended Well Construction Practice

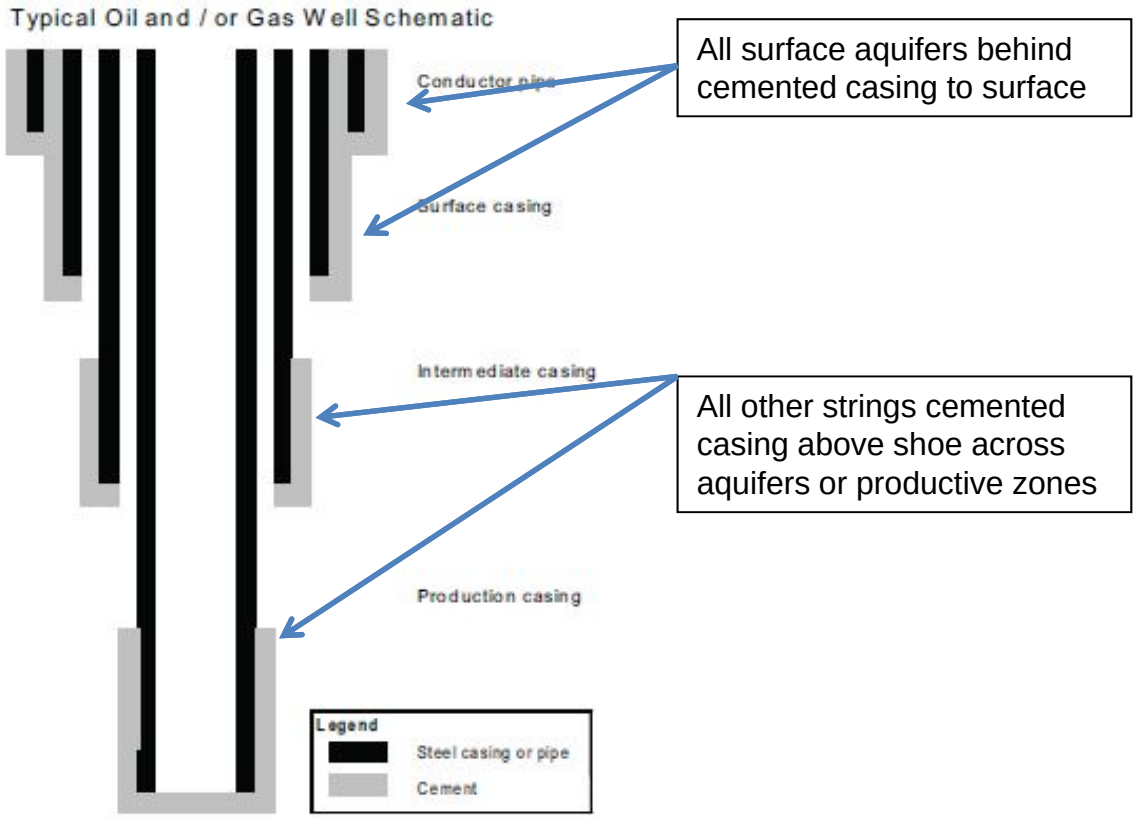
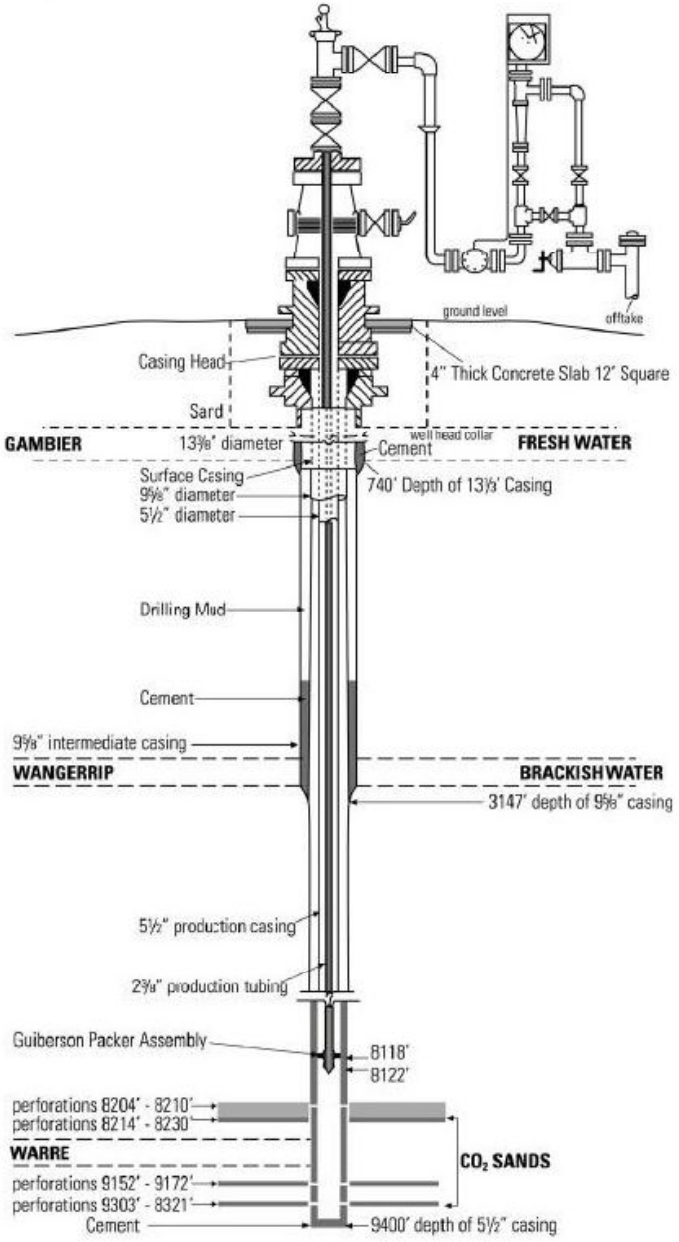


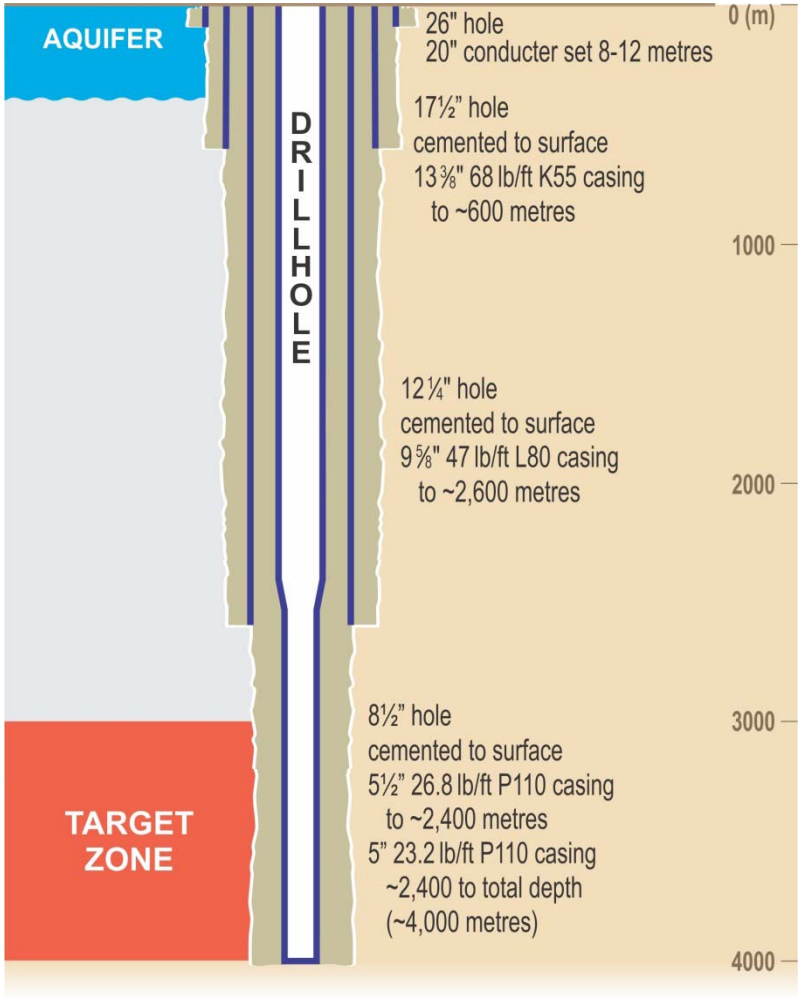
Figure 1—Typical Well Schematic

CAROLINE CO_2 COMPLETION DIAGRAM



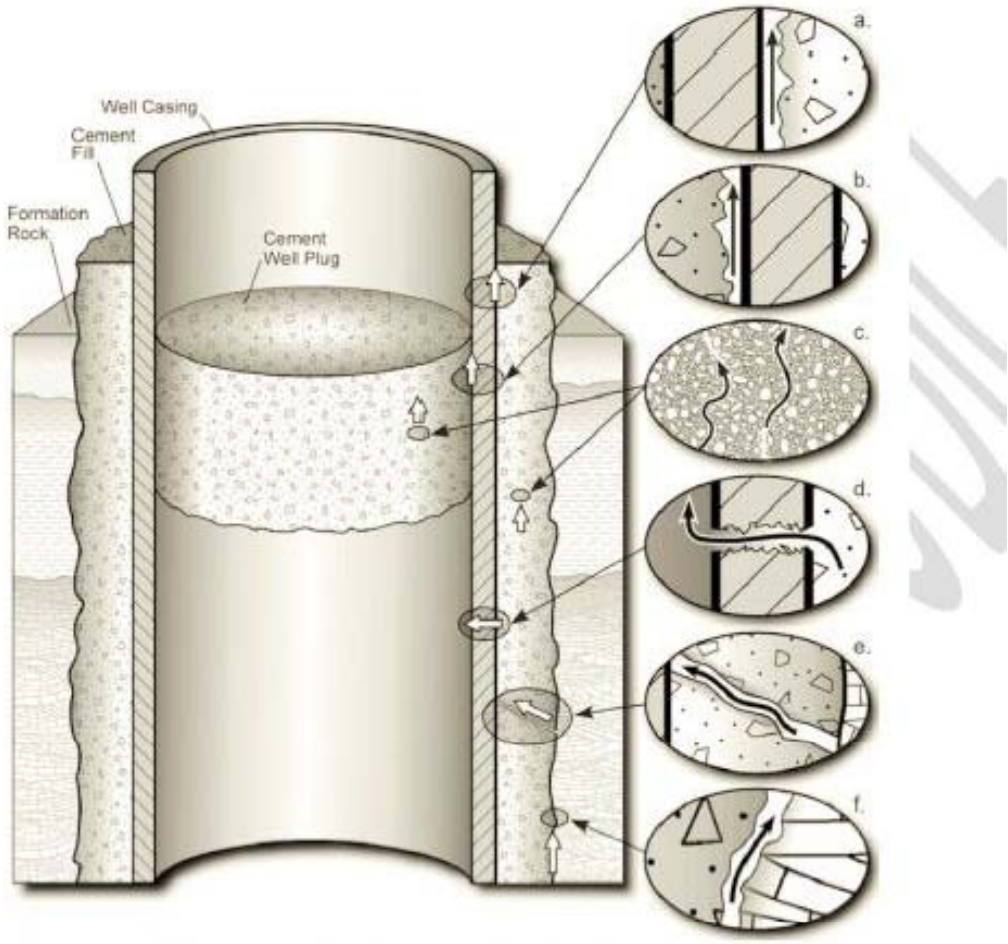
Approved Practice for All future Wells

- Well will be drilled through the surface sediments into the Eumeralla Formation and casing run so that the surface aquifers are not in communication with the well bore
- All casing strings will be cemented to surface
- Beyond recommended practice



What are the risks

Casing and cement integrity



Not acceptable or tolerable...

BRIEF OF EVIDENCE

Investigation into the circumstances surrounding the Uncontrolled Release of Oil and Gas from the Montara Wellhead Platform

MONTARA DEVELOPMENT PROJECT

located in the Timor Sea approximately 250 km north-west of the Western Australian coast, almost 700 km from Darwin in the offshore area of the Territory of Ashmore and Cartier Islands

Owned and Operated

By
PTTEPAA Australasia (Ashmore Cartier) Pty Ltd
PTTEPAA

(ACN 004 210 164)

On

21st AUGUST 2009

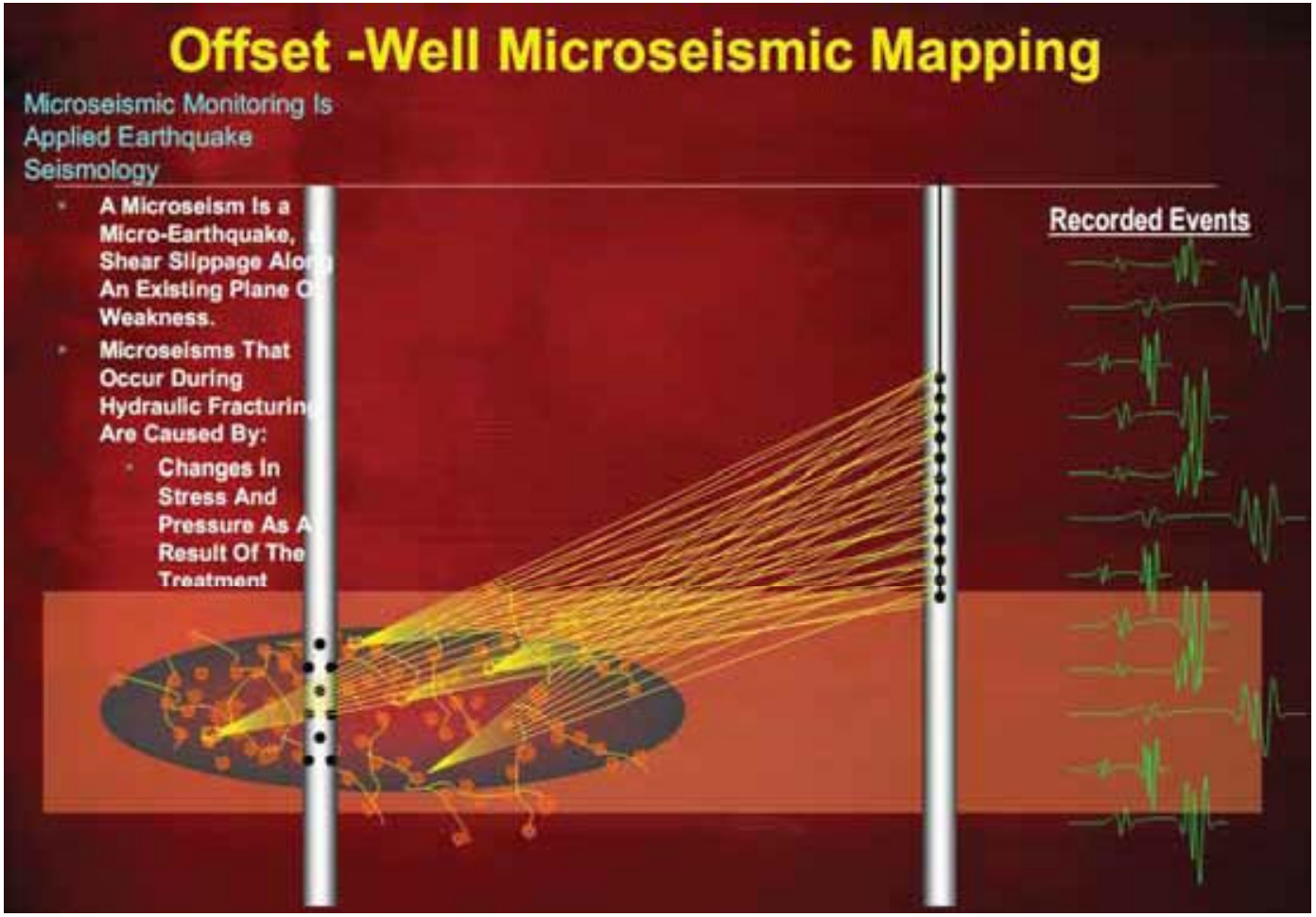
EIR Summary

HAZARDOUS EVENTS	POTENTIAL CONSEQUENCES	MITIGATION MEASURES
Access & pad construction, vehicle & people movement.	Intrusion or physical damage to areas of Aboriginal heritage significance.	Scouting for such sites to be undertaken ahead of activity.
Crossflow from hydrocarbon zones or lesser quality aquifers.	Contamination of aquifers.	Identified aquifers isolated behind casing.
Drilling through fresh water aquifers.	Pollute water source of other users	Use of non-toxic muds.
Fraccing into adjacent and overlying aquifers		Non-toxic frac fluid. Monitor frac through micro seismic and control pump pressures accordingly

Offset -Well Microseismic Mapping

Microseismic Monitoring Is Applied Earthquake Seismology

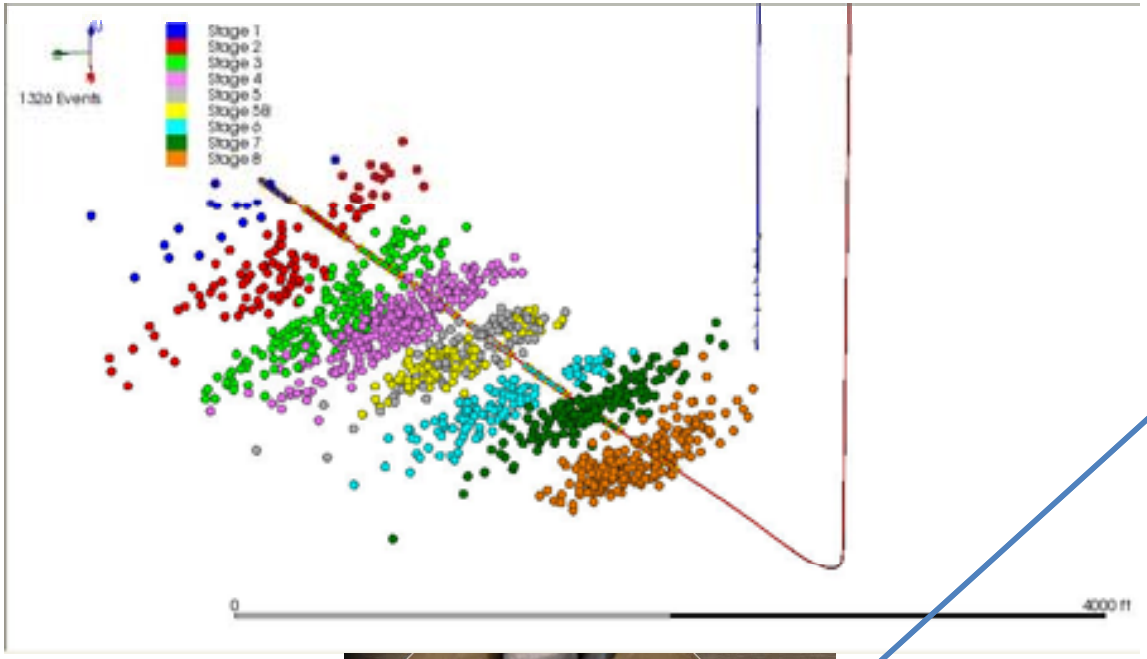
- A Microseism Is a Micro-Earthquake, Shear Slippage Alon An Existing Plane O Weakness.
- Microseisms That Occur During Hydraulic Fracturin Are Caused By:
  - Changes In Stress And Pressure As A Result Of The Treatment



Specialised extraction Technology

Stimulated rock volume in horizontal well (from microseismic monitoring)

Coloured dots indicate fracture events related to hydraulic stimulation of each perforated stage



Fracture half length and complexity is controlled by:

- Frac fluid viscosity (gel vs “slickwater”)
- Pump rate
- Pump pressure
- Proppant “mesh” size
- In situ stresses
- Existing natural fractures
- Natural frac barriers (ductile rocks that don’t break easily)
- Rock brittleness

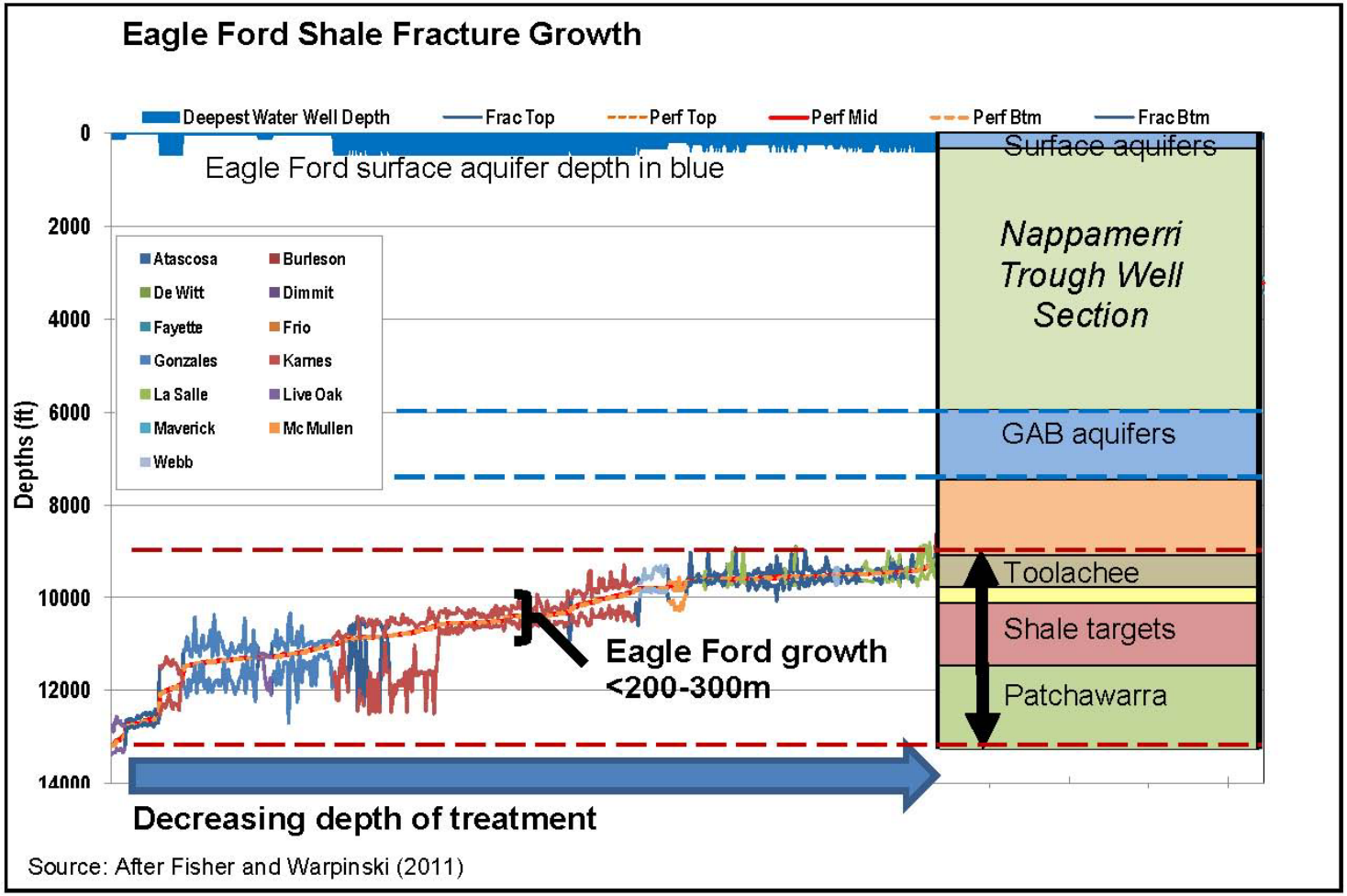


Figure 24: Typical fracture height growth measured during shale gas stimulation in the Eagle Ford (USA) with Nappamerri Trough well section superimposed

EIR Summary

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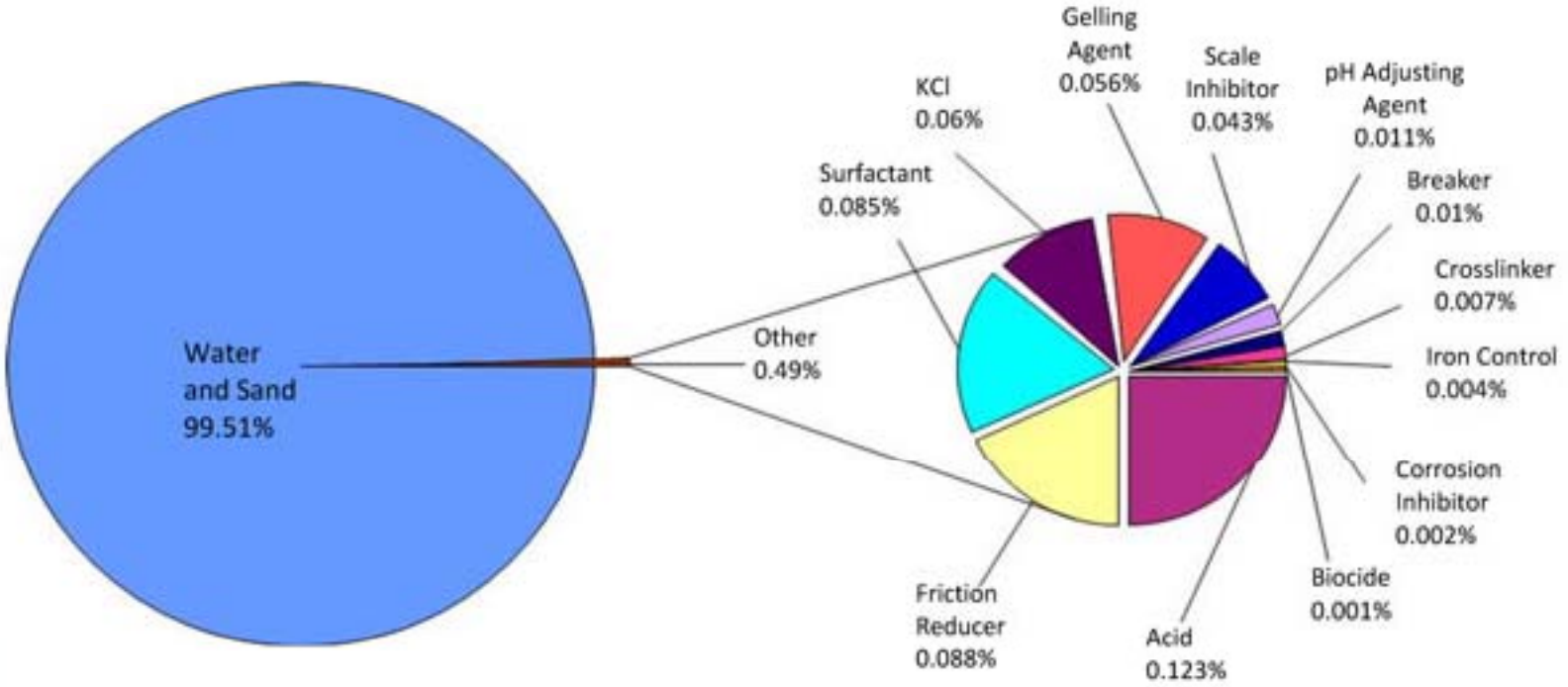
Water
and Sand
99.51%
Other
0.49%
Gelling
Agent
0.056%
Scale
Inhibitor
0.043%
pH Adjusting
Agent
0.011%
KCl
0.06%
Surfactant
0.085%
Breaker
0.01%
Crosslinker
0.007%
Iron Control
0.004%
Corrosion
Inhibitor
0.002%
Biocide
0.001%
Acid
0.123%
Friction
Reducer
0.088%

Additive Type	Main Compound(s)	Purpose	Common Use of Main Compound
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant; sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion inhibitor	N, n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, Acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, and cosmetics
Friction reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make up remover, laxatives, candy
Gel	Guar gum or hydroxyethyl	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice cream
Iron control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavouring in food and beverages; lemon juice ~7% Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, and de-icing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color

Source: Engineering Energy: Unconventional Gas Production, ACOLA, 2013

EIR Summary (cont)

HAZARDOUS EVENTS	POTENTIAL CONSEQUENCES	MITIGATION MEASURES
Flow back of frac fluids	Contamination of soil, impact vegetation and potential contamination of surface aquifers	Frac fluid contained within lined pits
Vehicle and plant refuelling during operations.	Oil spill damage to soil & vegetation.	Refuel in designated bunded area.
Seed importation on vehicles and equipment.	• Introducing alien vegetation species (weeds). • Impact on other land users, eg farmers, pastoralists	All vehicles steam cleaned prior to entering district.

EIR Summary (cont)

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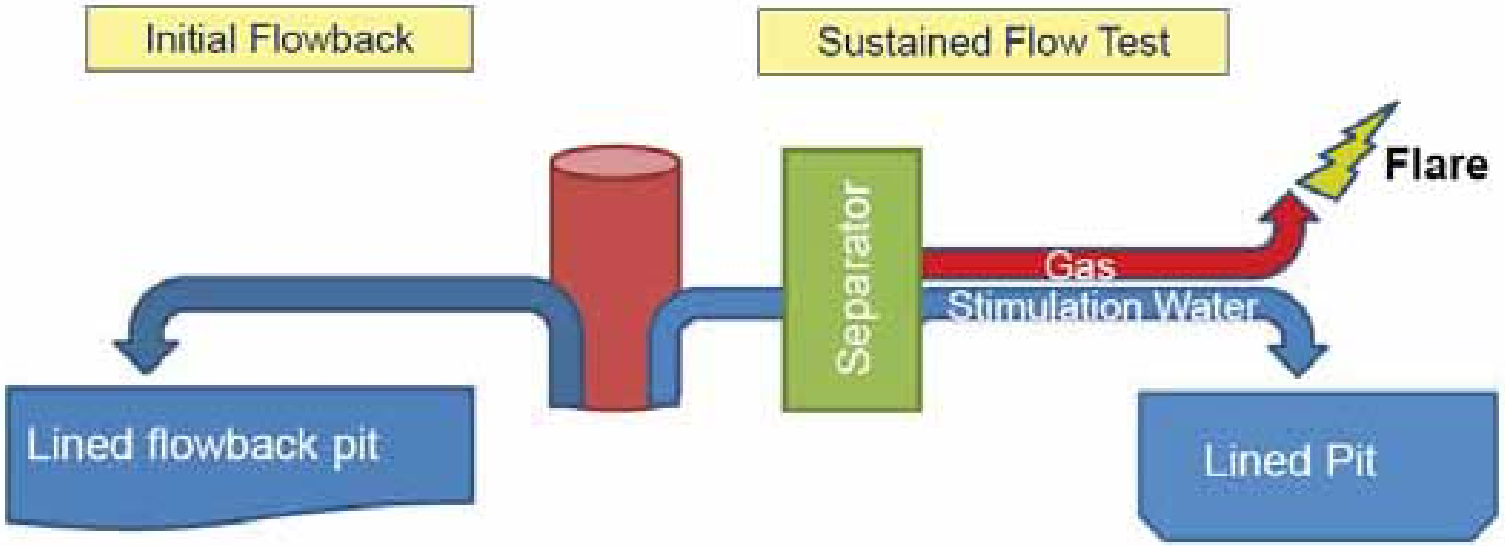
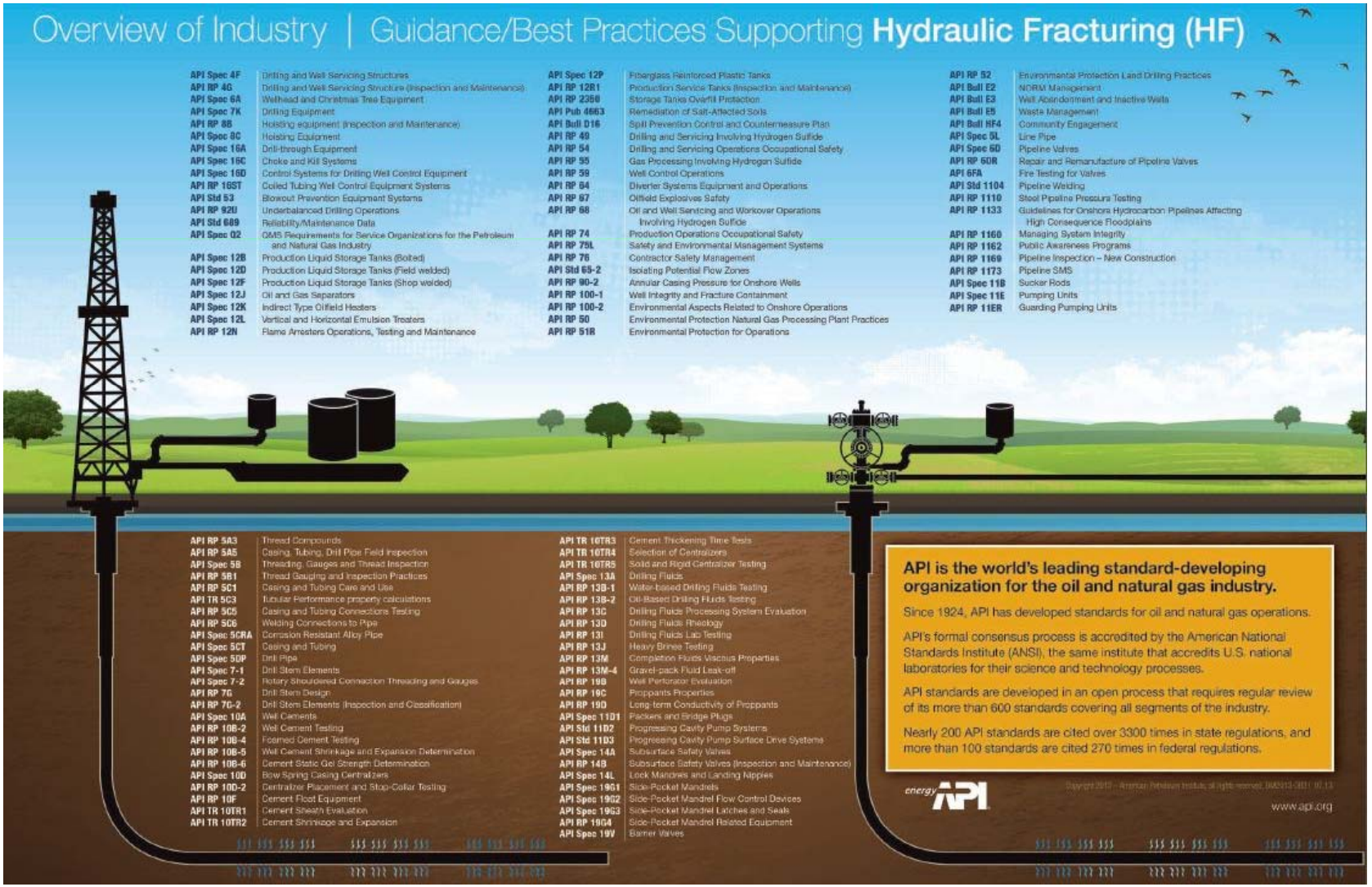
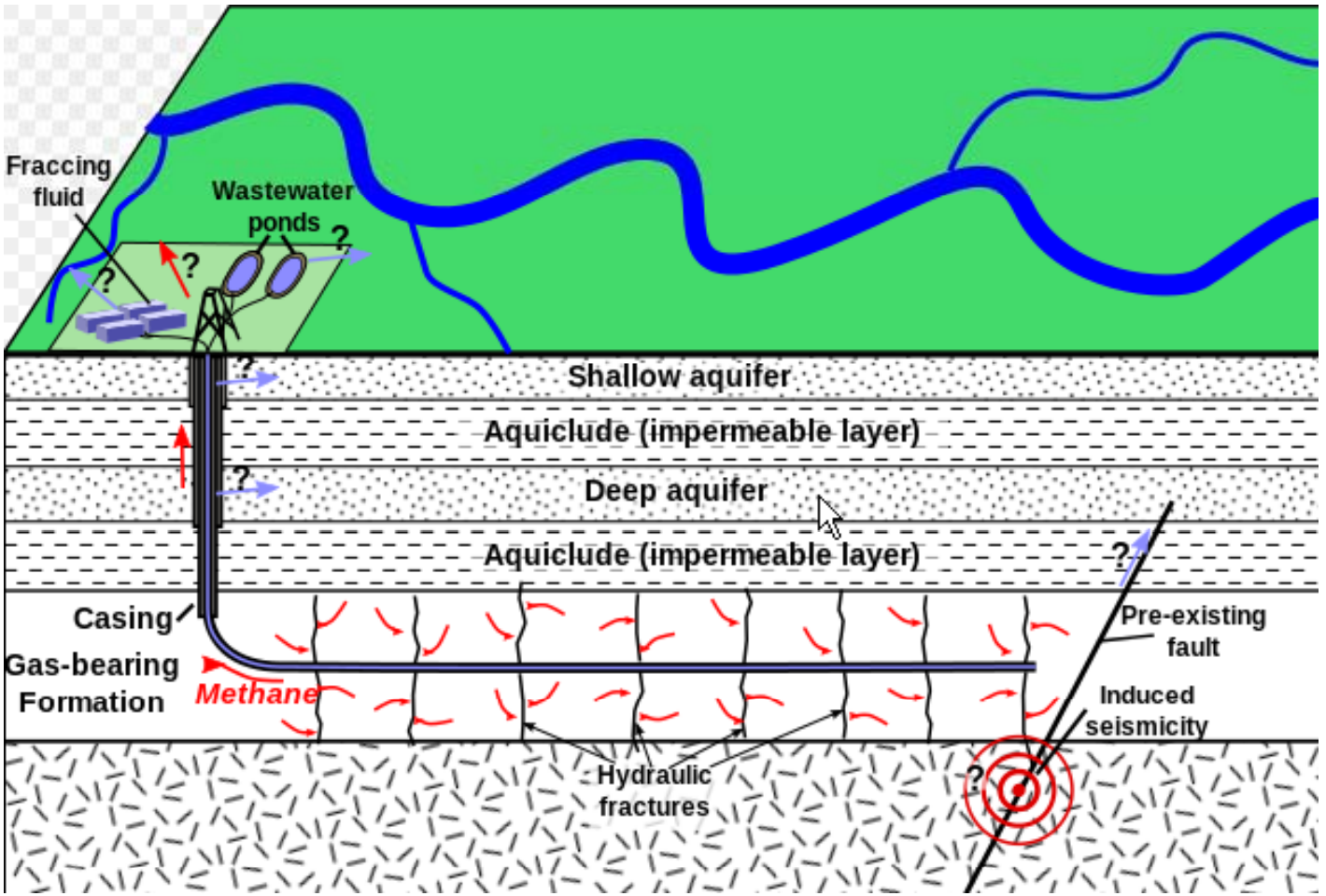
Green Completion
Its all about Containment



Well and Fraccing Operation Standards



Are Earthquakes are risk?



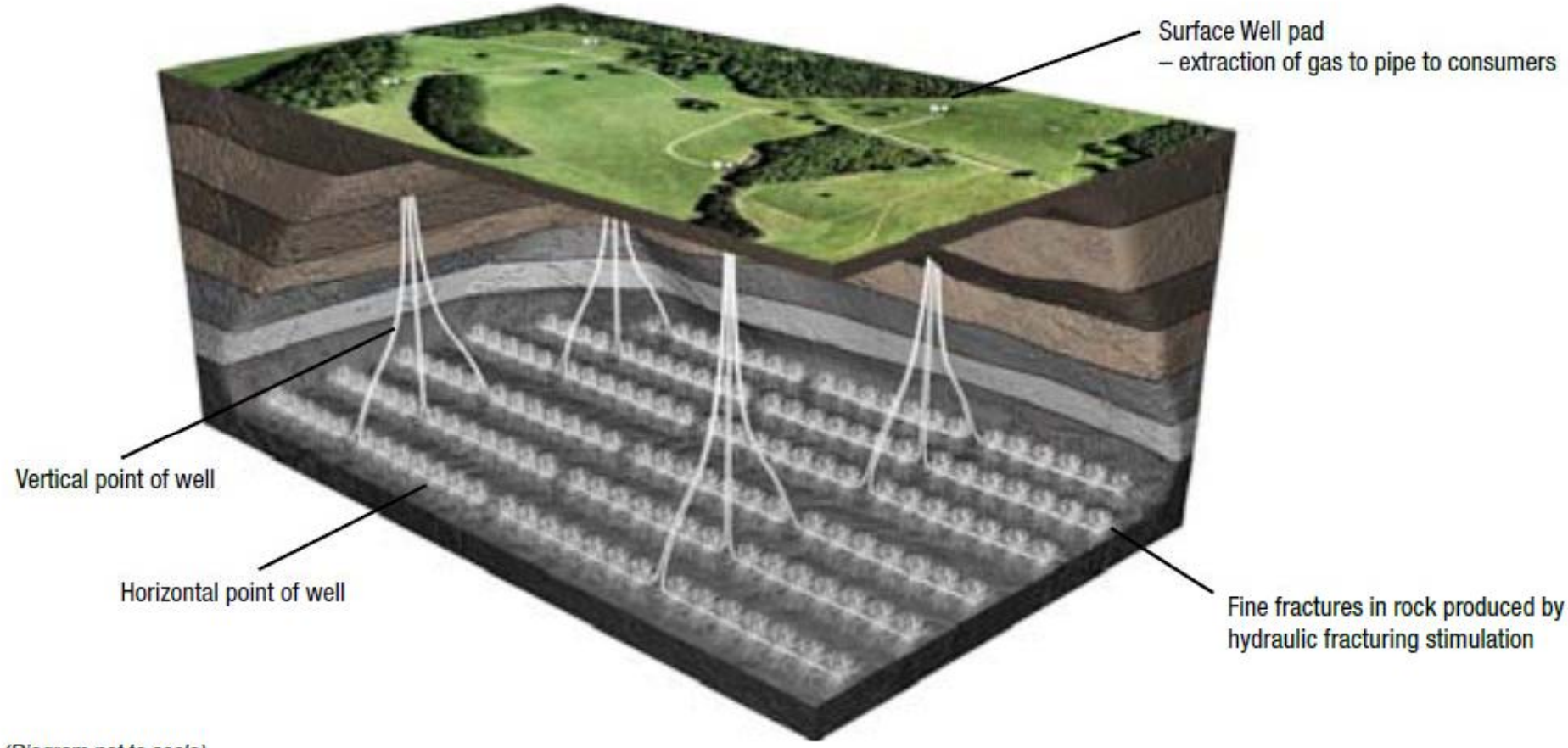
Impacts on Other Landowners

Environmental Footprint

Its not CSG

Environmental Footprint

Its not CSG

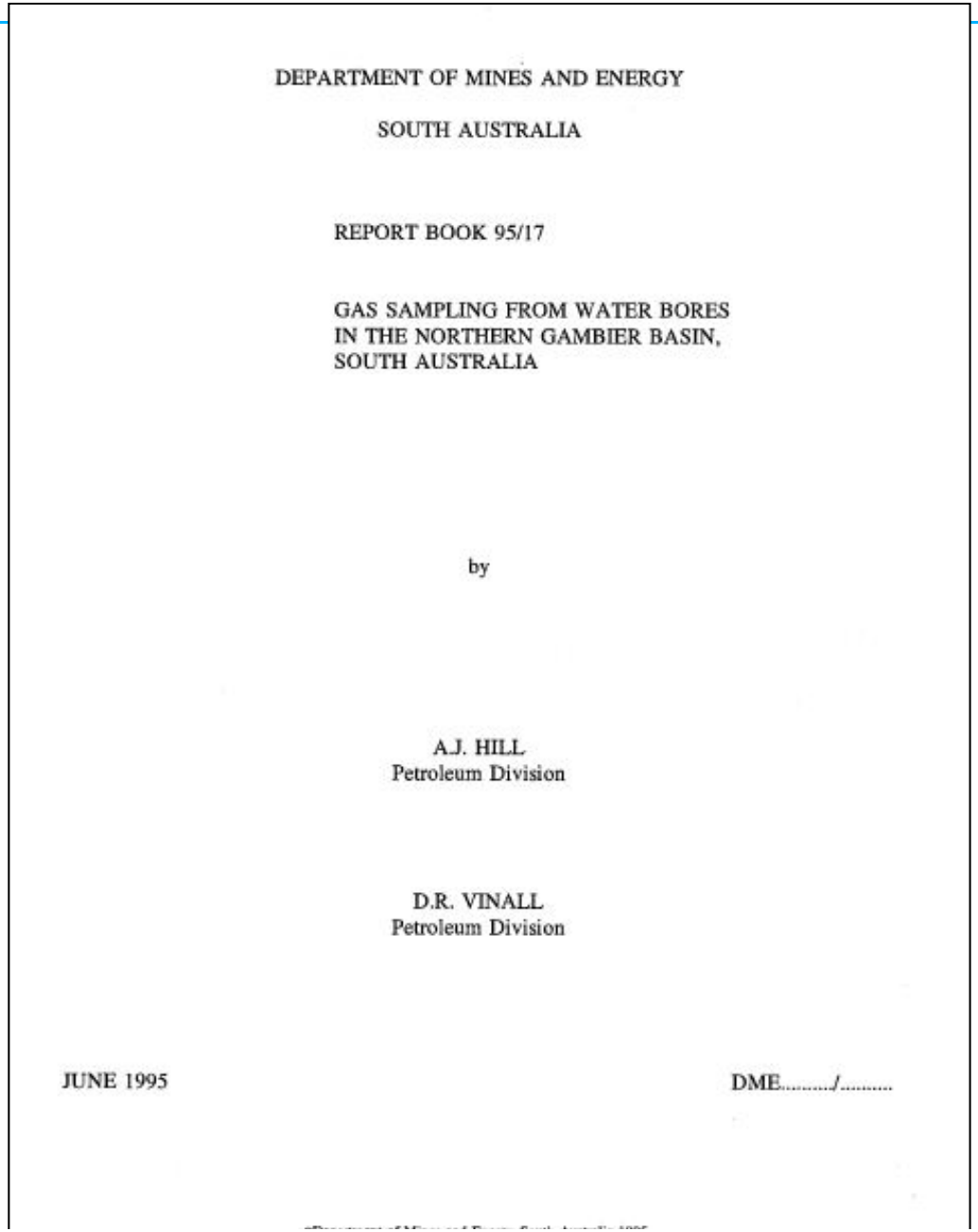


(Diagram not to scale)

Source: Styles, Keele University, UK

Presence of Hydrocarbon in Shallow Aquifers

Water Bore Sampling



DEPARTMENT OF MINES AND ENERGY

SOUTH AUSTRALIA

REPORT BOOK 95/17

GAS SAMPLING FROM WATER BORES
IN THE NORTHERN GAMBIER BASIN,
SOUTH AUSTRALIA

by

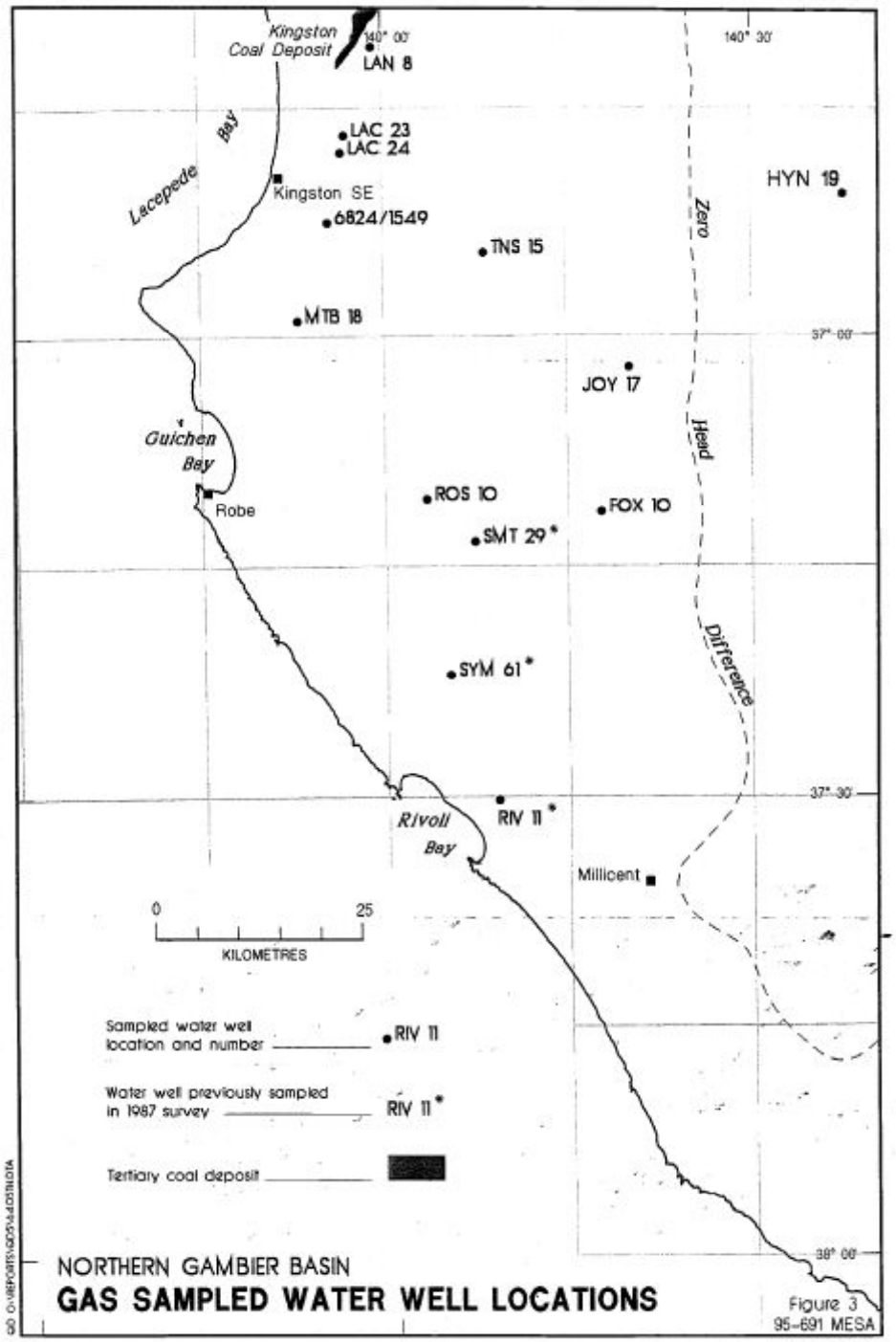
A.J. HILL
Petroleum Division

D.R. VINALL
Petroleum Division

JUNE 1995

DME...../.....

Available on DMITRE SARIG Web site


Kingston Coal Deposit
140° 00'
140° 30'
LAN 8
LAC 23
LAC 24
Lacepede Bay
Kingston SE
6824/1549
TNS 15
HYN 19
Zero
MTB 18
37° 00'
JOY 17
Guichen Bay
Robe
ROS 10
FOX 10
SMT 29*
Head
Difference
SYM 61*
37° 30'
RIV 11*
Rivoli Bay
Millicent
0
25
KILOMETRES
Sampled water well location and number
RIV 11
Water well previously sampled in 1987 survey
RIV 11*
Tertiary coal deposit
38° 00'
NORTHERN GAMBIER BASIN
GAS SAMPLED WATER WELL LOCATIONS
Figure 3
95-691 MESA

Head Space Gas Sampling

Dilwyn Formation

Table 1: Compositional analysis of water bores sampled in 1987 survey.

Sample	RIV 11 sample 1	SYM 61 sample 1	SMT 29 sample 2	SMT 29 sample 1
$N_2 + O_2$	92.67	99.39	94.51	98.92
CO_2	0.96	0.32	3.12	0.39
CH_4	5.39	0.29	0.00	0.00
C_2H_6	0.30	0.00	0.00	0.02
C_3H_8	0.00	0.00	0.00	0.00
C_{4+}	0.68	0.00	2.37	0.00
Total	100	100	100	100

Table 2. Headspace gas volumes, 1993 survey.

Sample	Volume (mL)
JOY-17-1	100
JOY-17-2A	800
SMT-29-1	50
SMT-29-2	450
SMT-29-1A	950
6824-1549-1	100
6824-1549-2	1100
FOX-10-2	1150
SYM-61-1	400
MTB-18-1	1000

Methane

Dilwyn Formation

Table 3: Bulk composition, water bore gases

Components	JOY-17-1	JOY-17-2A	SMT25-1	SMT29-2	SMT29-1A	6824-1549-1	6824-1549-2	FOX10-2	SYM61-1	MTB18-1
N_2 (mol %)	52.3	50.9	47.2	46.2	48.3	7.74	10.2	35.1	72.5	95.5
O_2+Ar (mol %)	4.79	1.03	2.46	2.87	1.17	0.42	0.50	0.80	1.38	1.45
CO_2 (mol %)	0.18	1.86	0.05	0.15	0.09	0.04	0.06	0.08	0.56	2.90
C_1 (mol %)	42.7	46.2	50.3	50.8	50.4	91.8	90.2	64.0	25.6	0.16
C_2 (µL/L)	<30	<30	<30	<30	<30	<30	<30	<30	<30	3
C_3 (µL/L)	<1	1	1	<1	1	4	1	<1	<1	<1
C_4 (µL/L)	<1	1	1	<1	2	4	6	2	1	2
C_5 (µL/L)	<1	<1	<1	<1	1	5	5	2	3	1
C_6 (µL/L)	<1	60	30	2	4	11	20	4	15	10

Methane

Dilwyn Formation

Table 4. Stable Carbon isotope analyses, $\delta^{13}C/_{oo}$ PDB

Sample	Methane $\delta^{13}C$	Carbon Dioxide $\delta^{13}C$
JOY-17-2A	-77.7	-20.2
SMT-29-1A	-72.4	-
6824-1549-2	-52.4	-
FOX-10-2	-64.1	-
SYM-61-1	-99.8	-
MTB-18-1	-63.3	-18.6

Carbon Isotope Thresholds

- < -60 Biogenic Source
- > -60 Thermogenic Source

Salamander #1 Geothermal Well