To flow or not to flow, *that* is the question…

Ruth Thomas
Subsurface Manager

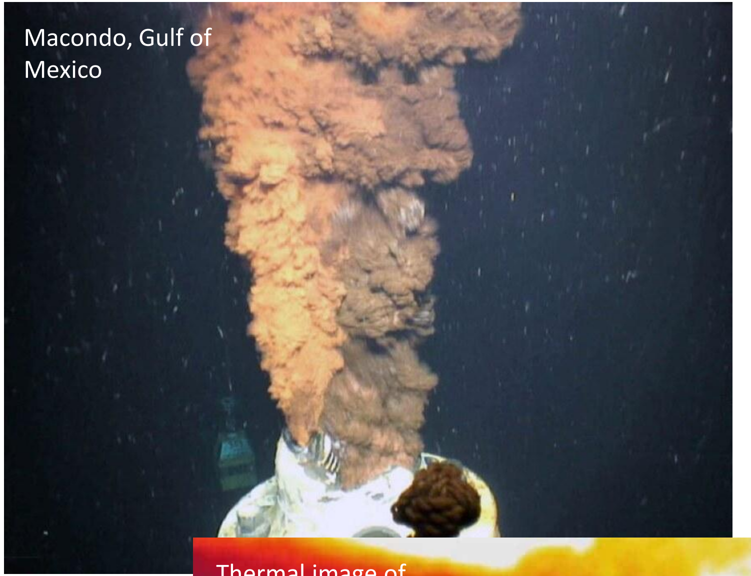
To flow or not to flow...

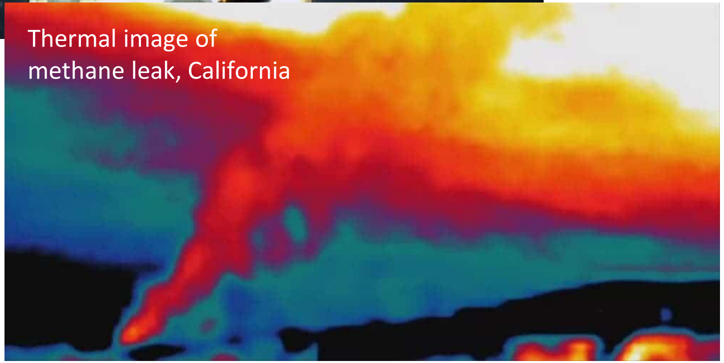
- The Inconvenient Truth
- Regulatory Context
- What Is Sustained Flow Potential?
- Case Study Examples
  - “Confirmation Bias”
  - “Challenging The Norm”

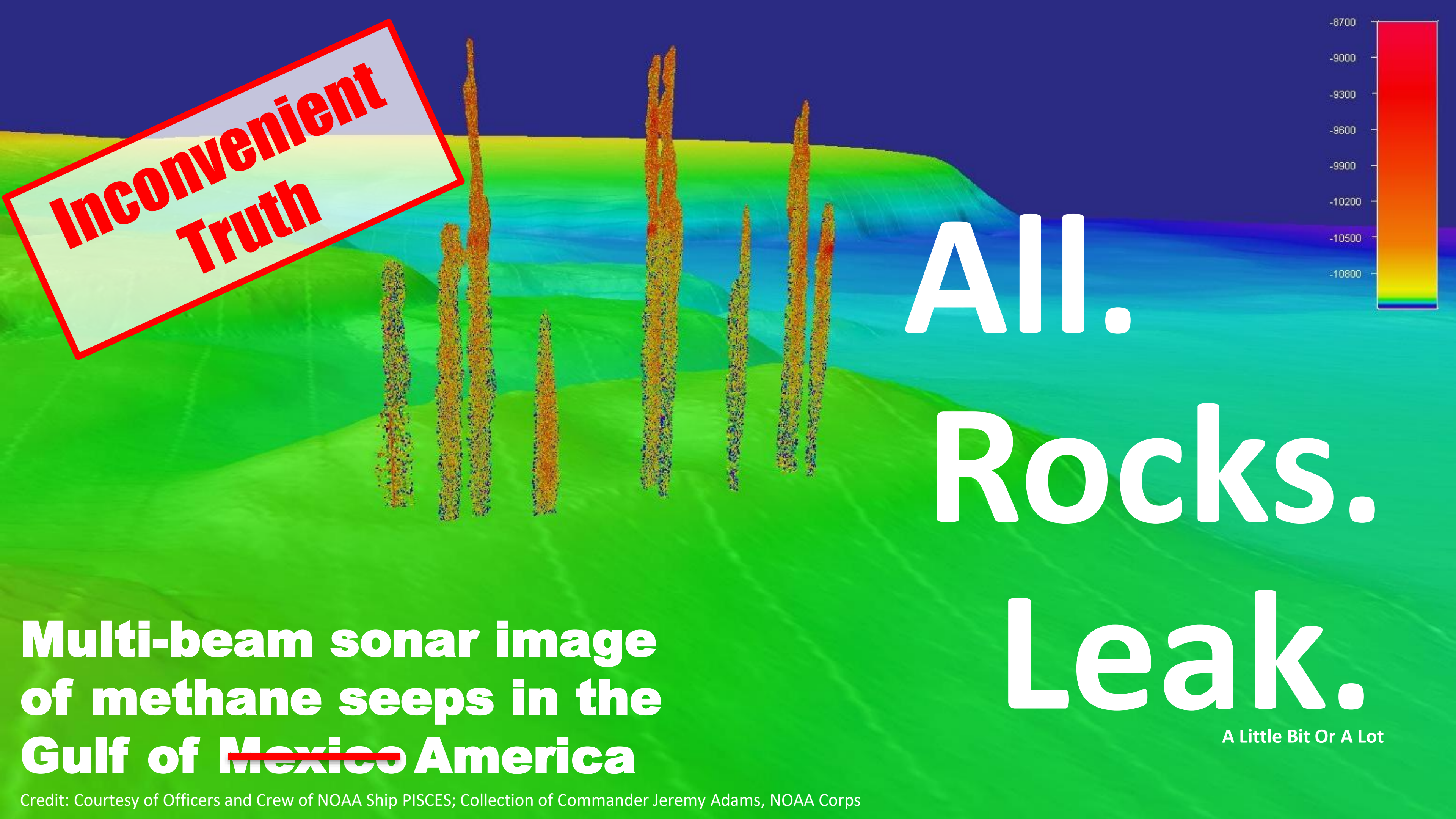
Why Abandon?

- Wells need to be abandoned to ensure **safety, environmental protection**, and **regulatory compliance** after they are no longer productive or operational.

“…no unplanned escape of fluids from the well or from the reservoir to which it led.”


Macondo, Gulf of Mexico

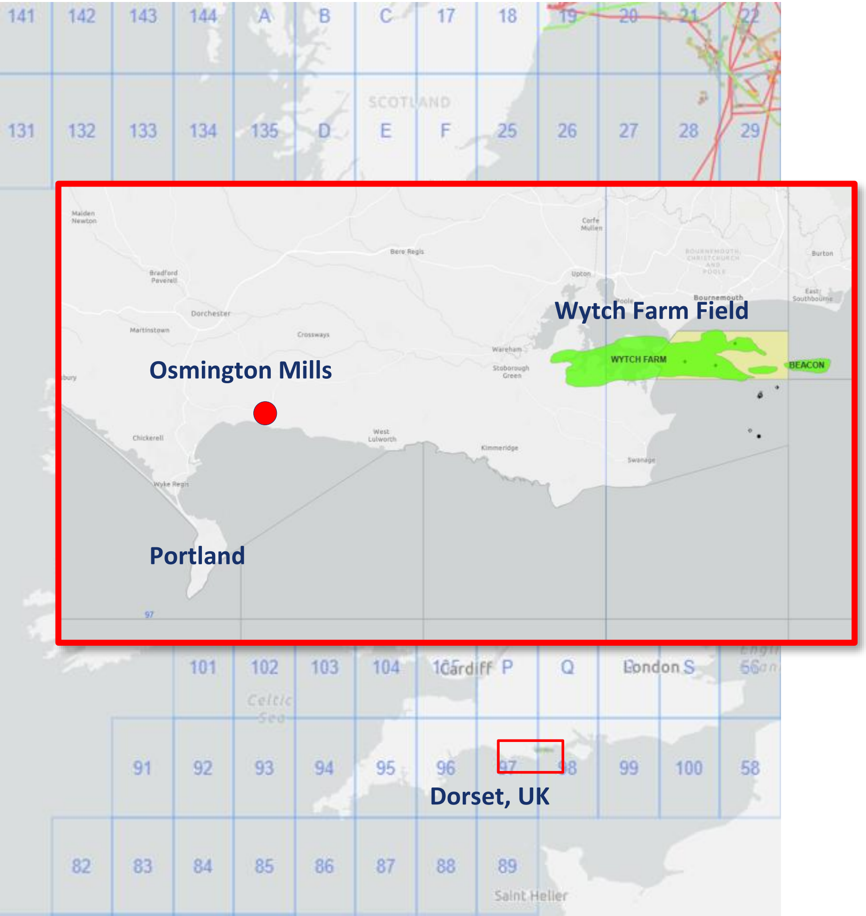

Thermal image of methane leak, California

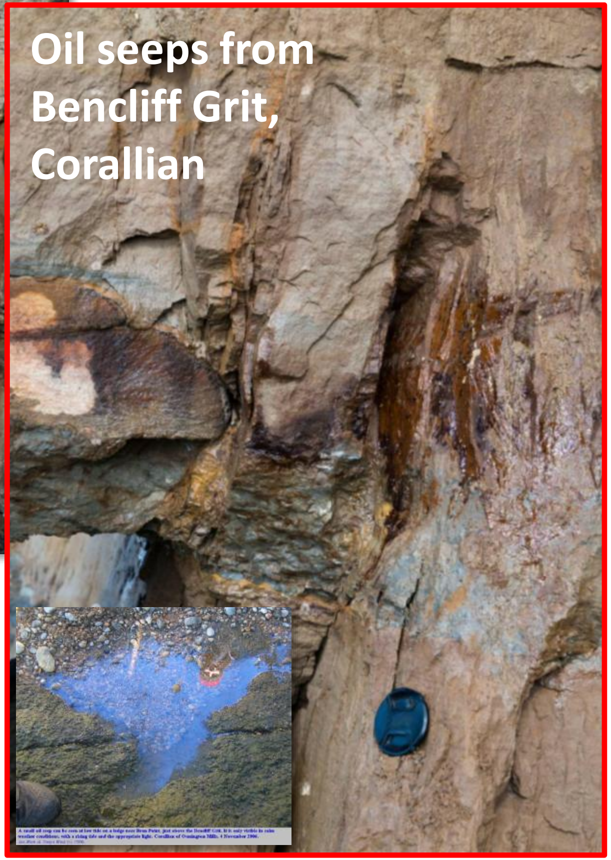


Credit: Courtesy of Officers and Crew of NOAA Ship PISCES; Collection of Commander Jeremy Adams, NOAA Corps

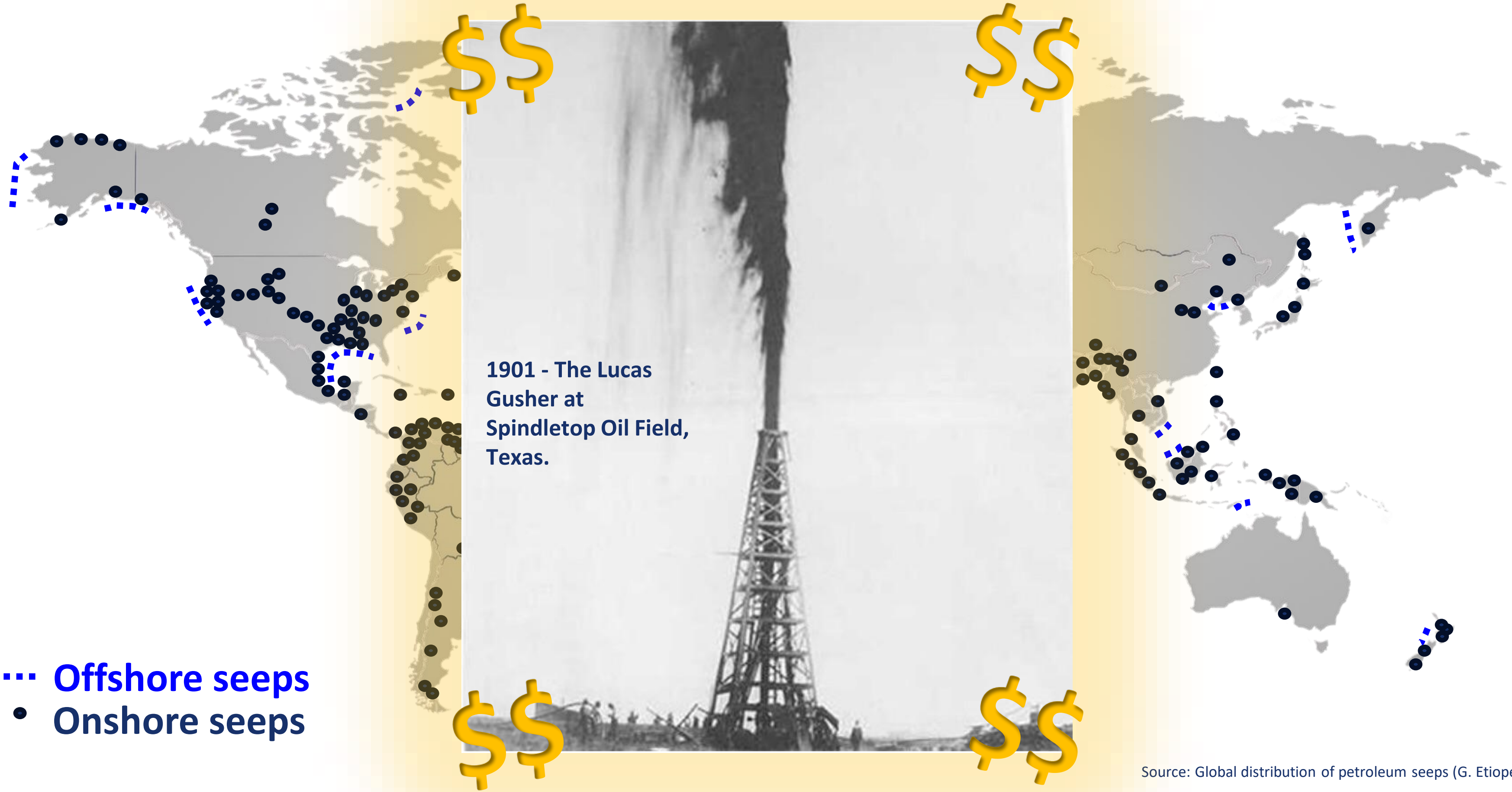

Credit: NOAA OKEANOS Explorer Program, 2013 ROV Shakedown and Field Trials
Methane bubbles flow, offshore Virginia

Somewhere a little closer to my home…





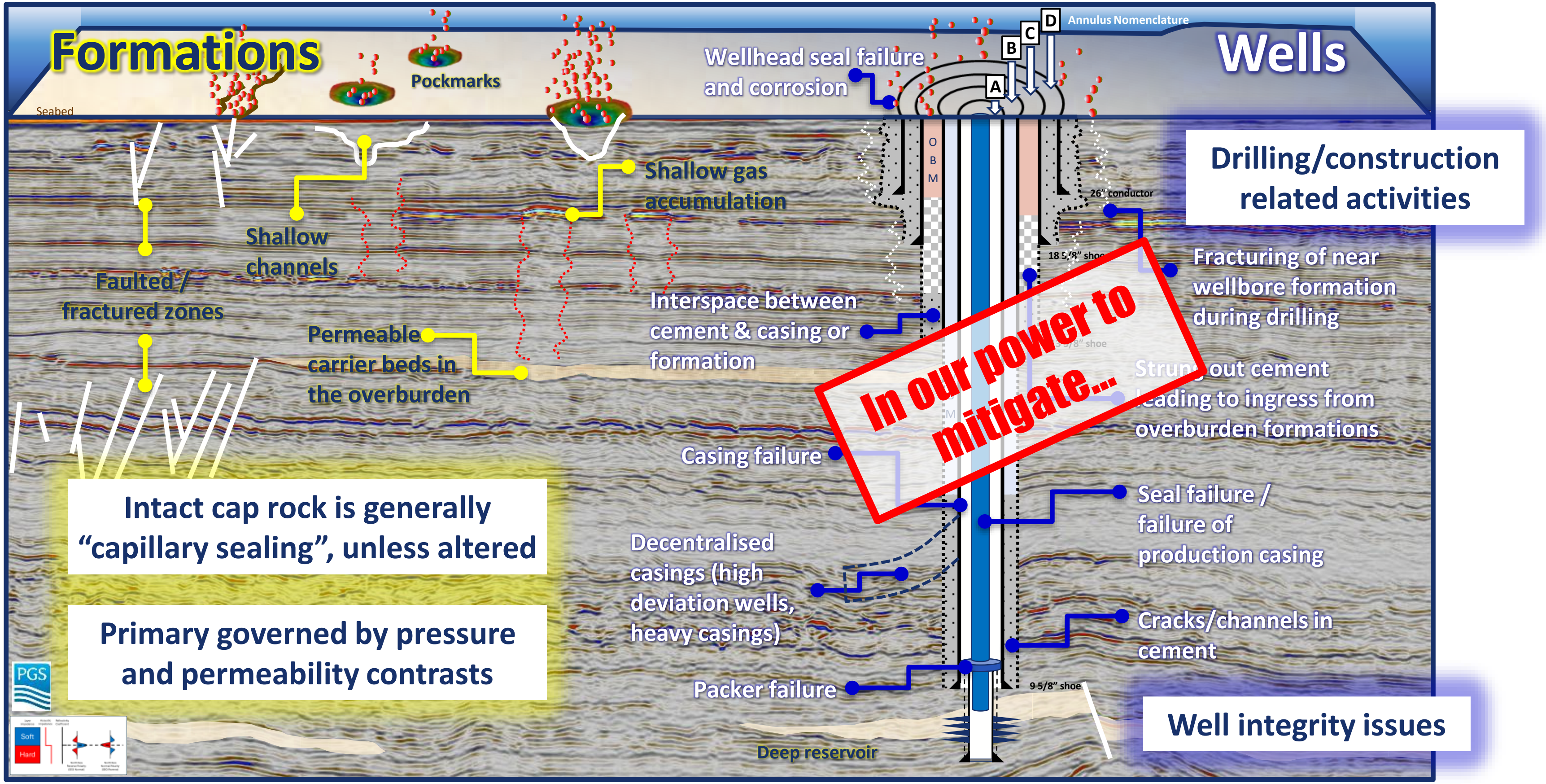
Global Seeps & Weeps



Source: Global distribution of petroleum seeps (G. Etiope, 2009)

What Can Flow/Leak?

Figure not to scale

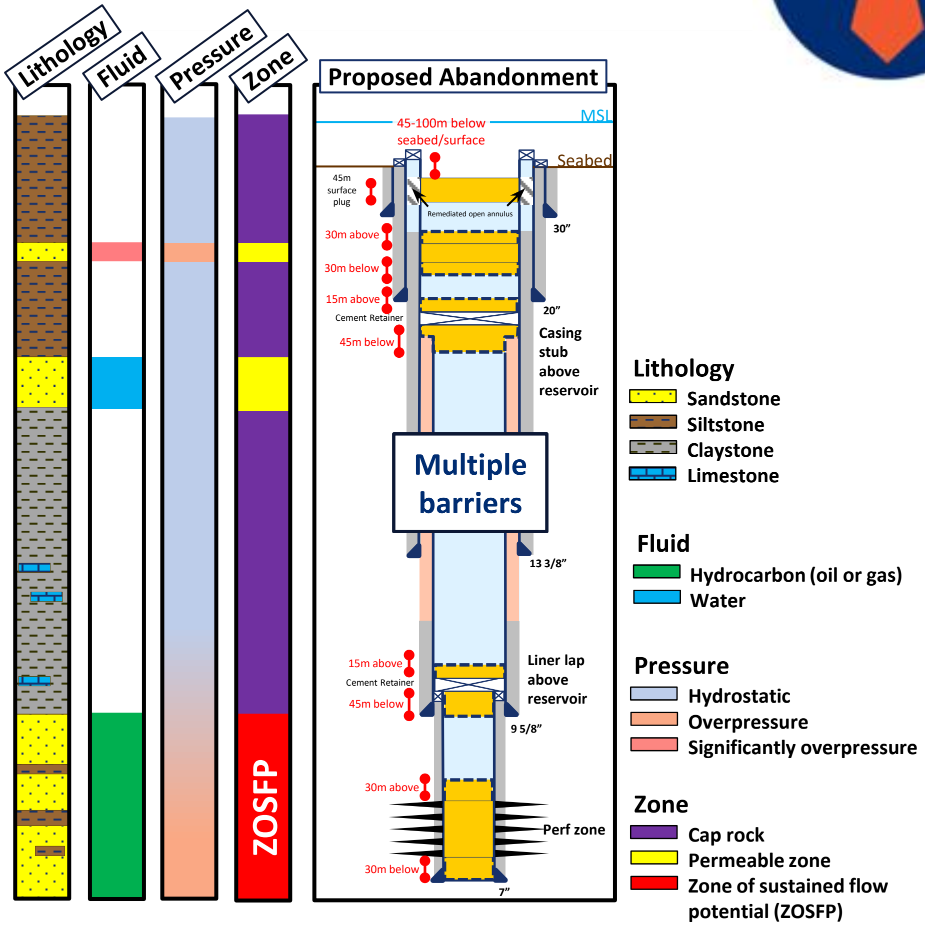


Regulatory Context

The Global Context

"Zero Leaks Forever" Mindset

Conservative, multi-level plugging strategy driving cost-escalation and project deferment



Regulatory Context

The Global Context

Risk-Based Mindset

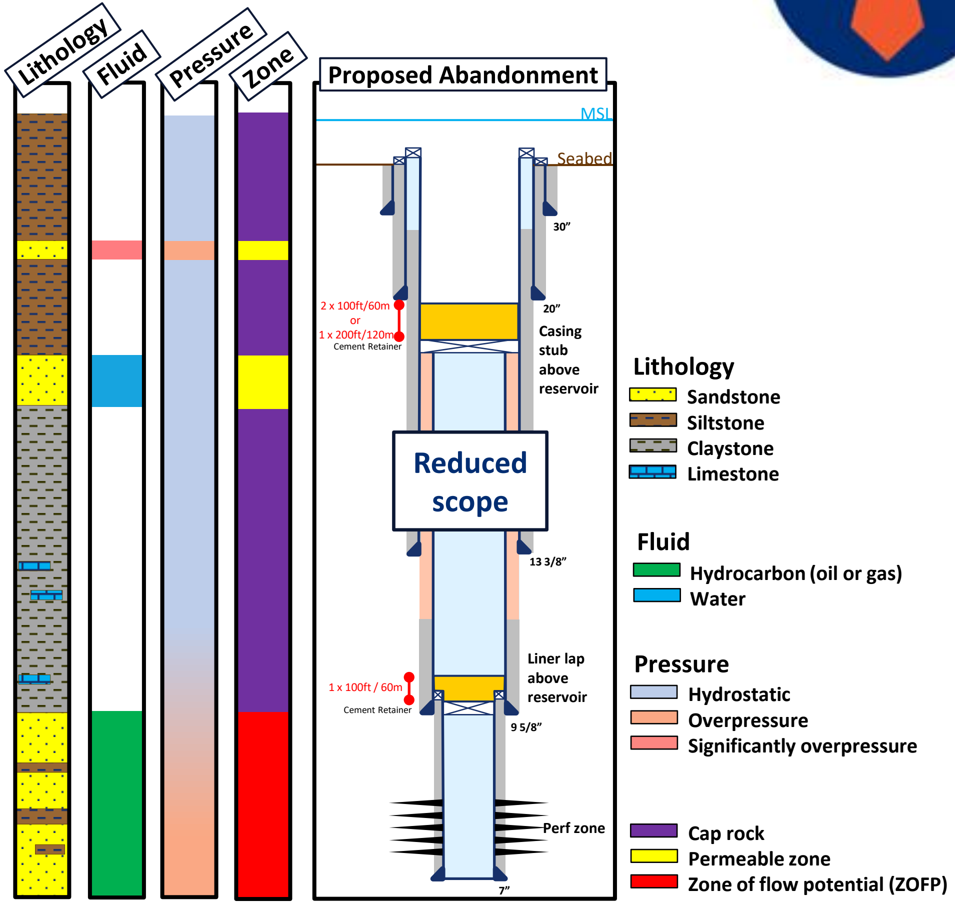
Use data, and specific engineering & subsurface studies to "reduce the leak risk to ALARP*"

1996 No. 913 HEALTH AND SAFETY statutory instrument

Reg. 13 of Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 (SI 1996/913) [DCR]

OEUK Well Decommissioning Guidelines

Issue 7, "Section 2, Evaluation of Formations with Flow Potential"

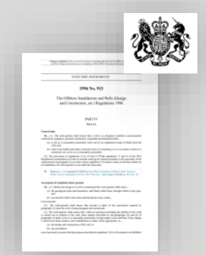


*as low as reasonably practicable

Regulatory Context

What Does The UK Regulator Expect?

UK Legislation



1996 No. 913 HEALTH AND SAFETY statutory instrument

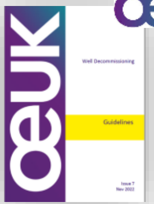
Reg. 13 of Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 (SI 1996/913) [DCR]

"…no unplanned escape of fluids from the well…."

"…. abandoned in a safe manner…"

"….risks to the health and safety of persons are as low as is reasonably practicable (ALARP)…."

UK Guidance



OEUK Well Decommissioning Guidelines

Issue 7, "Section 2, Evaluation of Formations with Flow Potential"

"… **subsurface assessment** to understand **formation flow potential**…"

"…risk-based approach…"

"…leak risk should be ALARP…"

*as low as reasonably practicable

Regulatory Context

What Is Subsurface Assessment?

OEUK Well Decommissioning Guidelines

Issue 7, "Section 2, Evaluation of Formations with Flow Potential"

Excerpt from page 14 of the Guidance:

Flow originates from formations with permeability and a pressure differential with respect to other formations or the surface/subsea environment. The pressure differential needs to be sufficient to maintain flow once the well is filled with formation fluids. Typically, assessment of flow potential

includes an evaluation of formations known to be productive from field or offset data. Formations with low (e.g. <0.1mD) matrix permeability, like shales and chalk, may also have flow potential (e.g. if fractured), in which case these may require isolation. Fractures may be natural or induced by operations

It is important to note that direct permeability and pressure data are typically only available for formations that have produced hydrocarbons, hence the requirement for subsurface expertise to identify relevant offset and analogue data in the assessment of flow potential. The value of such

Subsurface Assessment

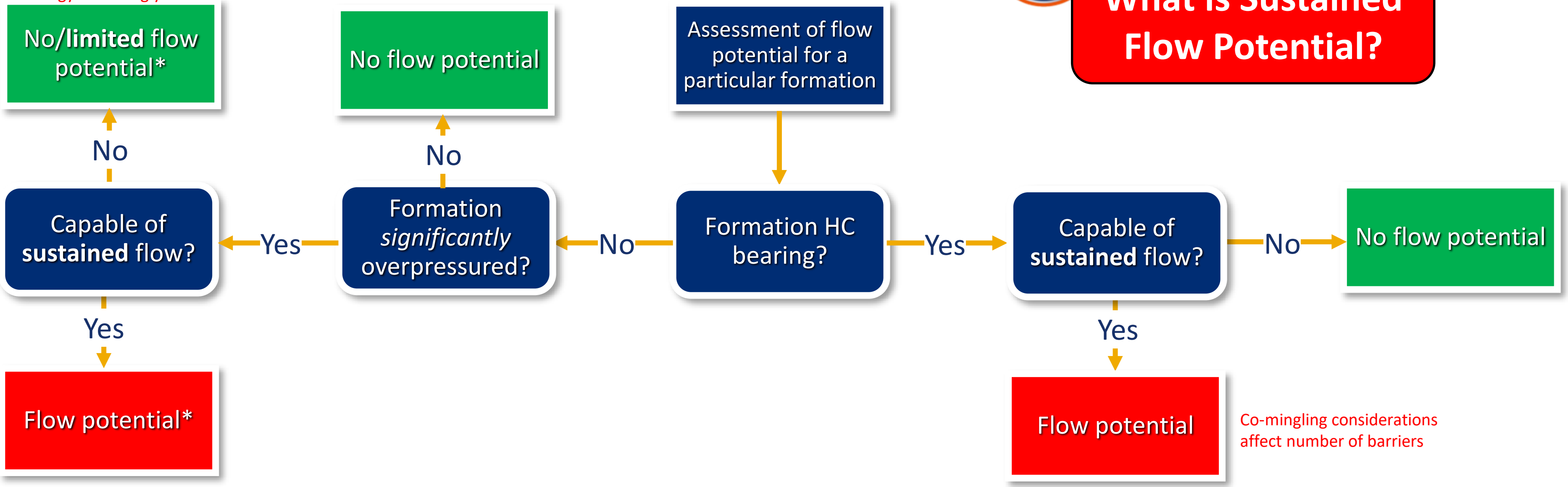
Workflow For Determining Formation Flow Potential

OEUK Well Decommissioning Guidelines

Issue 7, "Section 2, Evaluation of Formations with Flow Potential"

Q **What is Sustained Flow Potential?**

*Assess risk of potential flow and design isolation strategy accordingly

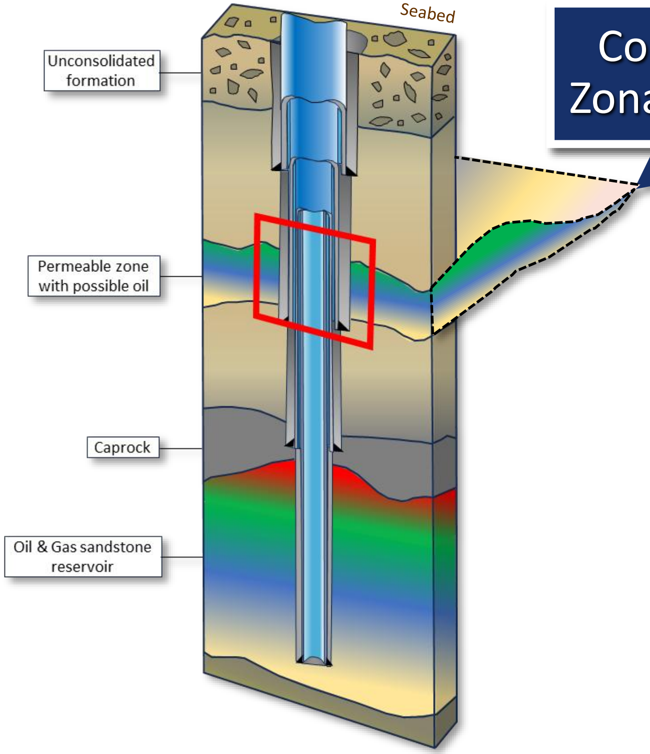


*Formations require isolation from environment – deviation may be considered if risk of release is deemed ALARP and satisfy DCR Reg 15

Subsurface Assessment

Sustained Flow Potential

OEUK Well Decommissioning Guidelines
Issue 7, "Section 2, Evaluation of Formations with Flow Potential"



Connected Zonal Volume

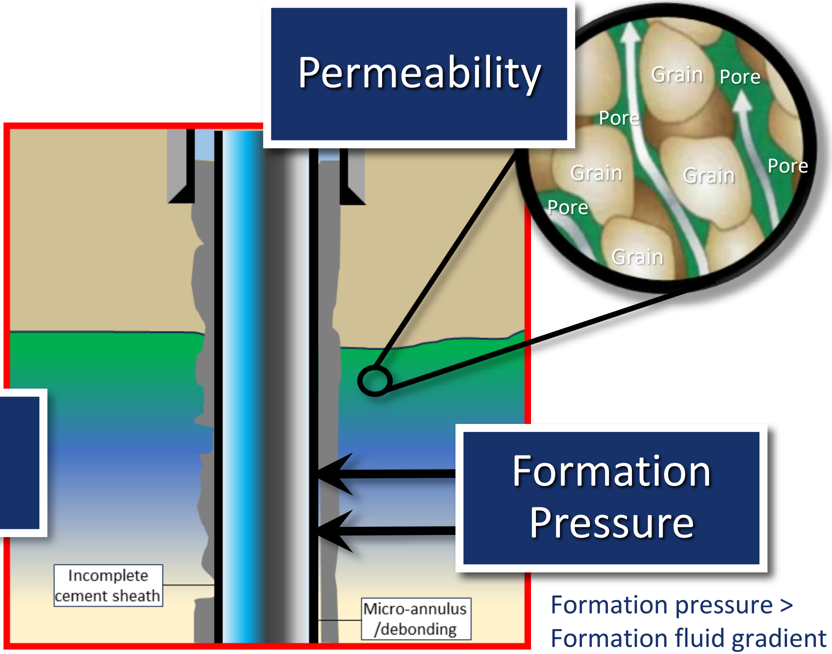
Heterogeneity
Distribution
Connectivity

Fluid Properties

Phase
Saturation
Viscosity
Relative mobility

Effective / Relative

Permeability



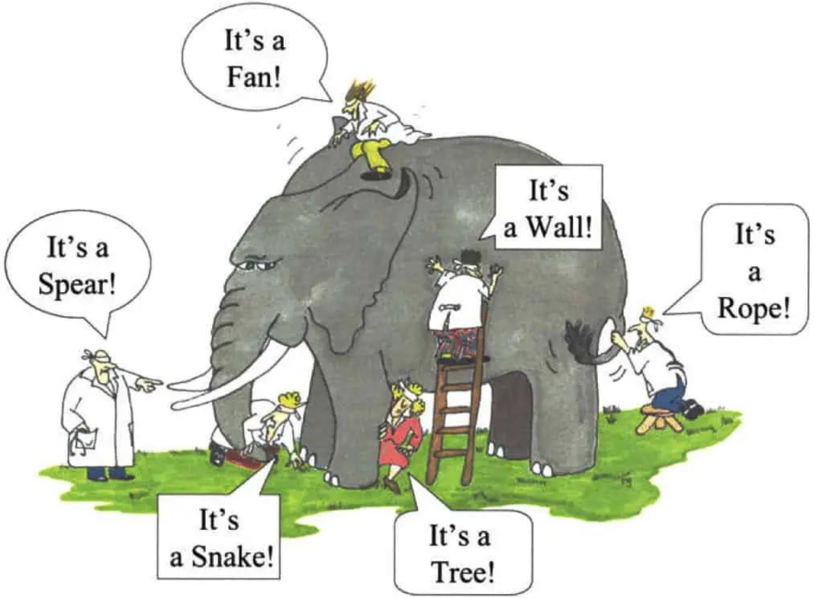
Formation Pressure

Formation pressure >
Formation fluid gradient

Why Does It Matter?

What is the impact on our abandonment cost?

- Impact of mis-identifying sustained flow potential?
- Impact of “over-abandoning” a zone unnecessarily?
- Miss optimisation opportunities (cost-reduction) and/or risks



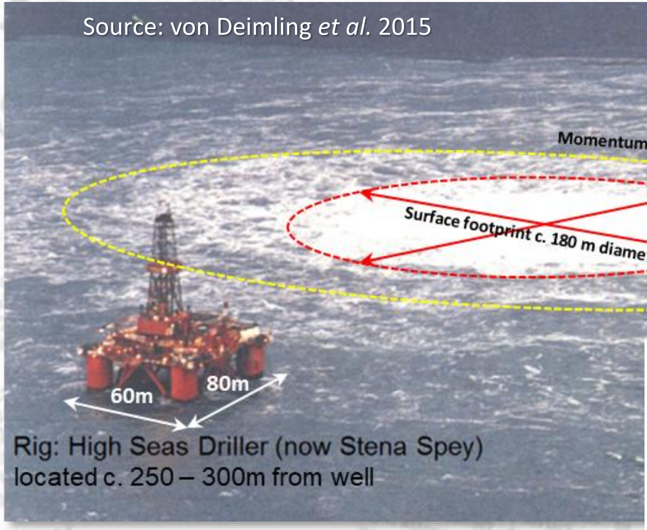
We might miss the bigger picture

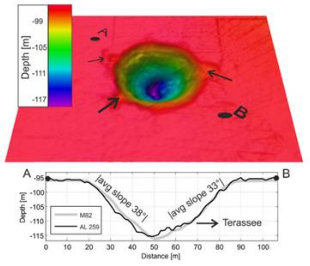
Case Study 1: "Confirmation Bias"

Major Event

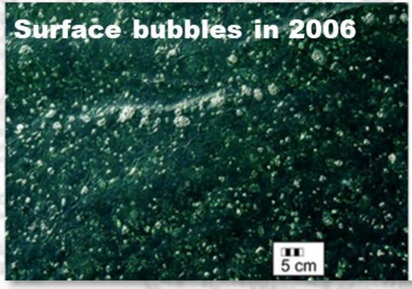
- 22/4b-4 blowout in November 1990
- Gas bubbles observed on surface (bit at 360 m, driller POOH, swabbing gas into the well (H_2S and methane)
- The well had encountered a 31 - 46m thick, 67 psia over-pressured gas column, with max. pressure of c. 9.5ppg EMW
- This blow out event directly influenced all subsequent drilling procedures in the area:

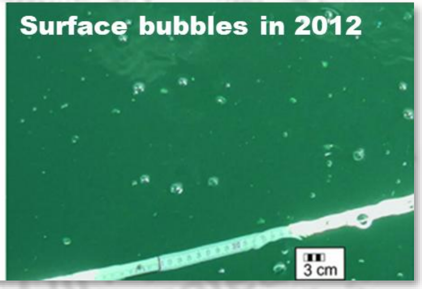
  1. **Surface casing should be set prior to penetrating this sandstone at c. 500 m**
  2. **A weighted mud system must be used for well control (>9.5 ppg mud)**





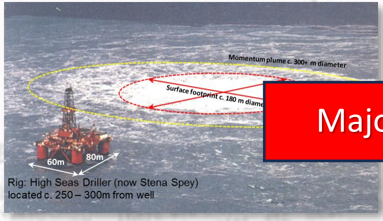
Leaving a 20 m x 70 m crater





“Confirmation Bias”

The Benefits of a “Fresh Eyes” Approach



Major Event

Change to drilling procedures for all subsequent wells

Wells drilled with little/no shallow gas **recorded**

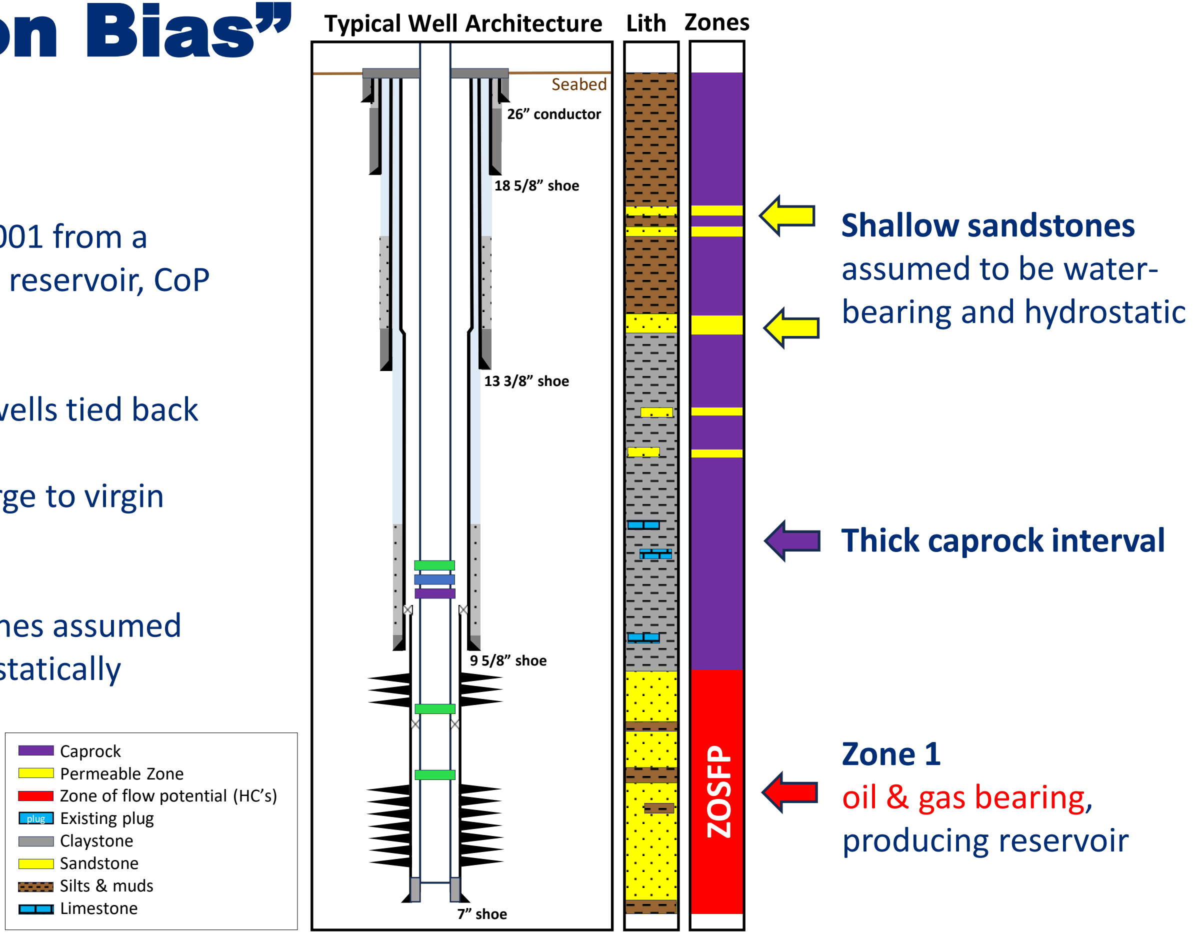
Flow potential falls out of the subsurface narrative

Flow Zone not recognised as requiring isolation in abandonment planning

"Confirmation Bias"

PP/FG

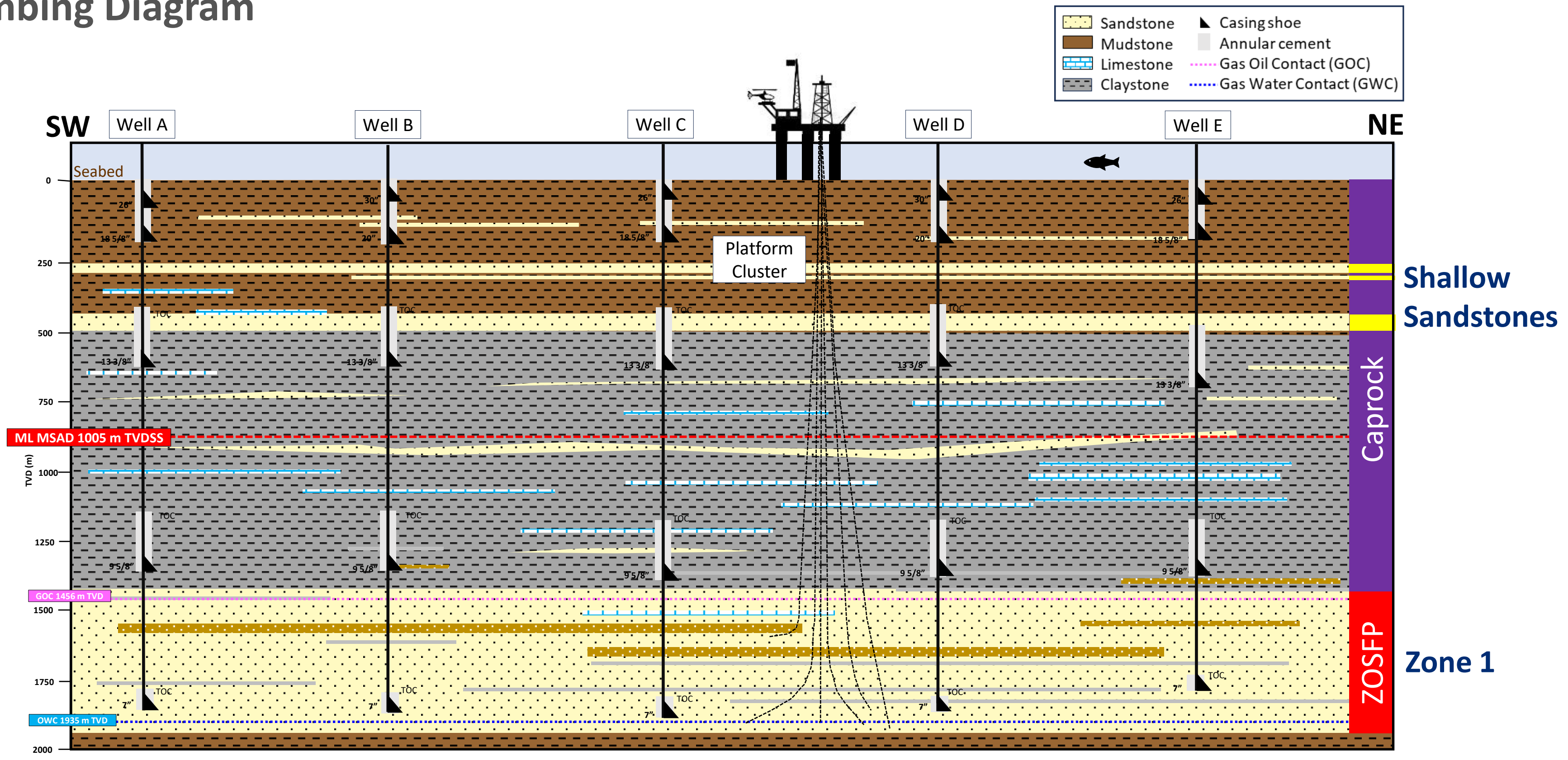
- Production commenced in 2001 from a Palaeocene oil & gas-bearing reservoir, CoP reached 2017
- 12 platform wells, 5 subsea wells tied back
- Minor depletion – will recharge to virgin due to large aquifer
- Shallow overburden sandstones assumed to be water-bearing & hydrostatically pressured



“Confirmation Bias”

Plumbing Diagram

12 platform wells, with 5 subsea wells tied back

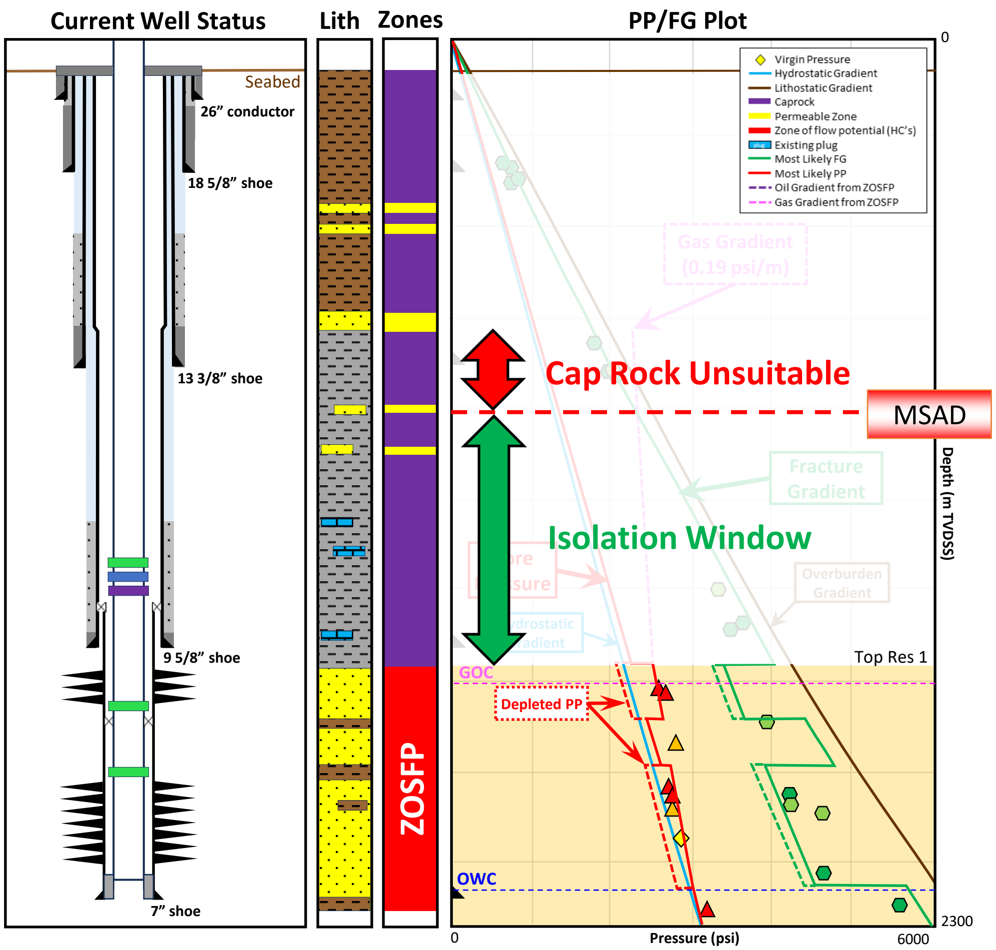


"Confirmation Bias"

PP/FG

- Pore Pressure and Fracture Gradient models provided showing depletion in reservoir
- Minimum safe abandonment depth (MSAD) calculated using gas gradient from top reservoir

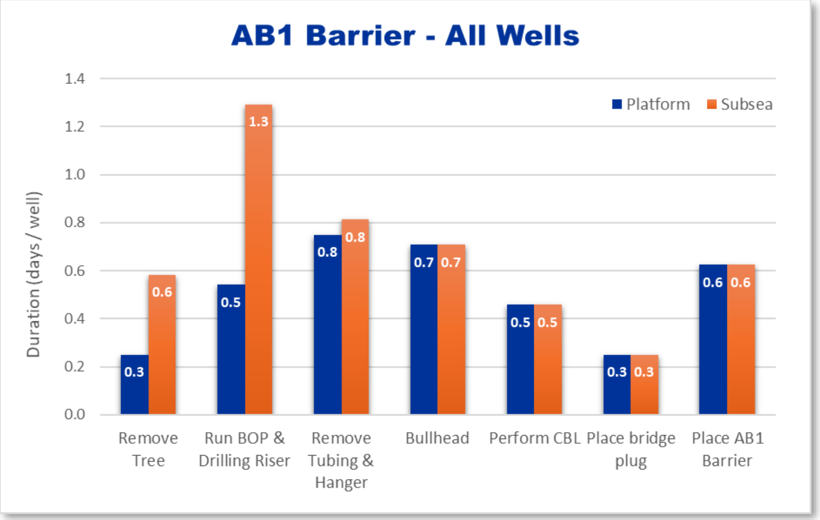
Zone 1
oil & gas bearing,
producing reservoir



“Confirmation Bias”

Operational Steps

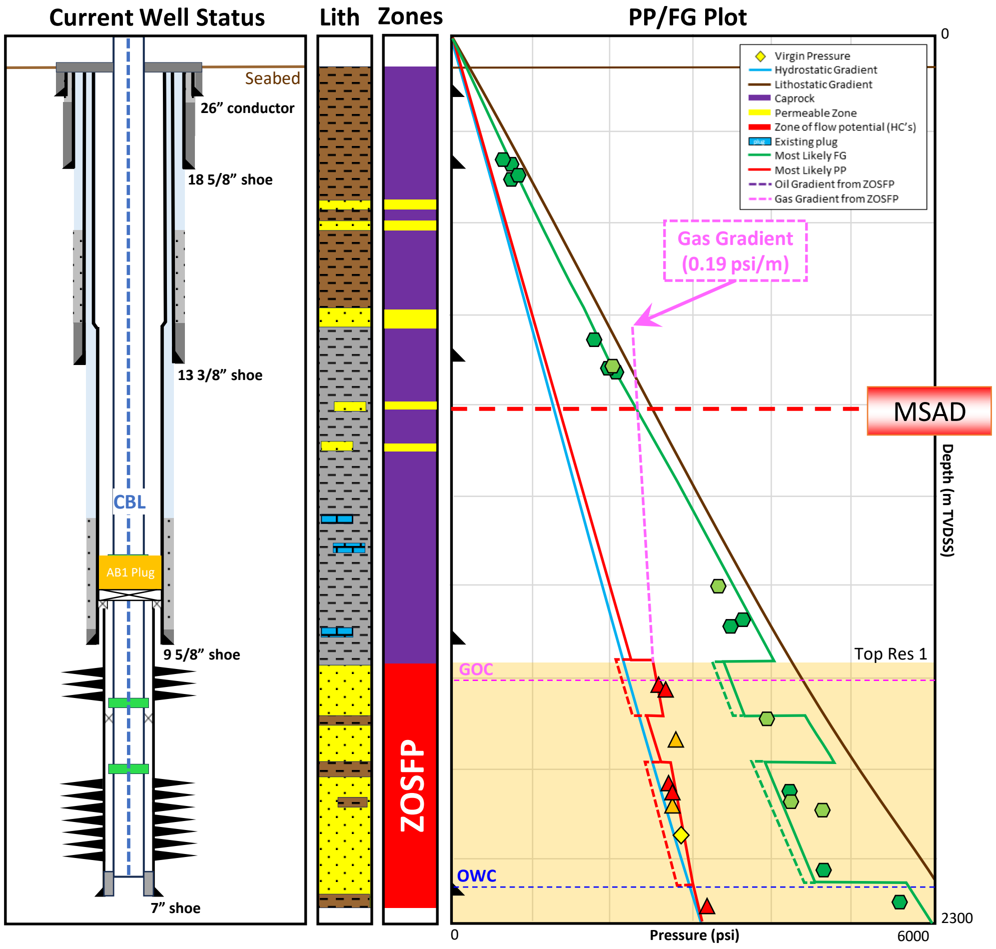
- Spread rate: £175,000 p/d
  (assumed jack-up or W/O unit)



Subsea £4.14 mm / 24 days

Platform £ 7.52 mm / 43 days

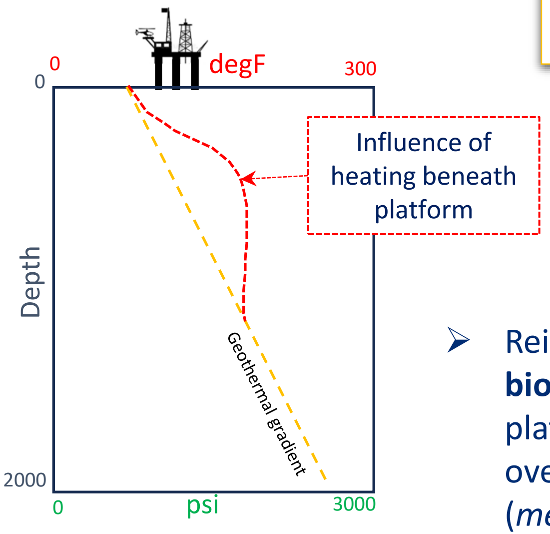
Overall Cost £11.66 mm



"Confirmation Bias"

Sustained Annular Pressure (SAP)

- Sustained annular pressure of up to **150 psi** present in C-annulus, sampling **methane**



D Annulus

Gas or fluid migration from formations

C Annulus

Gas lift

Out of Zone Injection

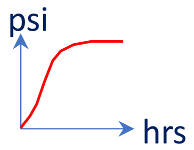
Formation pressure/fluids

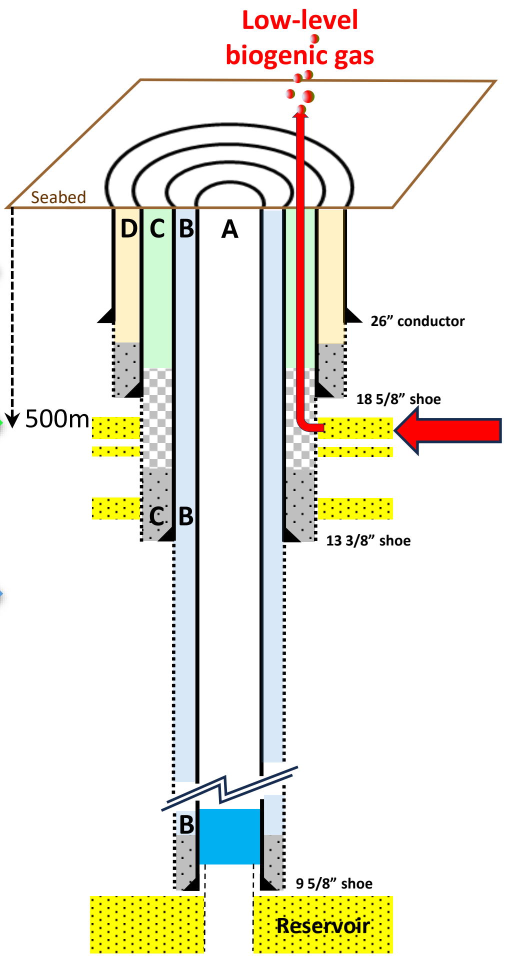
B Annulus

Cement/casing/tubing integrity failure

Long uncemented open-hole sections

Reservoir compaction





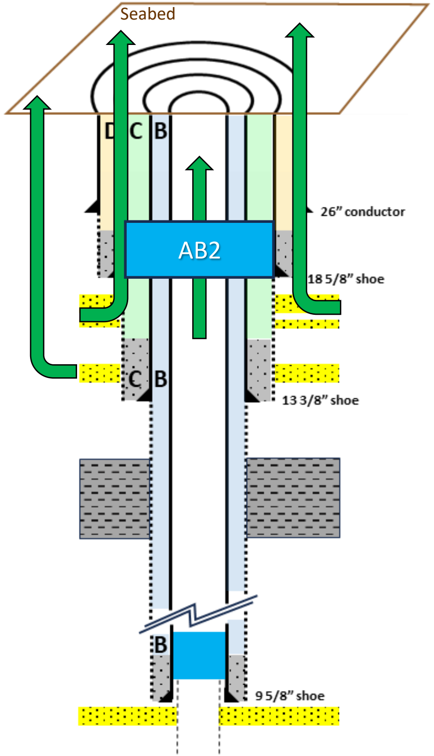
- Reinvigoration of **native biogenic system** due to platform heating overburden (*methanogenesis*)

“Confirmation Bias”

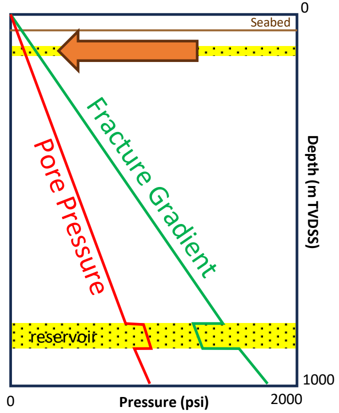
The problem with shallow barriers….

- Placement of pressure containing barrier at this depth – very challenging
- Difficult to verify
- Unknown formation properties
- Long term status of this zone? Remove platform – remove heat – remove problem?

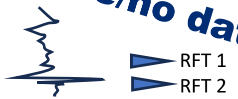
What is the best approach?



Little/no rock strength!



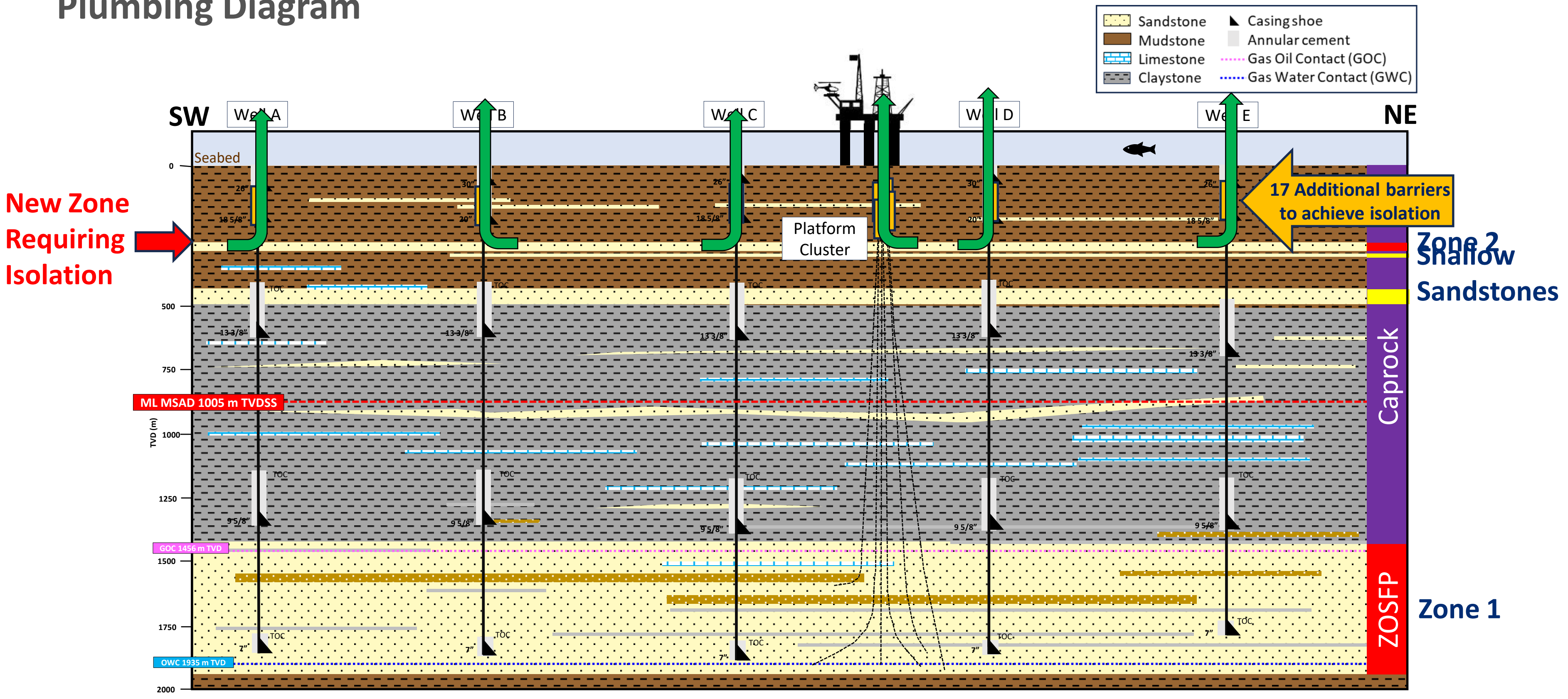
Little/no data!



"Confirmation Bias"

Plumbing Diagram

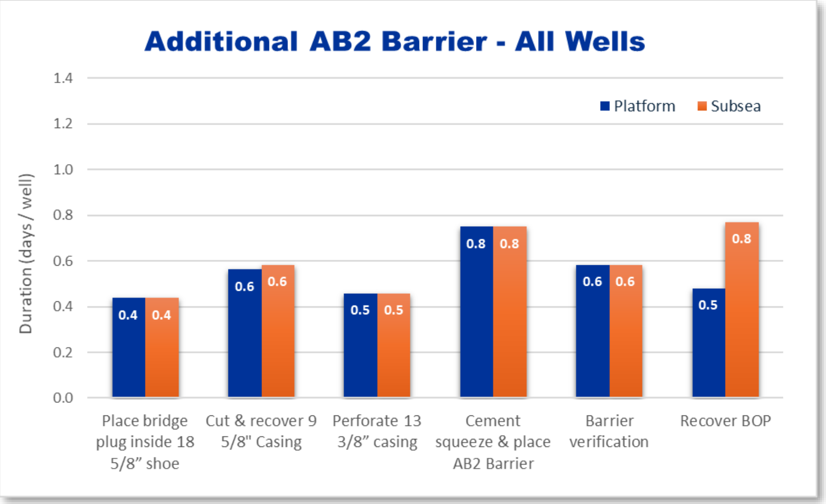
12 platform wells, with 5 subsea wells tied back



“Confirmation Bias”

New Operational Steps

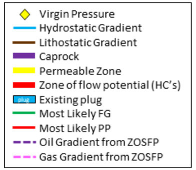
- AB1 scope same as before

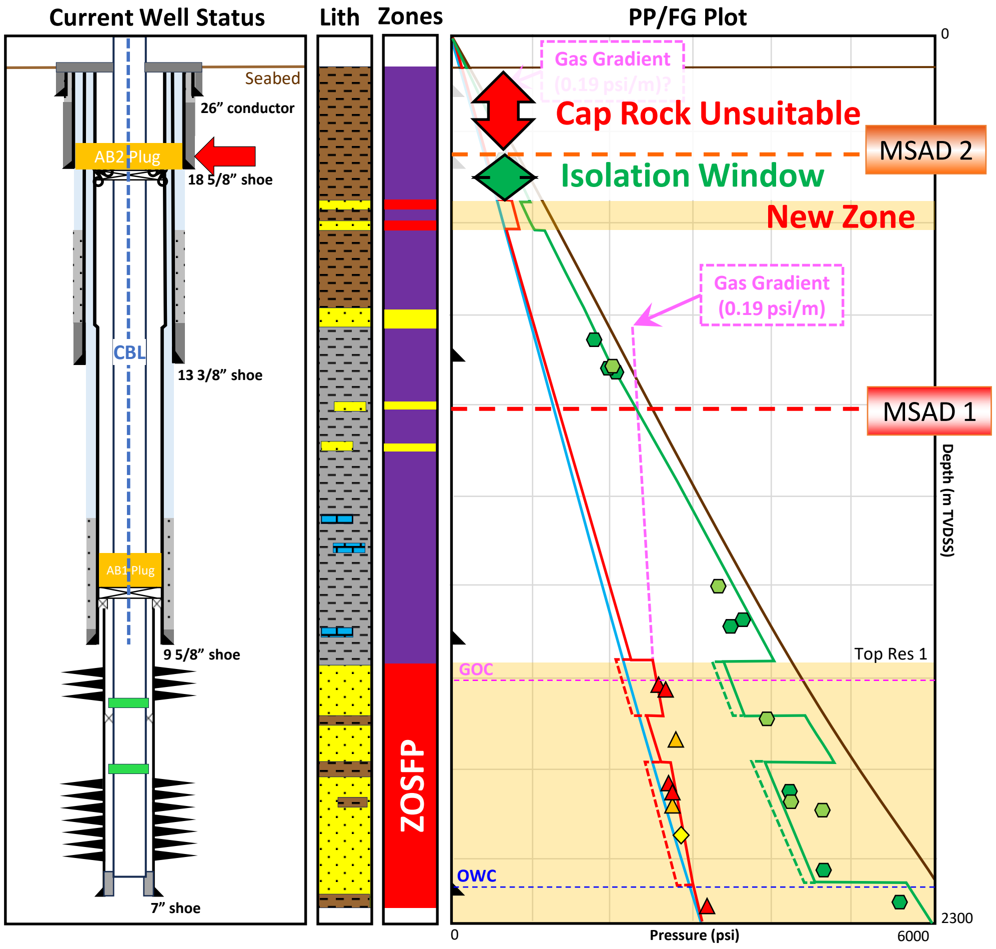


Subsea +£3.13 mm / +18 days

Platform +£6.33 mm / +39 days

Overall Cost £21.13 mm

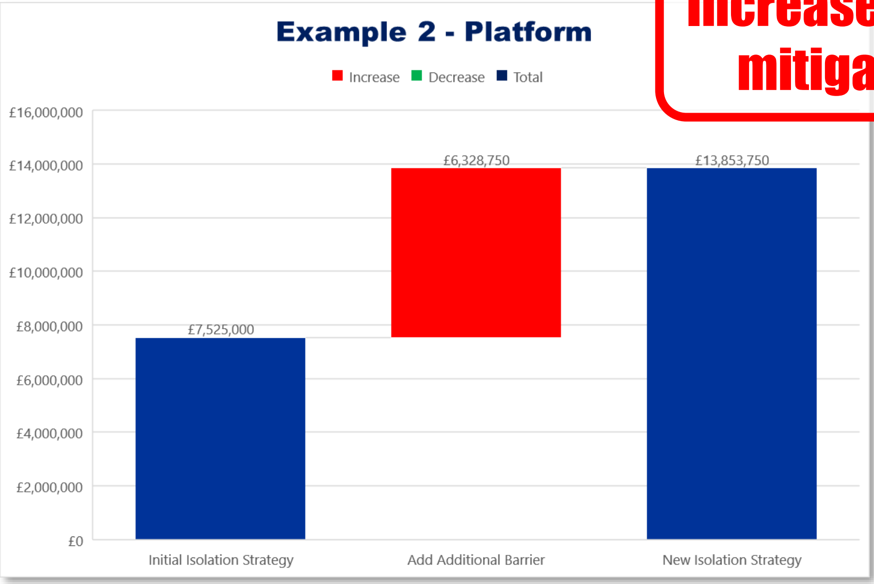


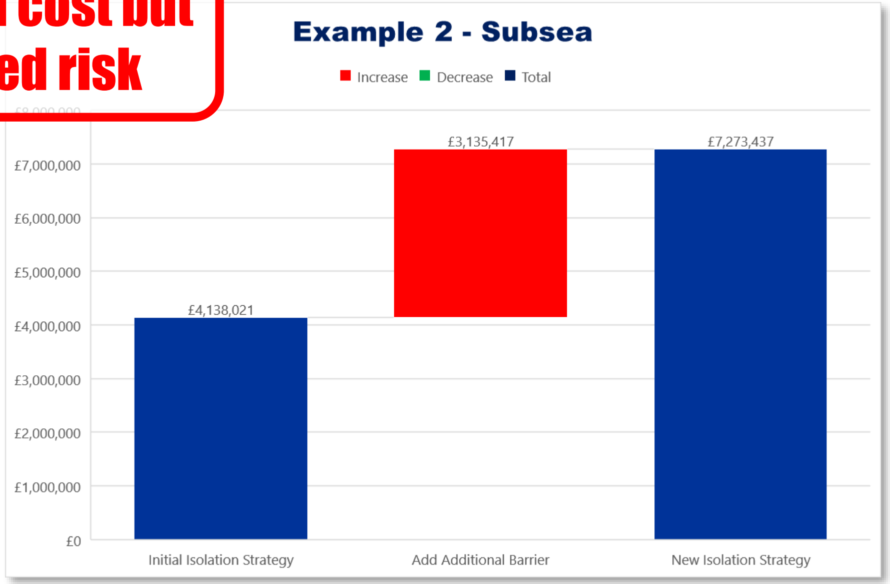


“Confirmation Bias”

Time/Cost Impact

Increased cost but mitigated risk





Cost increase from original strategy: + £9.46 mm / + 57 days

Case Study 2: "Challenging The Norm"

Blanket Isolation Philosophy

Huge cost / complexity implications for abandonment

Subsurface isolation requirements overly complex

Many wells drilled with additional cost

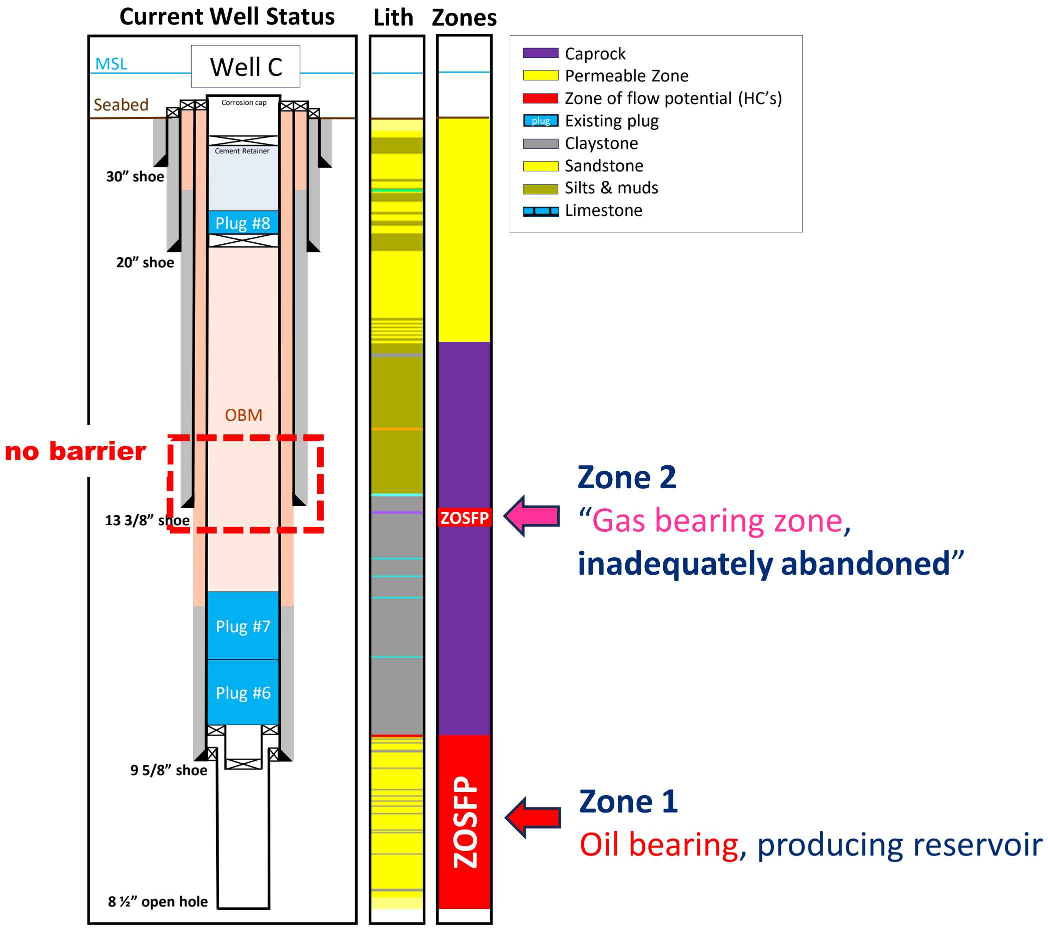
Change to drilling procedures for all subsequent wells

Zone of Sustained Flow Potential interpreted as requiring isolation <u>everywhere</u>

"Challenging The Norm"

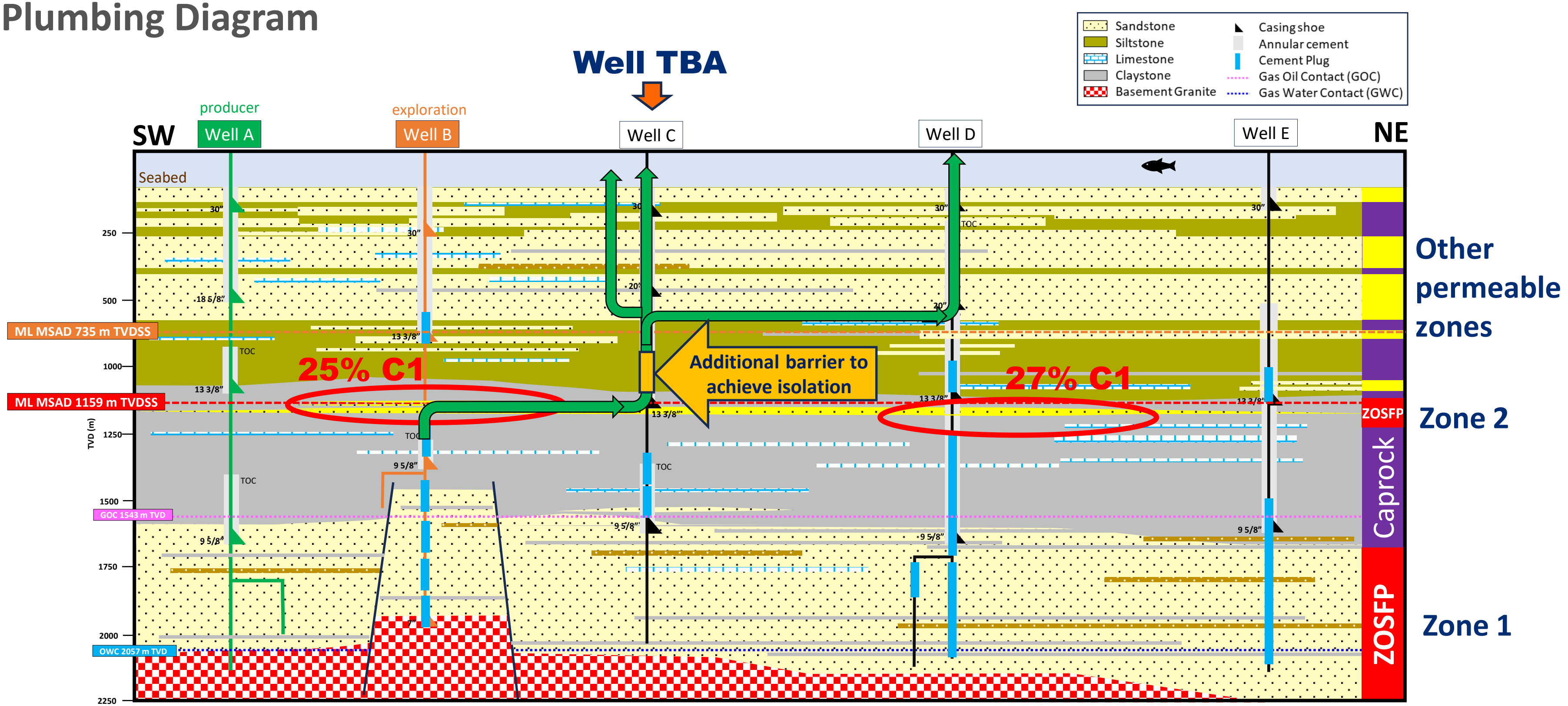
Subsurface Summary

- Drilled in 1999 as appraisal of the structure along strike from the original exploration and appraisal wells
- Oil encountered in a Cretaceous reservoir
- Overpressured in the region of 200 psi above hydrostatic
- Thick claystone overburden
- Thick sandstones in the shallow overburden, normally pressured and with connection to seabed



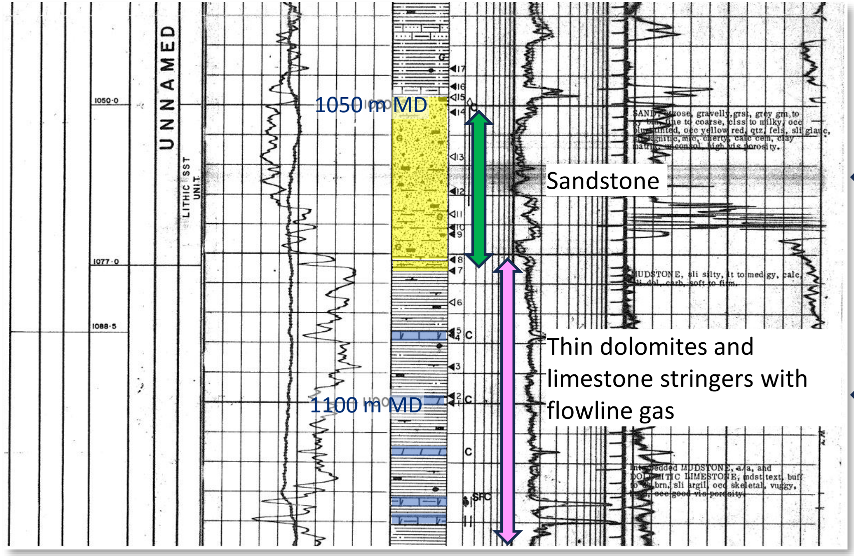
"Challenging The Norm"

Plumbing Diagram



“Challenging The Norm”

Flow Zone 2

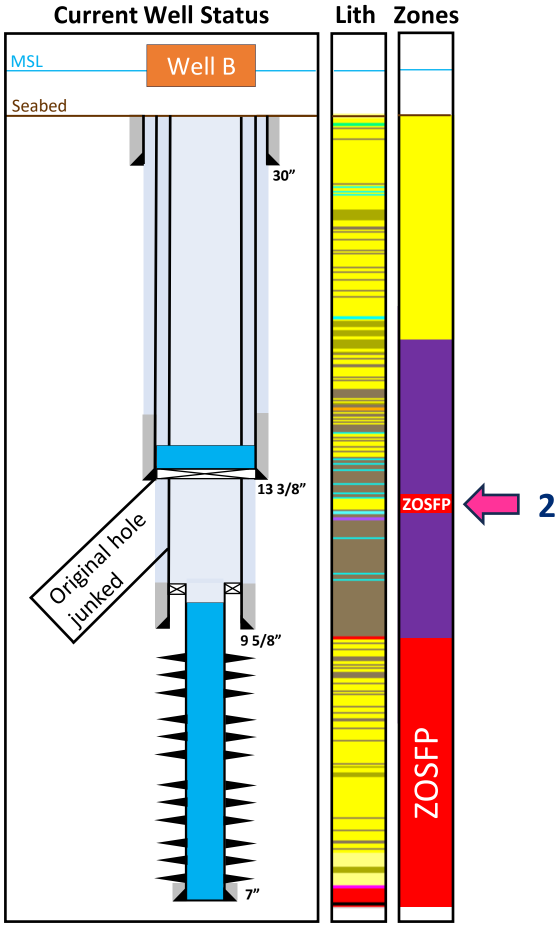


Excerpt from Well B Composite Log

Dead oil stain with fast, milky cut fluorescence

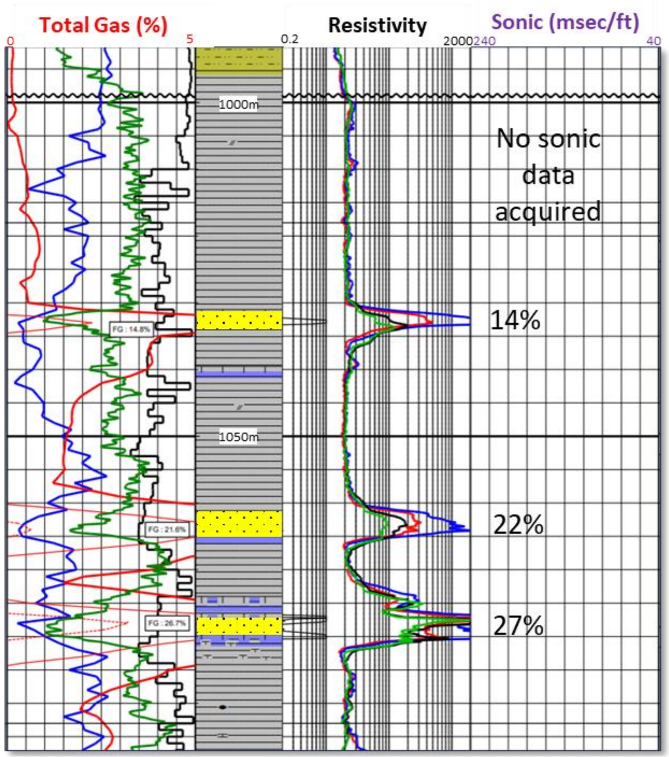
Gas max 25% C1, 2.5% C2, 1% C3

- Caprock
- Permeable Zone
- Zone of flow potential (HC’s)
- Existing plug
- Claystone
- Sandstone
- Silts & muds
- Limestone



"Challenging The Norm"

Flow Zone 2

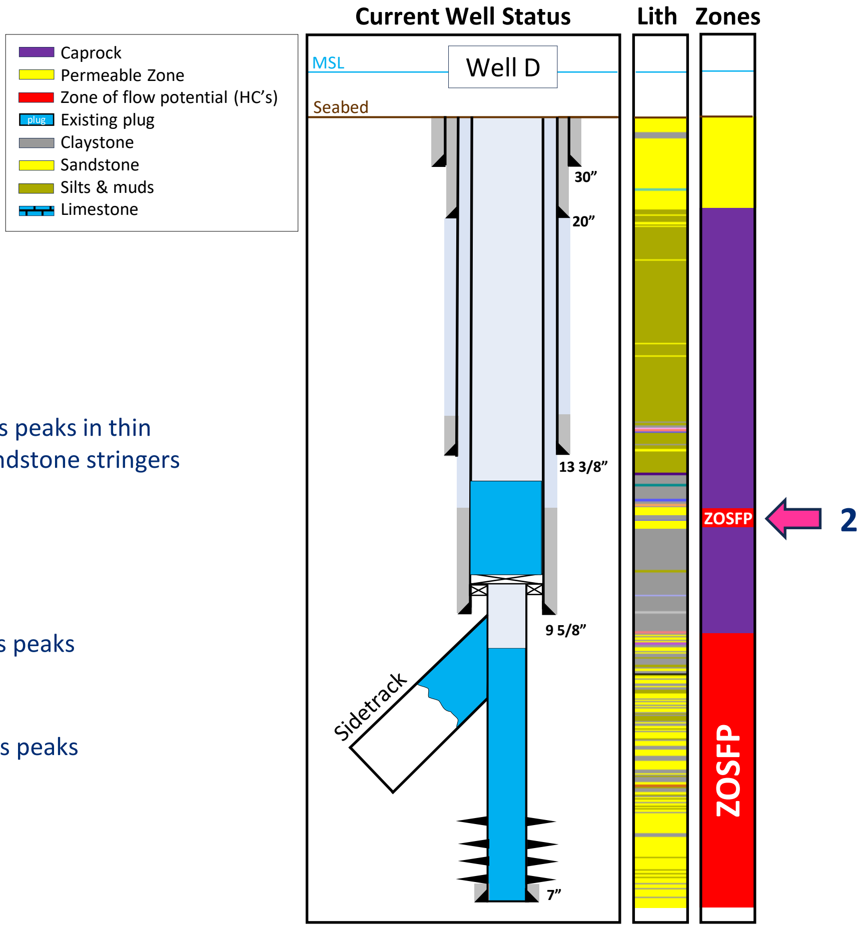


Excerpt from Well D Composite Log

Gas peaks in thin sandstone stringers

Gas peaks

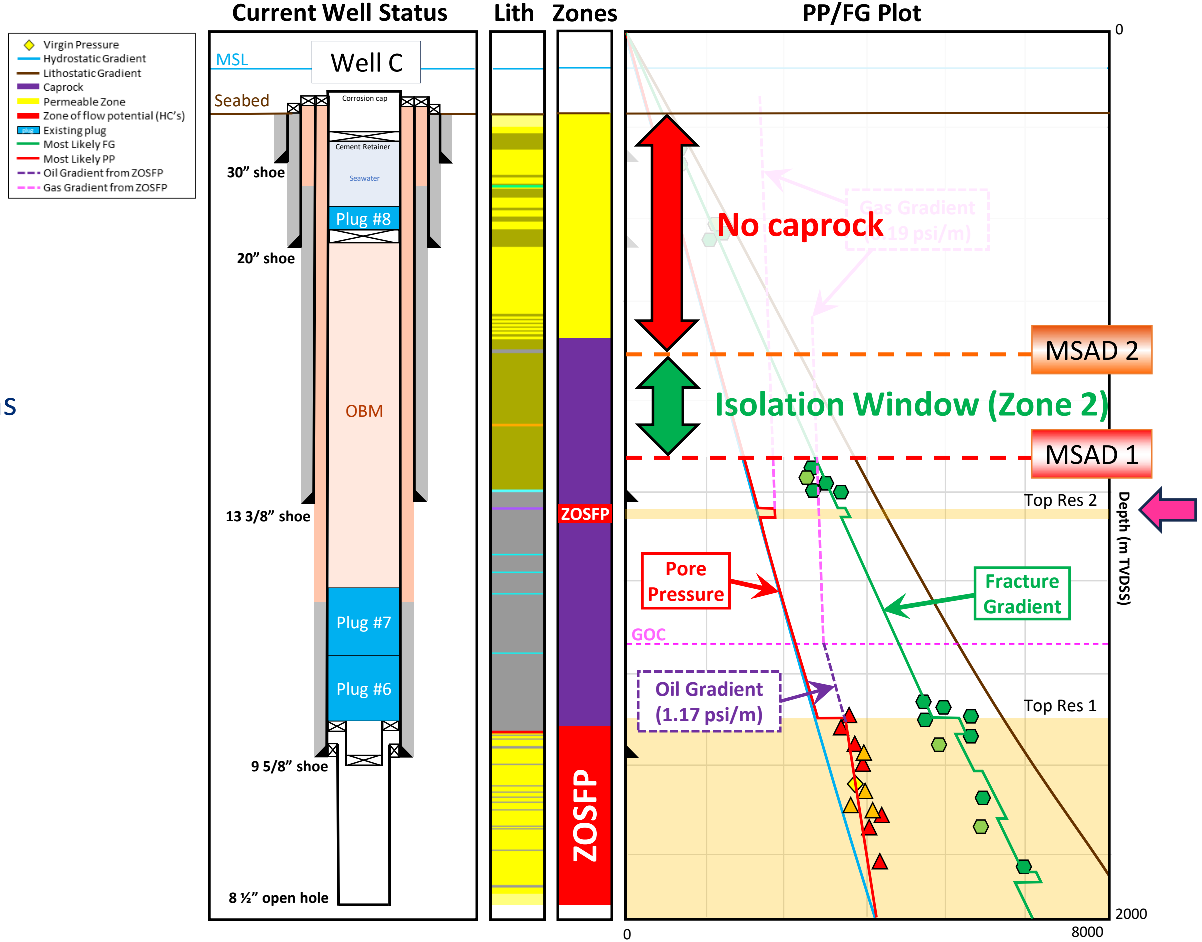
Gas peaks



"Challenging The Norm"

PP/FG

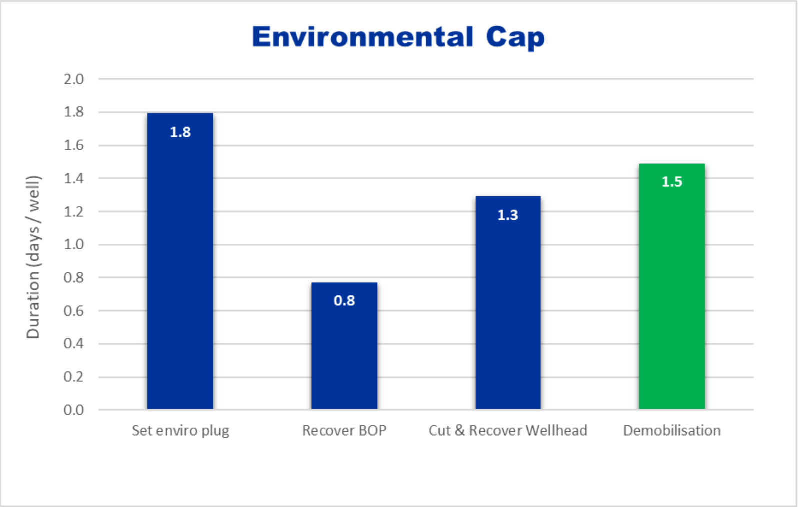
- Pore Pressure and Fracture Gradient models had accounted for this zone as a **field-wide** zone of flow potential requiring isolation



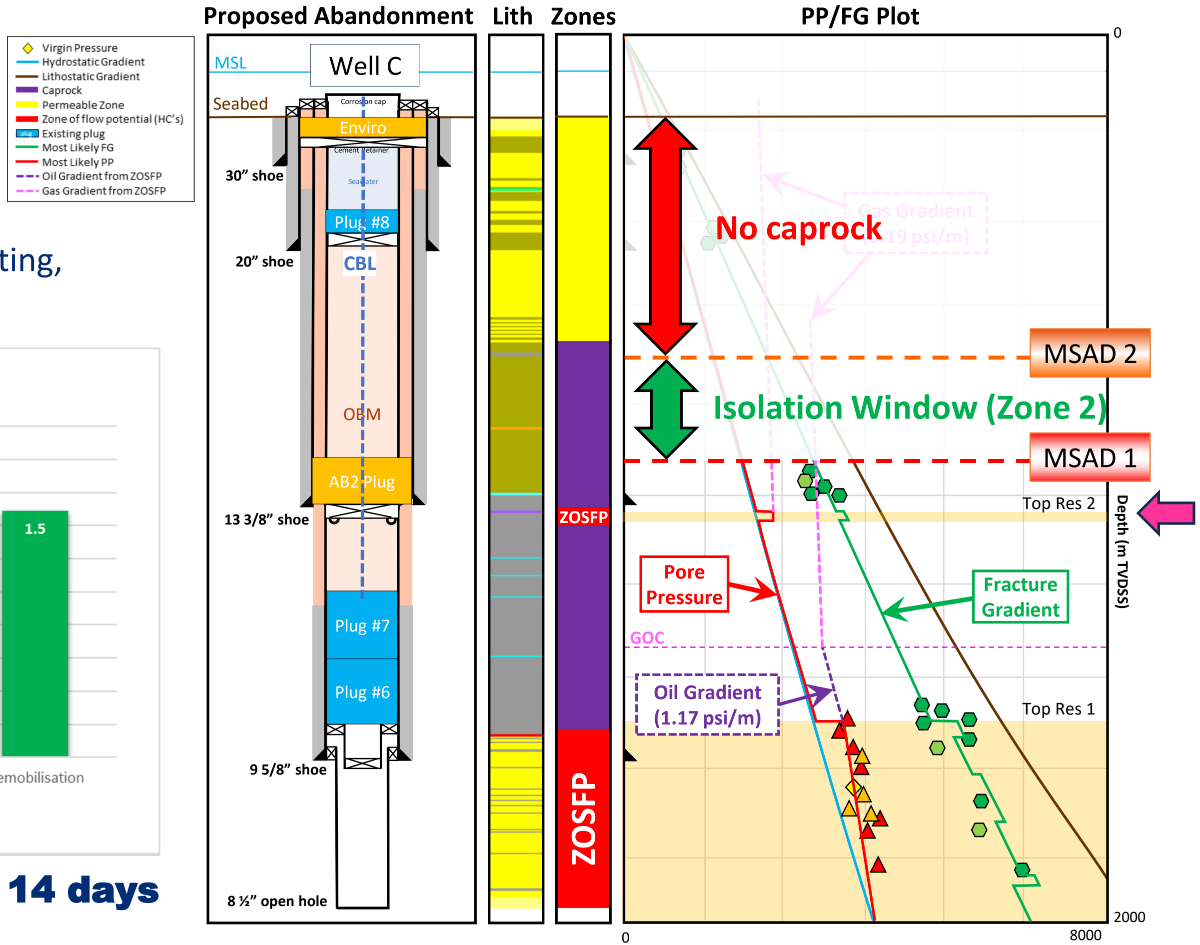
"Challenging The Norm"

Operational Steps

- Spread rate (**rig**): £300,000 p/d
- Requirement for well control (BOP), cutting, pulling and OBM handling



Overall Cost £4.27 mm / 14 days

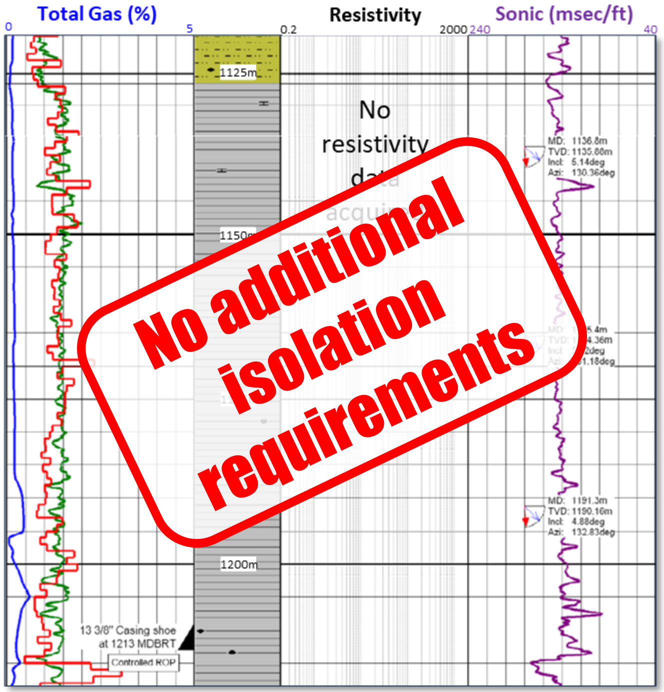


“Challenging The Norm”

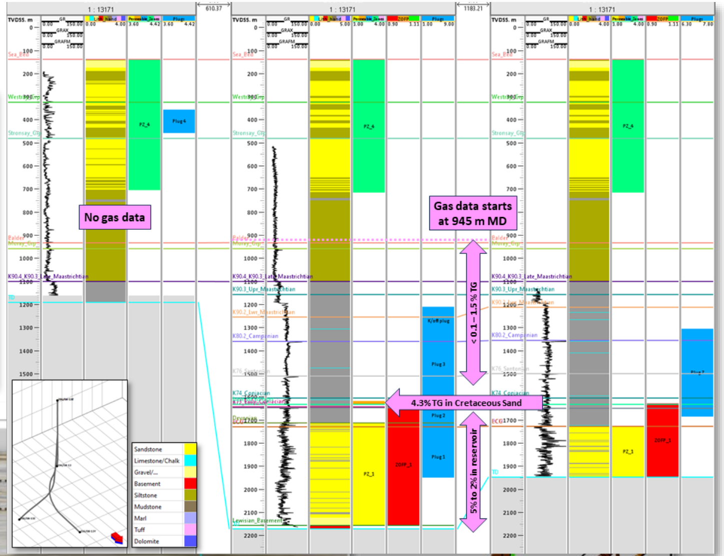
Subsurface Basis of Design Revealed…

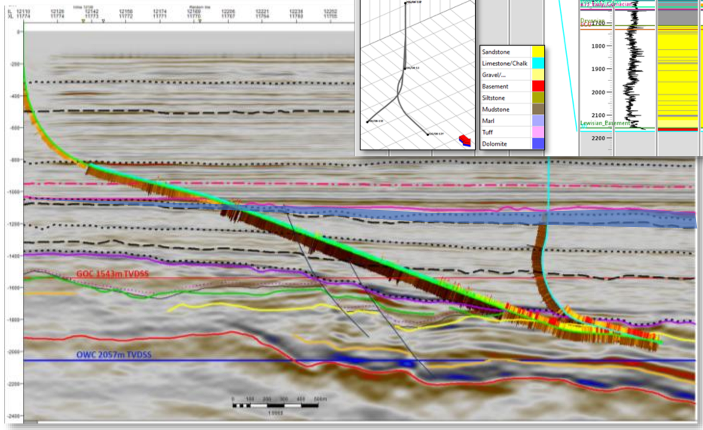
- Could not map zone aerially – zone considered restricted
- No gas, no permeable lithologies

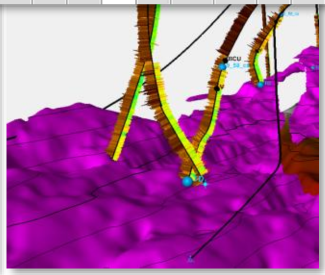
Well C



Depth	Lithology	Gas Classification	Total gas
m MD			% EMA
945	Shale		< 0.1
1027 - 1565	Shale/limestone		< 1
1565 – 1670	Shale/limestone		0.7 – 1.5
1670.25	Thin sandstone	Formation gas	4.283
1829	Sandstone	Formation gas	4.297
1911	Sandstone	Formation gas	5.201
1987	Sandstone	Formation gas	2.202
1163 - 1590	Shale/dolomite/limestone		< 0.1 – 0.4
1590	Shale	Formation gas	1.73
1680	Thin sandstone	Formation gas	4.61
1785	Shale	Formation gas	3.38
1800	Sandstone	Formation gas	4.75
1815	Sandstone	Formation gas	4.51
2075	Sandstone	Formation gas	4.18
2095	Sandstone	Formation gas	4.06
2170	Sandstone	Formation gas	3.84
2190	Sandstone	Formation gas	3.75
Faulty gas trap – readings invalid 2340 – 2370 m MD			
Below 2370	Sandstone	Formation gas	c. 0.1 - 1

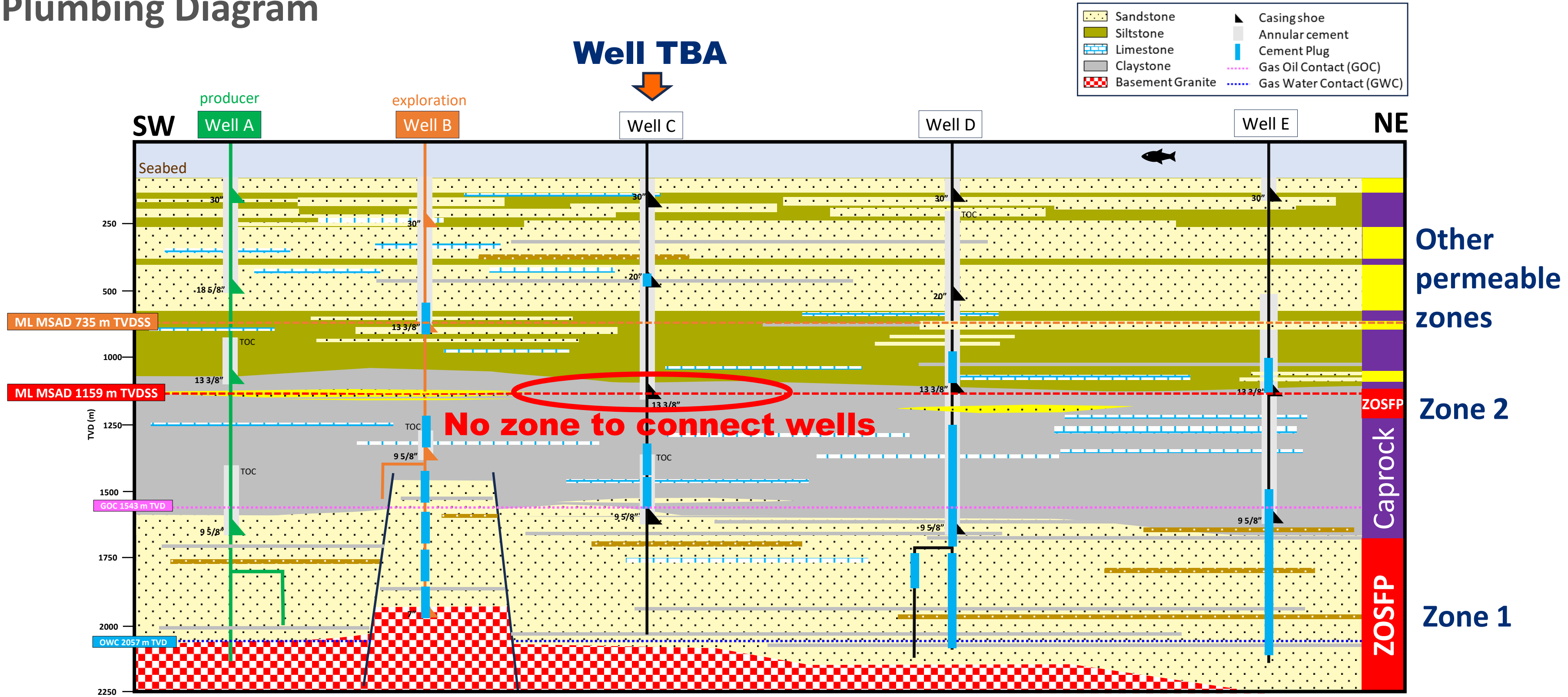






"Challenging The Norm"

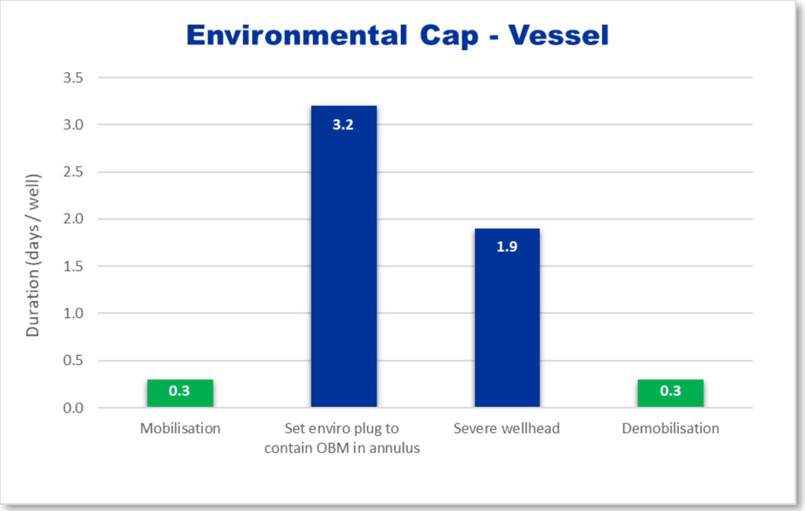
Plumbing Diagram



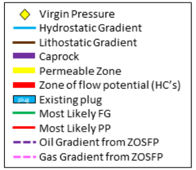
“Challenging The Norm”

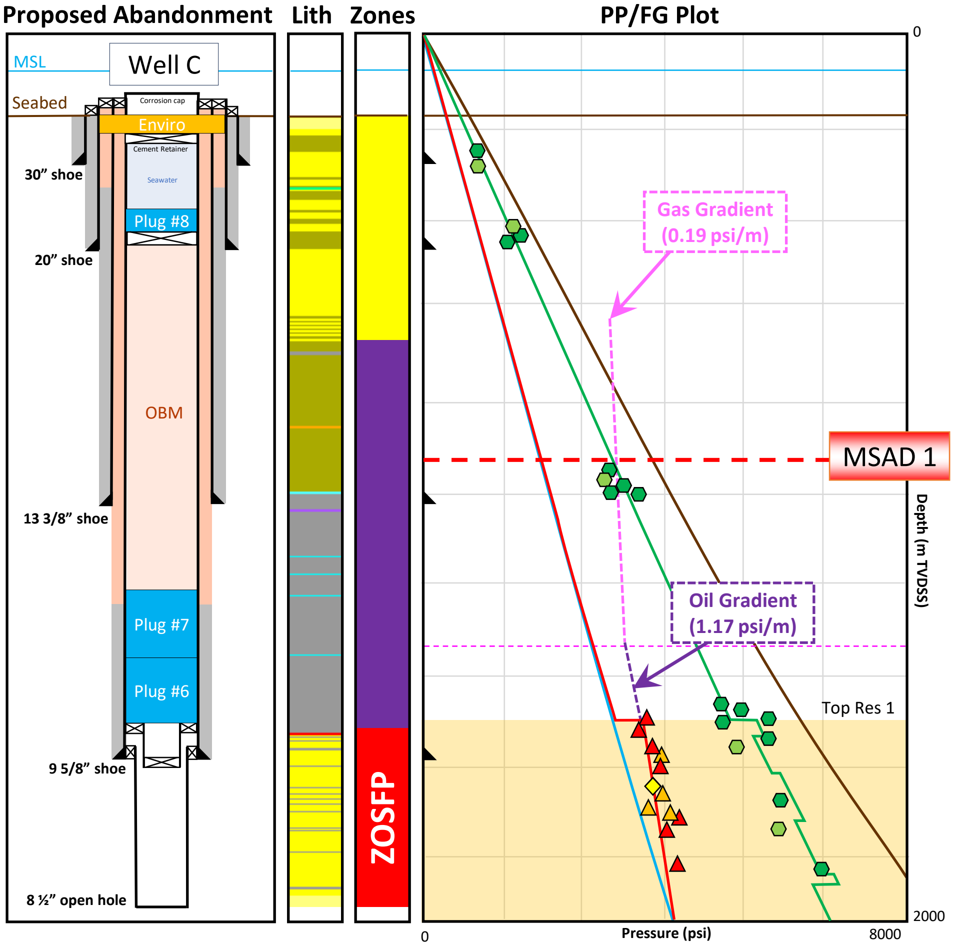
New Operational Steps

- Spread rate (**vessel**): £179,000 p/d (campaign)
- No requirement for well control



Total £1.02 mm / <6 days





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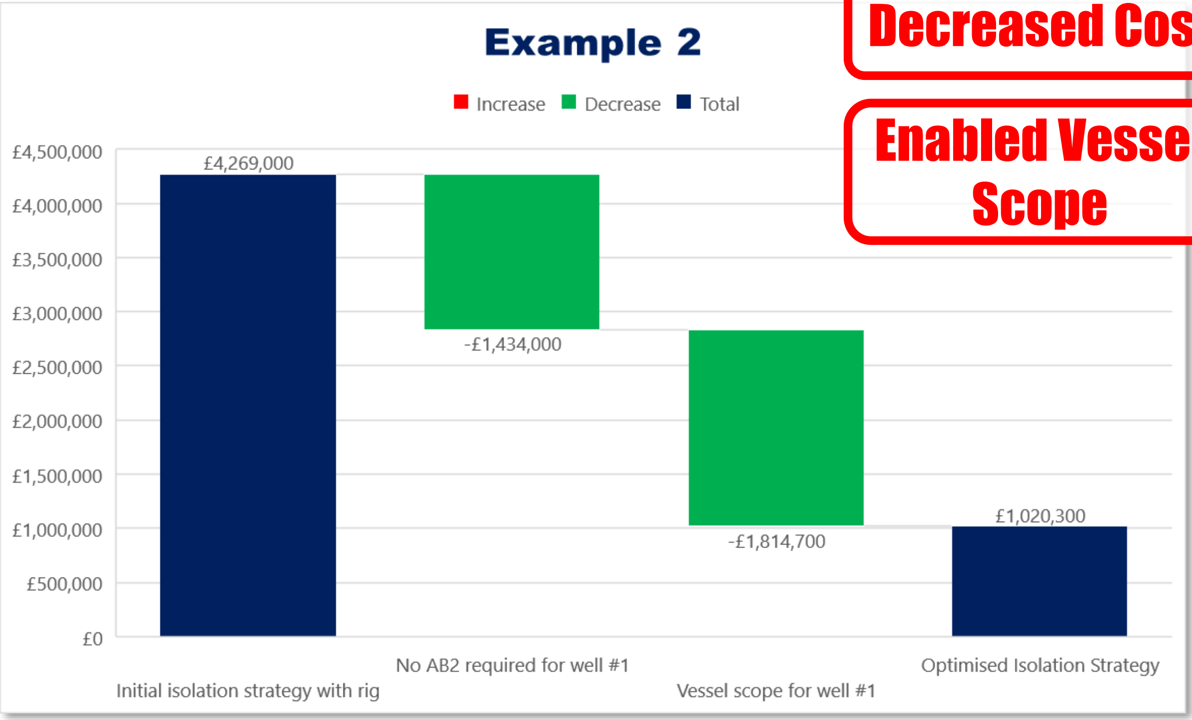
Time/Cost Impact



Decreased Cost

Enabled Vessel Scope

Saving from original strategy: - £3.25 mm / - 8.4 days

What do these examples demonstrate?

Workflow	Inputs	Deliverables
Data Review	Well & Seismic Data, Scanned Images, Reports	Database, Identify Data Gaps
Permeable Zones	Porosity, Permeability, Fluid Properties, Lithology	Identify Permeable Zones & Caprocks
Pressure Evaluation	Pore / Fracture / Fluid Gradients	Reservoir Recharge, Crossflow
Zonal Isolation Philosophy	Identify Zones Requiring Isolation	Minimum Safe Abandonment Depth & Isolation Windows
Risk Review	Identify Subsurface, Operational & Re-Use Risks	Risks Assessment & Opportunities Register
Well Abandonment (WA) Strategy	Stakeholder Engagement, Feedback & Assurance	Fully Approved Document

Typical Subsurface Basis of Design Workflow

Permeable Zones – Understand zonal properties and distribution in inter-well space

Zonal Isolation Philosophy – Determine how these zones communicate through well(s) – plumbing diagrams

Risk Review – How does an operational risk (gas/SAP) translate to a subsurface risk?

In Summary

- Sustained flow potential relies on multiple factors – particularly understanding the connected zonal volumes
- Offset data is the key to unlocking uncertainties and providing context
- A “fresh eyes” approach can be invaluable – reduces impact of confirmation bias
- Subsurface studies can materially change the operational strategy (vessel vs rig)
- A multi-disciplinary approach, dedicated to P&A, is the key to optimised and cost effective well abandonment!

WELL-SAFE SOLUTIONS

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Thank you!