WELL DECOMMISSIONING & LATE WELL LIFE IN THE NET ZERO ERA

SPE International

Aberdeen Section

WELL-SAFE SOLUTIONS

“To flow or not to flow.....*that* is the question”

Ruth Thomas

Subsurface Manager, Well-Safe Solutions

Presentation Outline

Regulatory Context → Guidance definition

What is Sustained Flow Potential? → What are the parameters? → Why is it important in P&A?

Examples → Confirmation bias → Challenging the norm → All models are wrong, some are useful

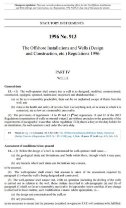
Regulatory/Guidance Context

How is Flow Potential Defined by Guidance?

Guidance:

OEUK Well Decommissioning Guidelines, Issue 7, November 2022

Aids compliance with:



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

Excerpt from p. 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

2.1 Identifying Formations that have the Potential to Flow

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 (fracturing or other stimulation), injection or production.

There is no recommended cut-off for permeability related to flow potential, however any assessment should be undertaken within the broad principles of keeping leak risk ALARP. In general, low permeability formations are unlikely to lead to sustained or significant flow. However, there are some areas in the UKCS and elsewhere where low permeability formations have proven hydrocarbon production potential, here detailed evaluation may be required to assess the magnitude of natural flow.

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 analogue and offset data should not be underestimated and can also complement direct data which may be unreliable or insufficiently representative.

The assessment of flow potential should consider the following processes:

- Drilling and hydrocarbon/other fluid production/ injection/disposal operations during the life of the well.
- Recharging of reservoirs with pressure and/or fluids due to connection to higher pressure connected hydraulic units, including ongoing expulsion from hydrocarbon source rocks.
- Potential for depletion induced compaction of the reservoir and/or overburden leading to flow potential.
- Intra-formation crossflow post-decommissioning where connected formations have different pressures at cessation of production and alternative recharge trajectories.
- Redevelopment for hydrocarbon extraction (including enhanced recovery techniques).
- Repurposing (such as use for geothermal projects, disposal and/or storage of energy, H2 or CO_2).

Indications of flow potential may be based on actual well test results, drilling records (gains/losses/gas levels, drilling exponent data), log evaluation (including from adjacent and offset wells), well annuli pressures, including well annuli build-up and bleed down history, fluid/gas sampling, geological setting and subsurface modelling. Evidence of flow potential may only become apparent during decommissioning operations. Precautions are required for adequate pressure control during such operations.

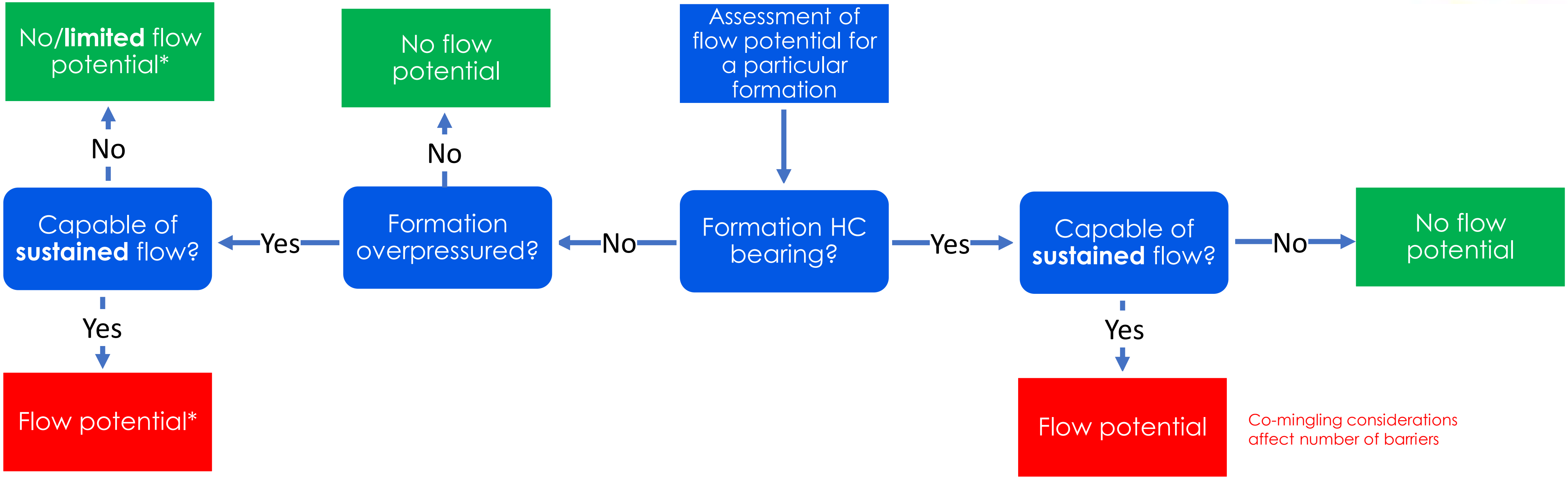
Formations may be grouped into zones of similar fluids and/or pressures where inter-zonal isolation has been assessed as not required, or where the consequences of cross flow are deemed acceptable within the broad principle of keeping leak risk ALARP. Such a group of formations can be isolated by a common barrier or dual barrier if required.

Workflow from OEUK Guidelines

Introducing “Sustained Flow Potential”

OEUK Well Decommissioning Guidelines, Issue 7, November 2022

*Assess risk of potential flow and design isolation strategy accordingly

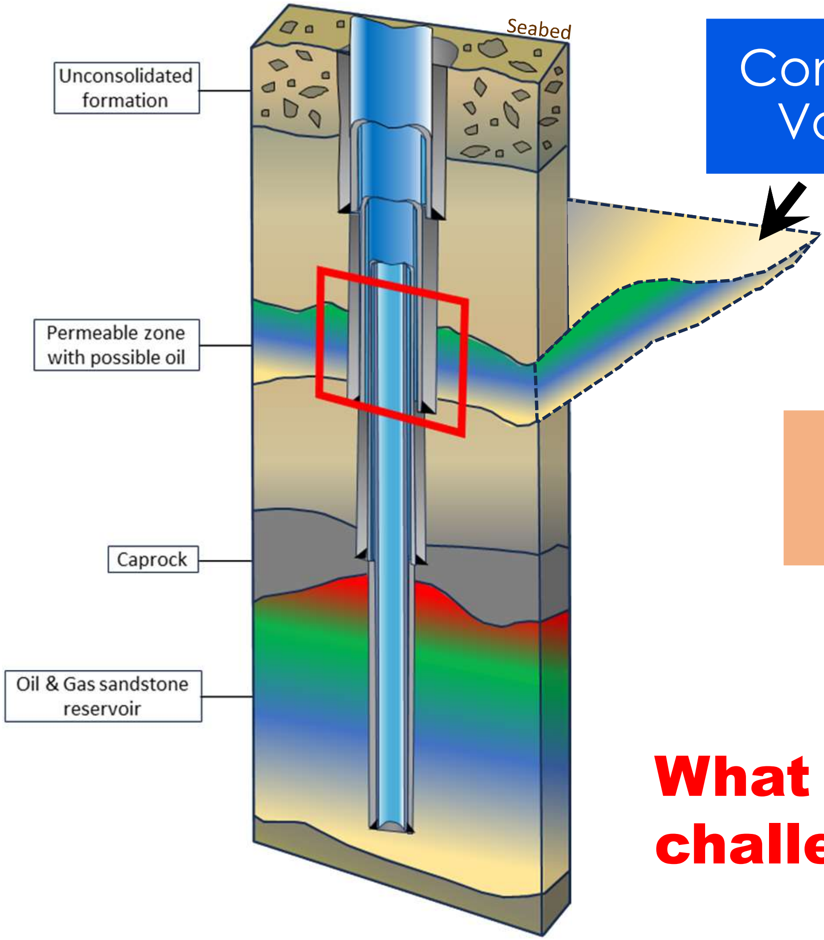


*Formations require isolation from environment – deviation may be considered if risk of release is deemed ALARP and satisfy DCR Reg 15

What is sustained flow potential?

Defining Sustained Flow Potential

What are the main parameters?



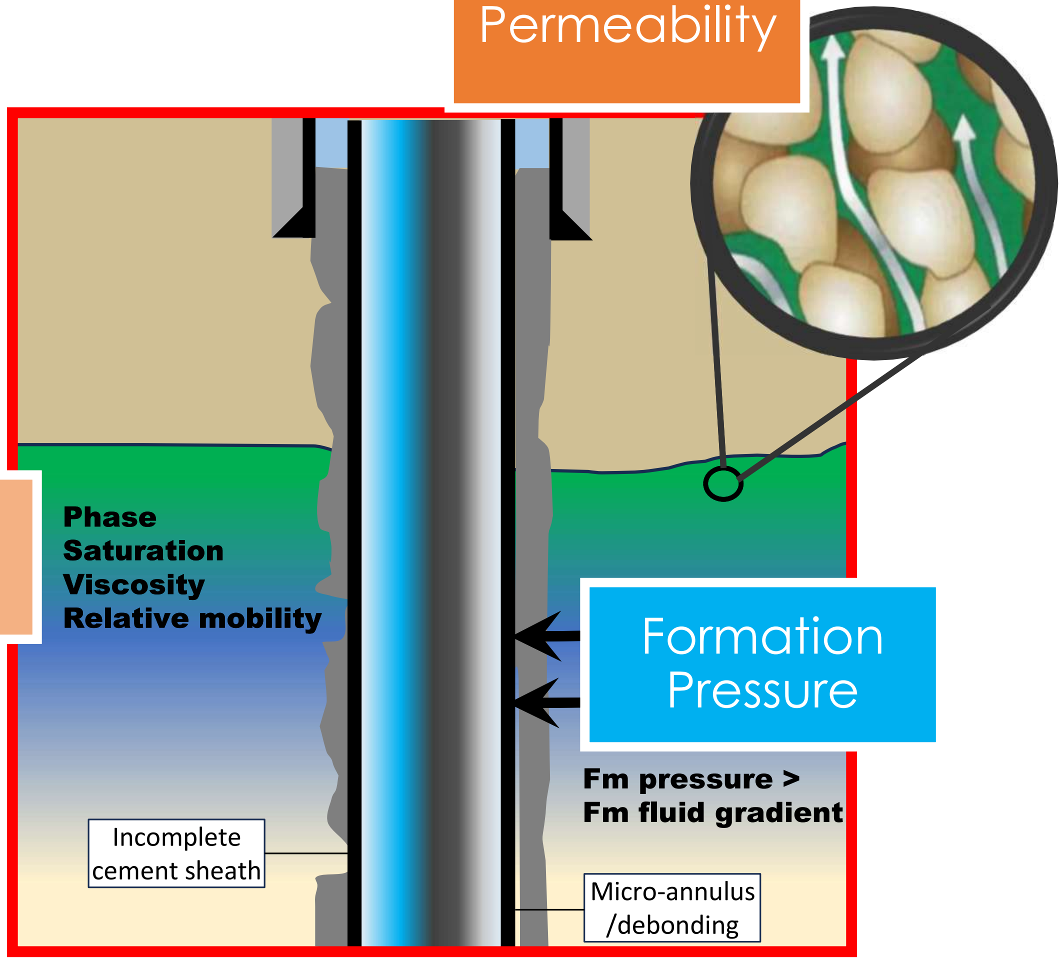
Connected Volumes

Heterogeneity
Distribution
Connectivity

Fluid Properties

Phase
Saturation
Viscosity
Relative mobility

Permeability



Formation Pressure

Fm pressure > Fm fluid gradient

What are the challenges?

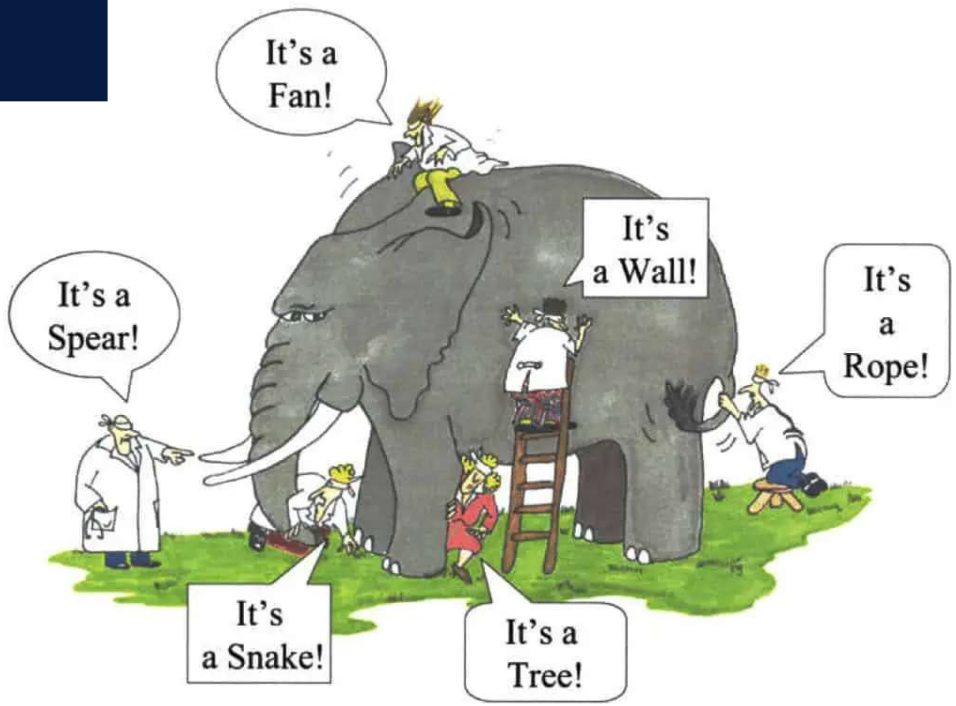
Why does all this matter?

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 and/or risks

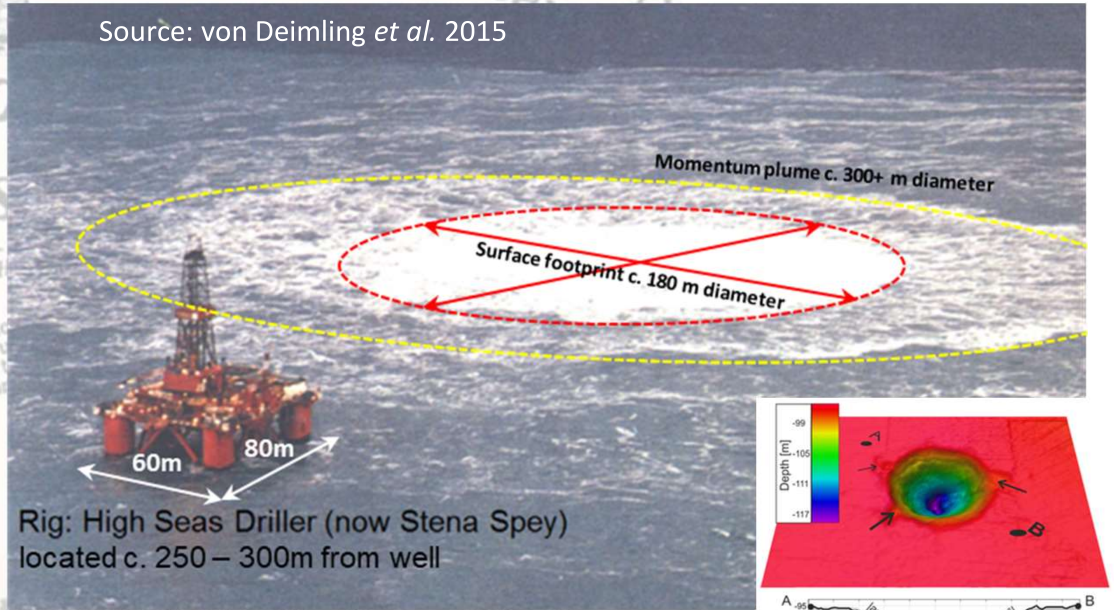


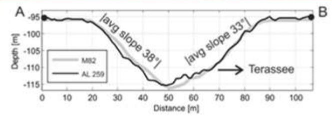
We might miss the bigger picture

“Confirmation Bias”

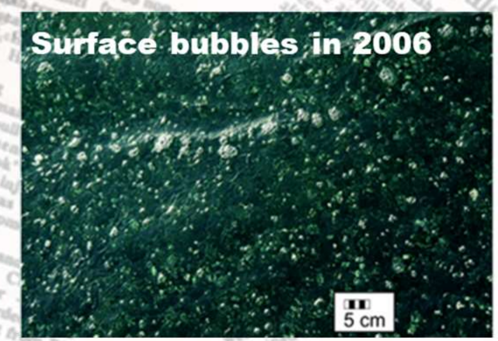
Major Event Influences All Subsequent Drilling

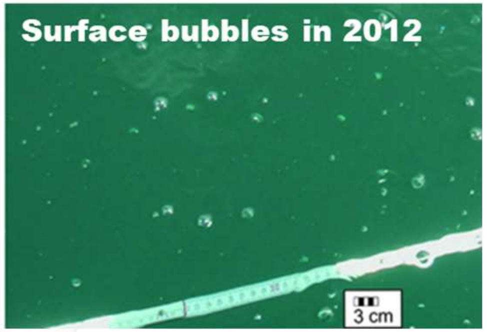
- 22/4b-4 blowout in November 1990
- Gas bubbles observed on surface (bit at 360 m, driller POOH, swabbing gas into the well (H_2S and methane)
- The well had encountered a 31 - 46m thick, 67 psia over-pressured gas column, with max. pressure of c. 9.5ppg EMW
- This blow out event directly influenced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





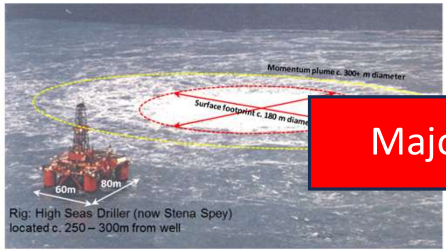
Leaving a 20 m x 70 m crater





Example 1: “Confirmation Bias”

The Benefits of a “Fresh Eyes” Approach



Major Event

Change to drilling procedures for all subsequent wells

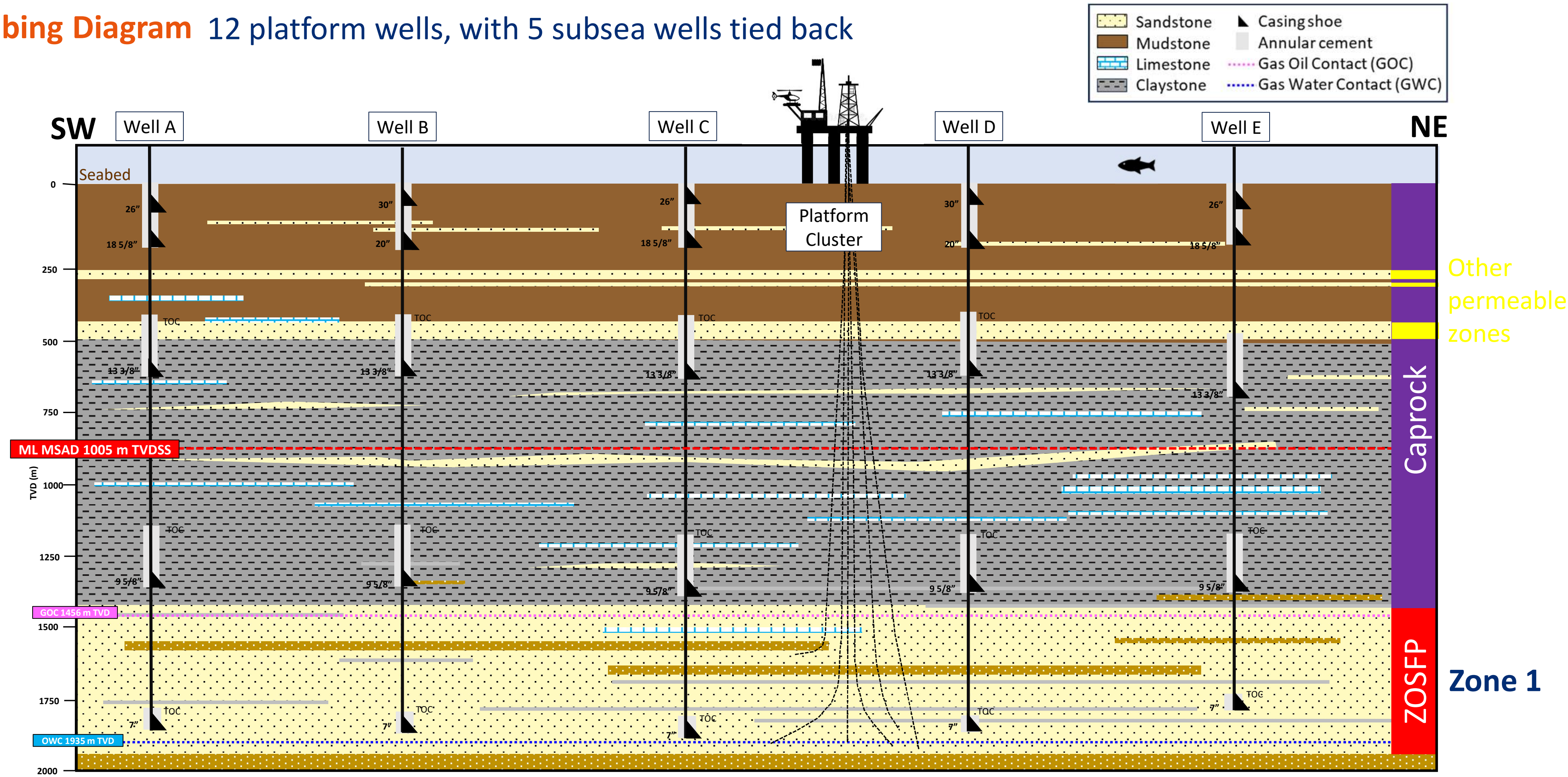
Wells drilled with little/no shallow gas **recorded**

Flow potential falls out of the subsurface narrative

Flow Zone not recognised as requiring isolation in abandonment planning

Example 1:

Plumbing Diagram 12 platform wells, with 5 subsea wells tied back

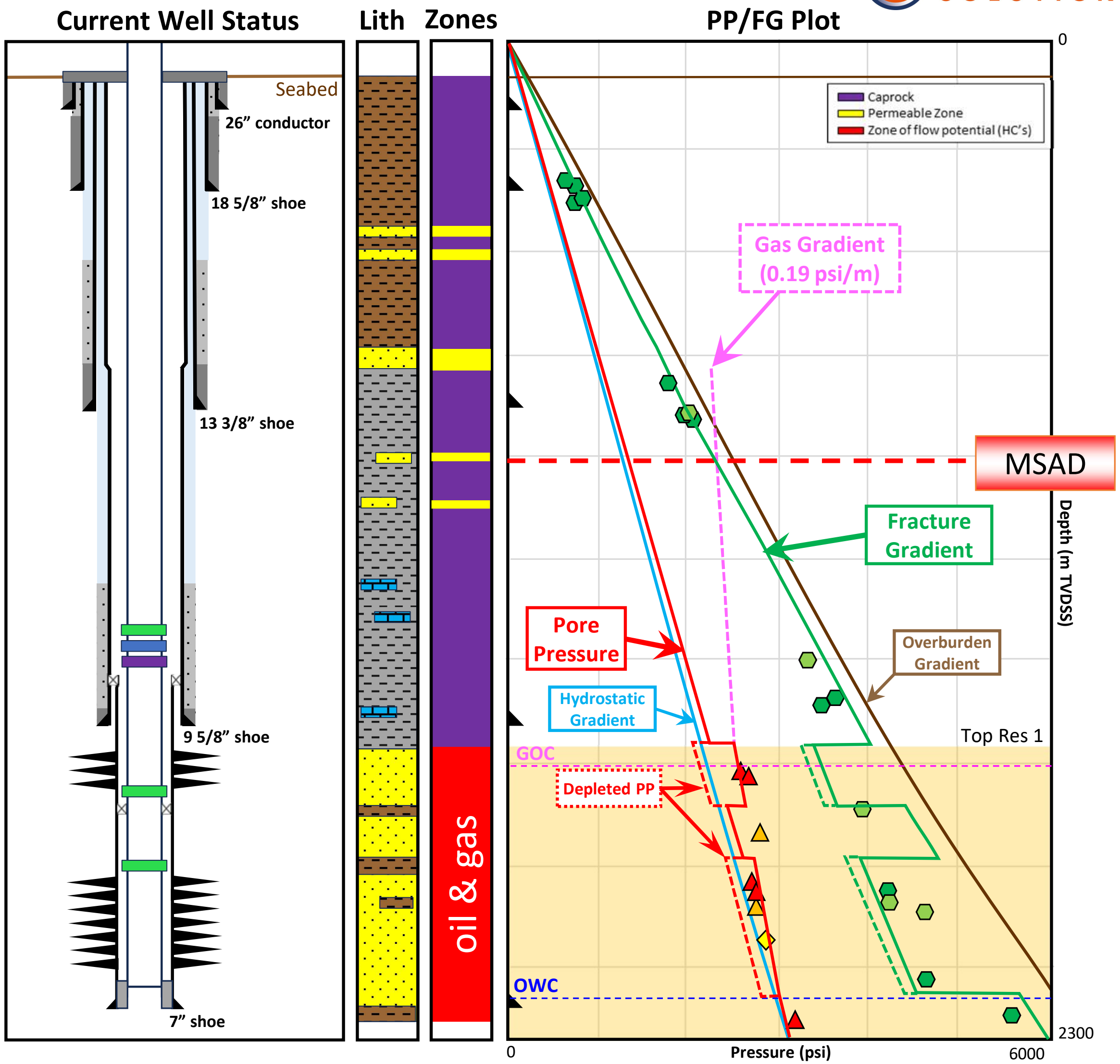


Example 1:

PP/FG Models

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

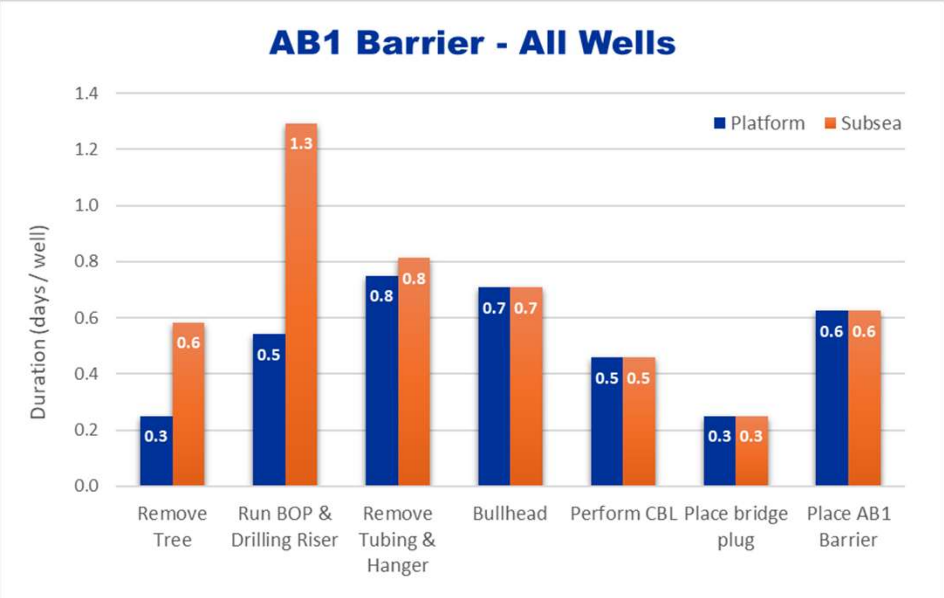
Zone 1
oil & gas bearing,
producing reservoir



Example 1:

Operational Steps

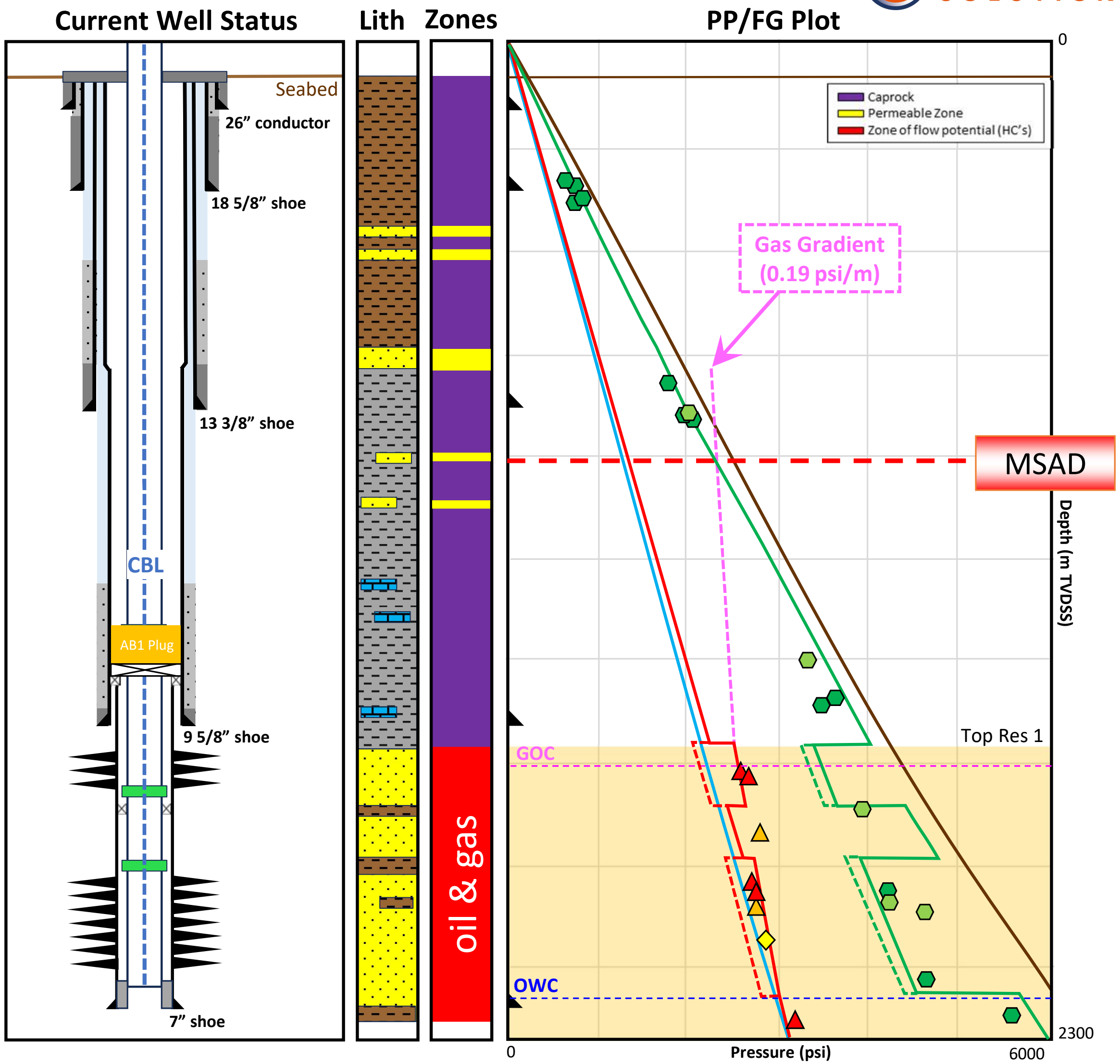
- Spread rate: £175,000 p/d (assumed jack-up or W/O unit)



Subsea £4.14 mm / 24 days

Platform £ 7.52 mm / 43 days

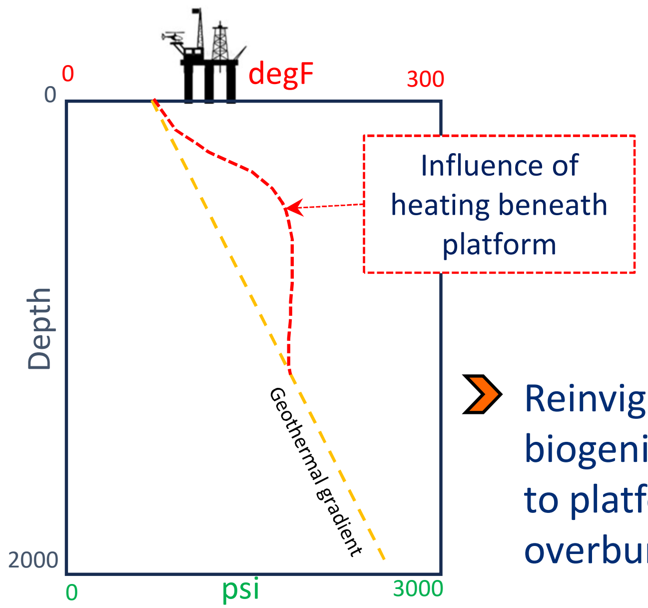
Overall Cost £11.66 mm



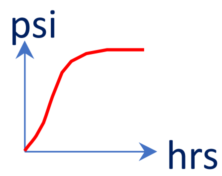
Example 1:

Sustained Annular Pressure (SAP)

- Sustained annular pressure of up to 130 psi present in C-annulus – possible causes?



- Reinvigoration of biogenic system due to platform heating overburden



D Annulus

Gas or fluid migration from formations

C Annulus

Gas lift

Out of Zone Injection

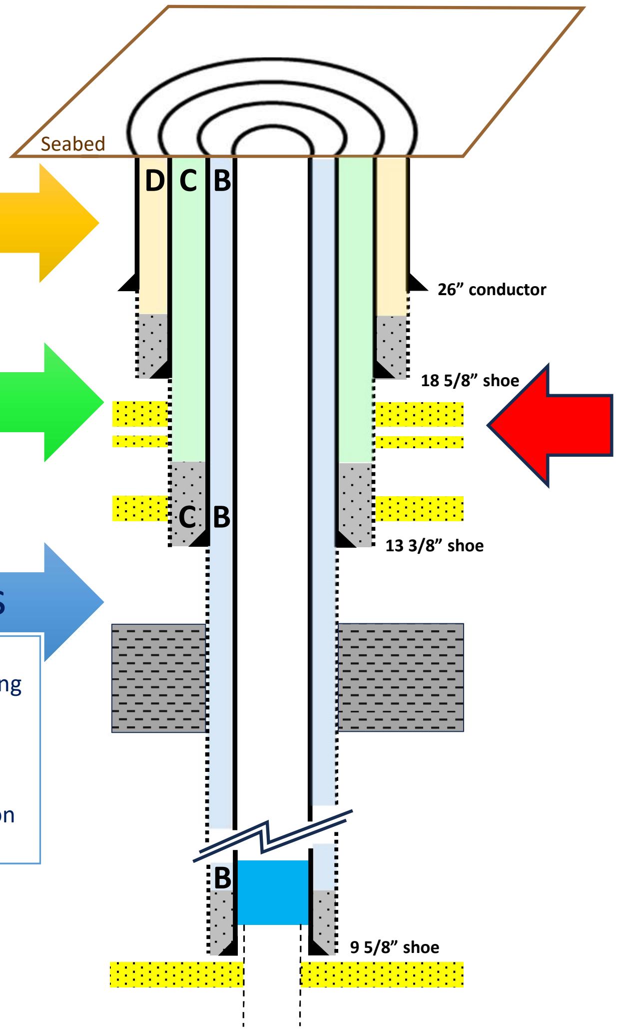
Formation pressure/fluids

B Annulus

Cement/casing/tubing integrity failure

Long uncemented open-hole sections

Reservoir compaction

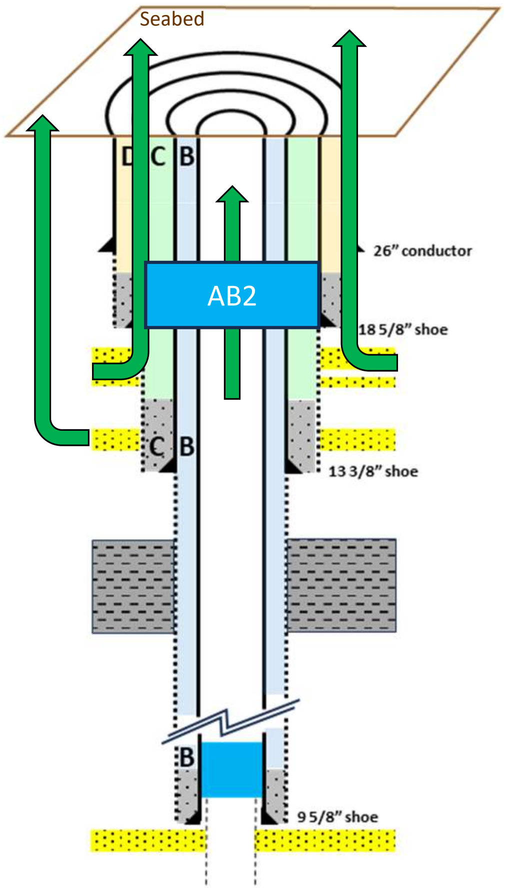


The problem with shallow barriers...

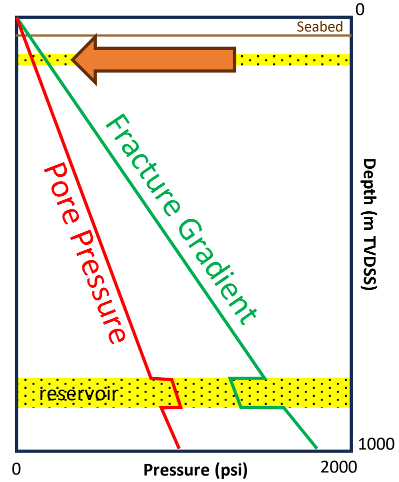
Setting shallow barriers may be difficult due to:

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

What is the best approach?



Little/no rock strength!



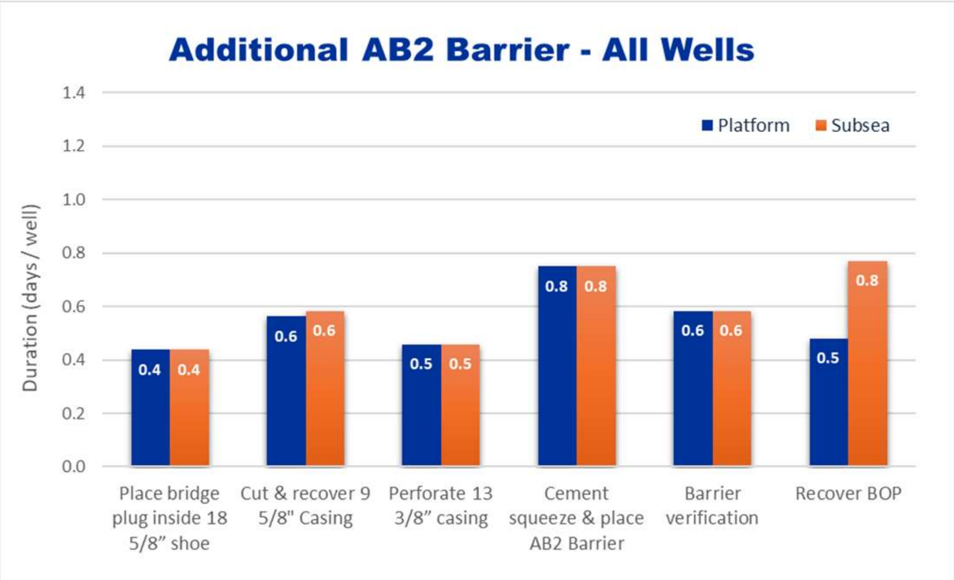
Little/no data!

RFT 1
RFT 2

Example 1:

New Operational Steps ("Best Endeavours")

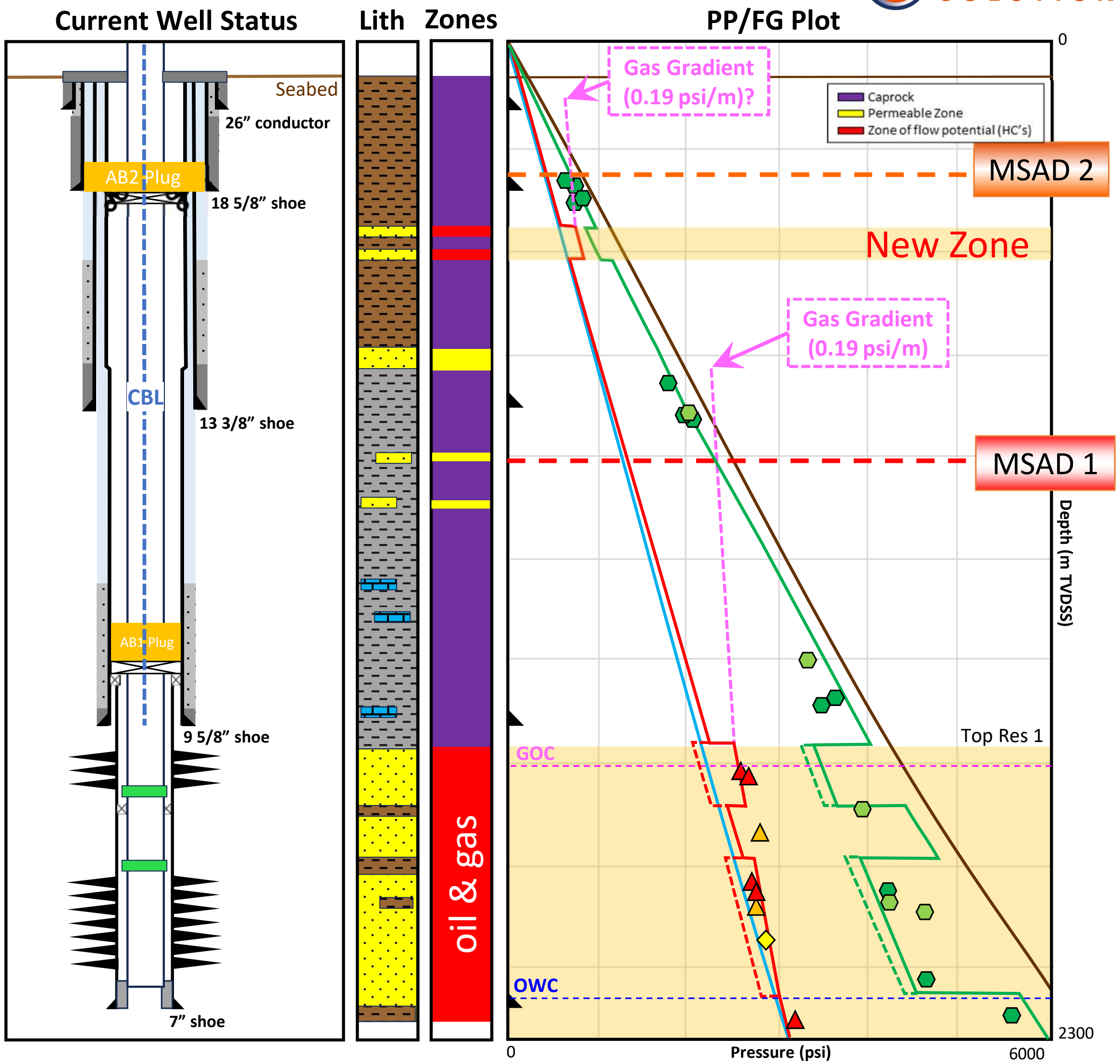
- AB1 scope same as before



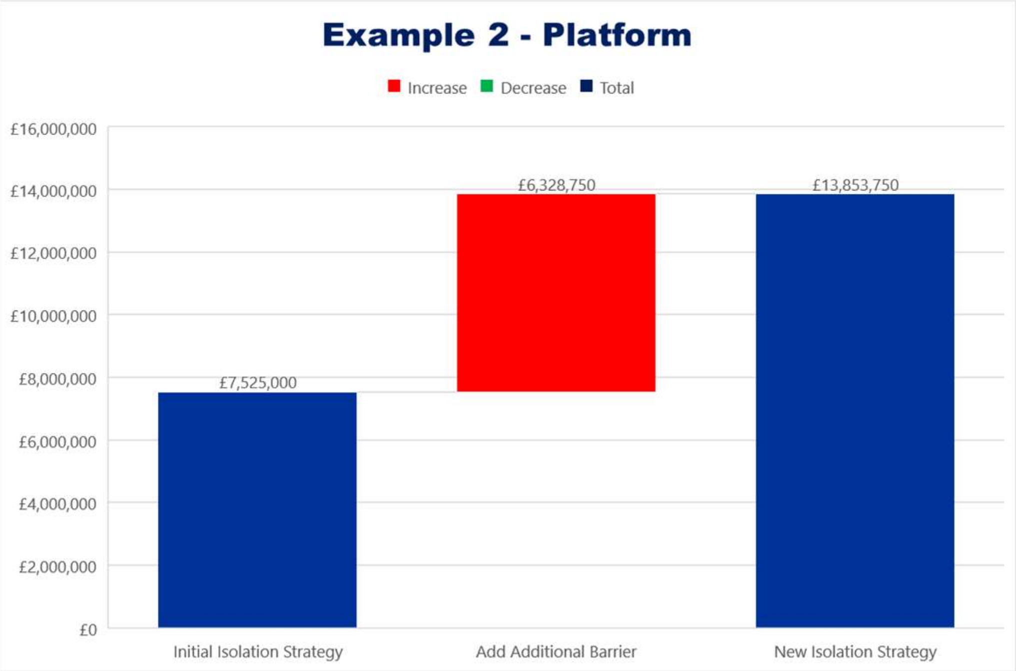
Subsea +£3.13 mm / +18 days

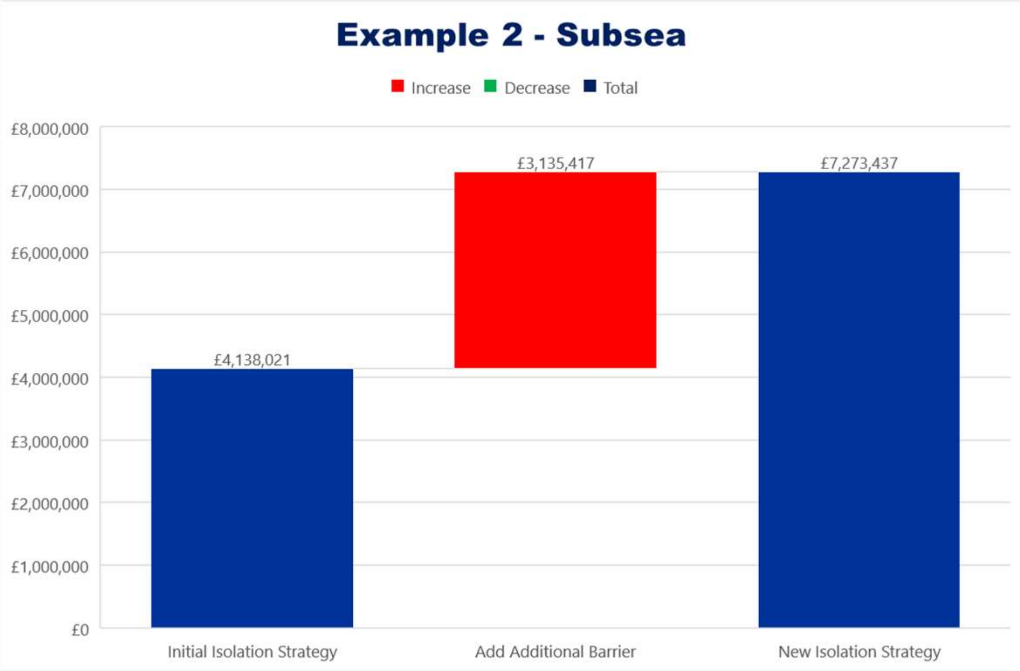
Platform +£6.33 mm / +39 days

Overall Cost £21.13 mm



Time/Cost Impact

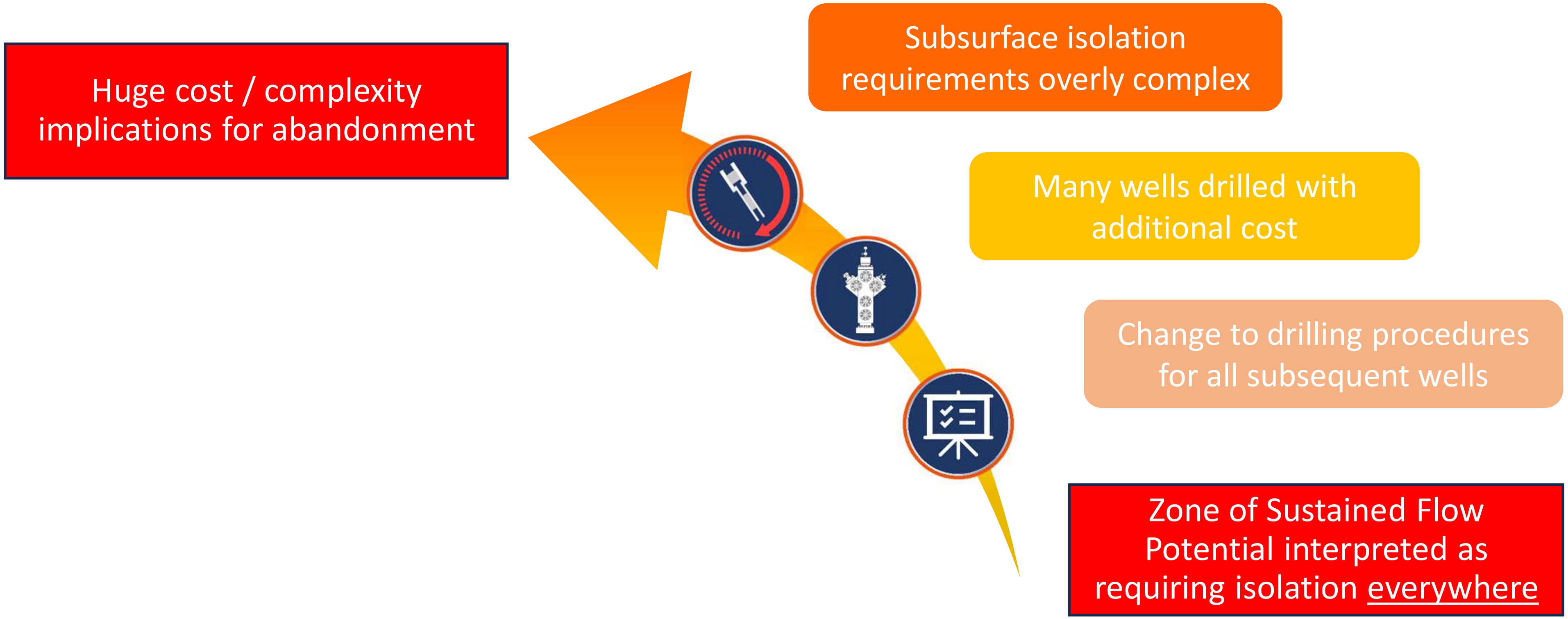




Price increase from original strategy: + £9.46 mm / + 57 days

Example 2: “Challenging the Norm”

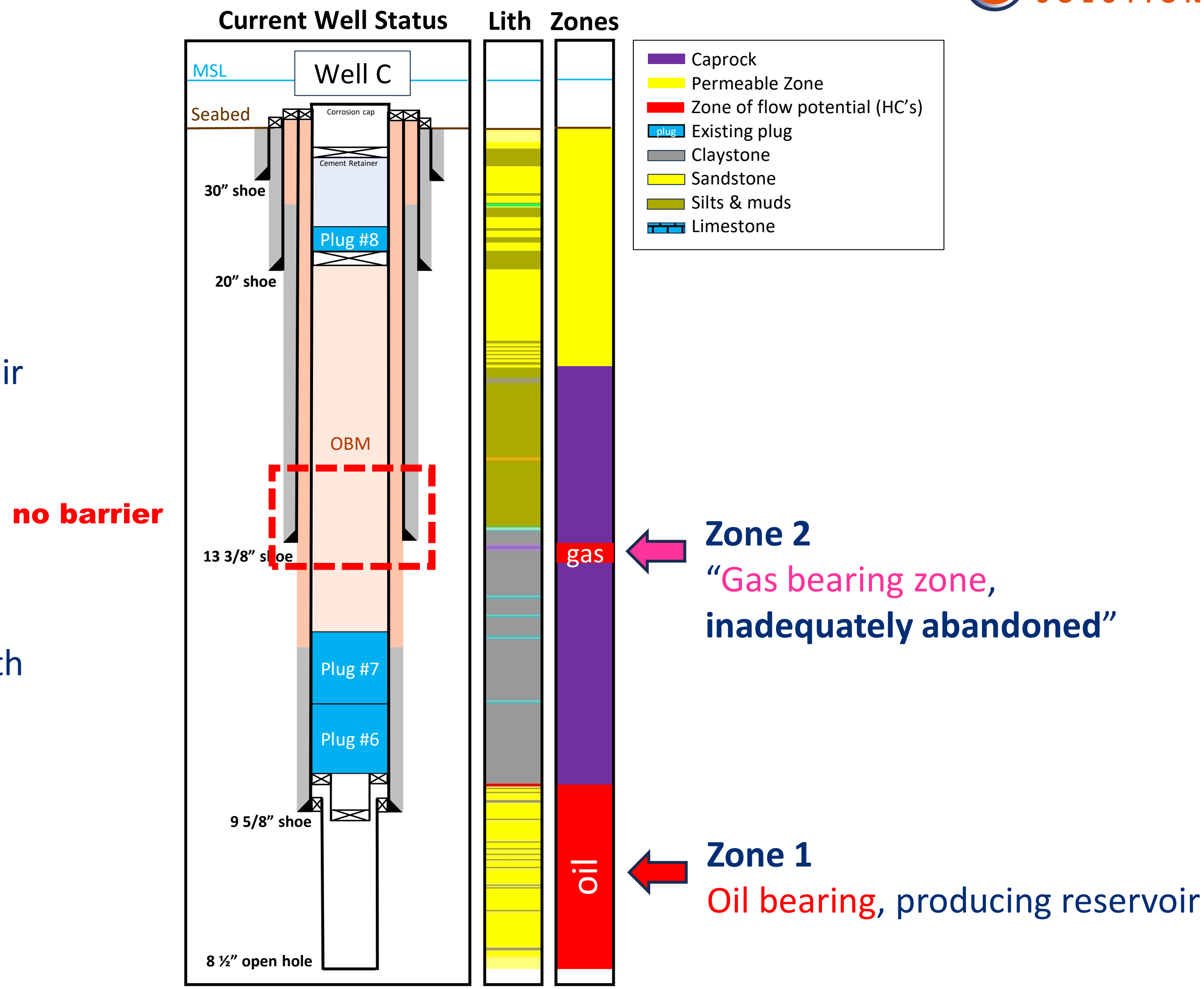
Get to know your wells, intimately!



Example 2:

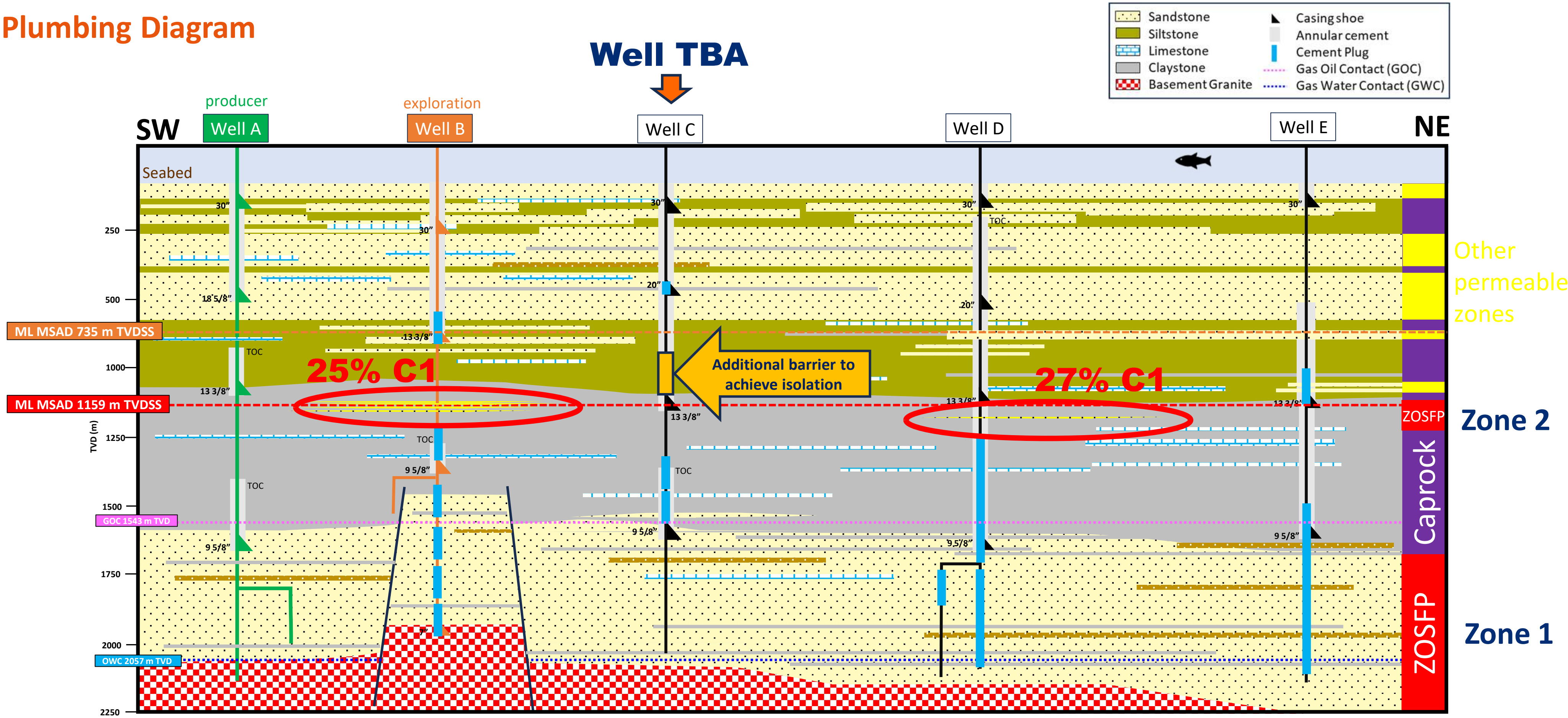
Subsurface Assumptions

- 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



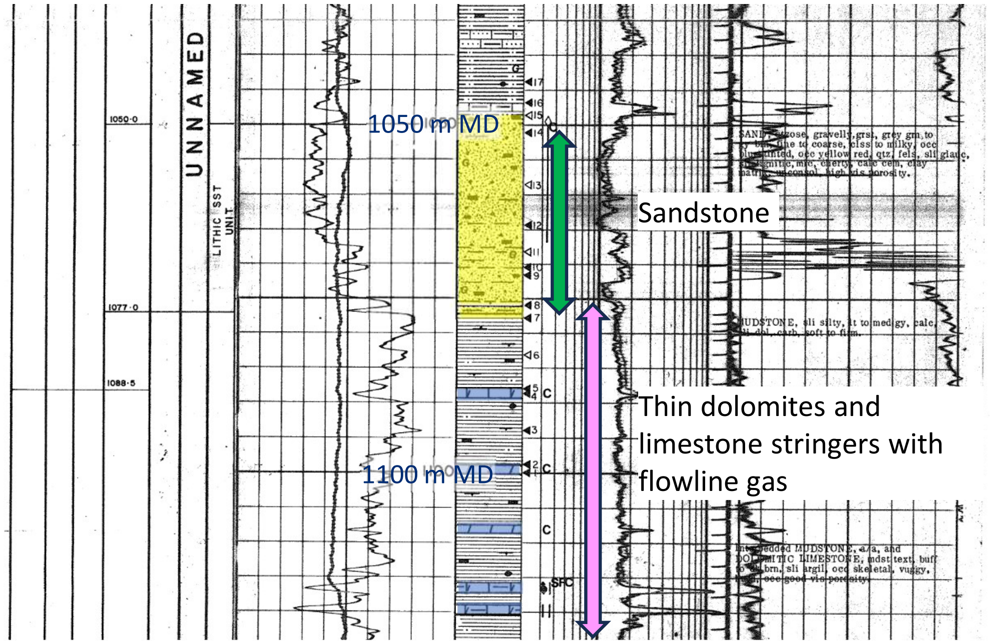
Example 2:

Plumbing Diagram



Example 2:

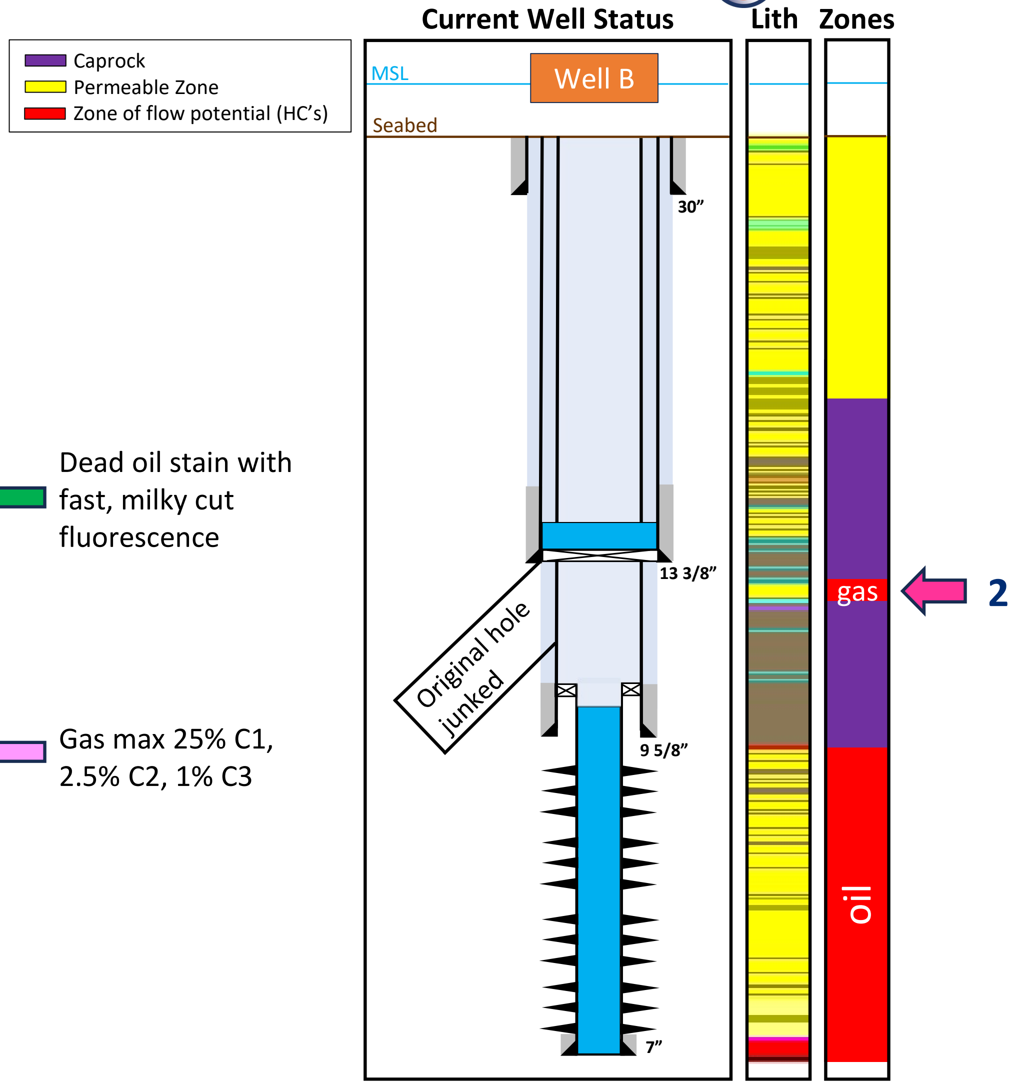
Flow Zone 2



Dead oil stain with fast, milky cut fluorescence

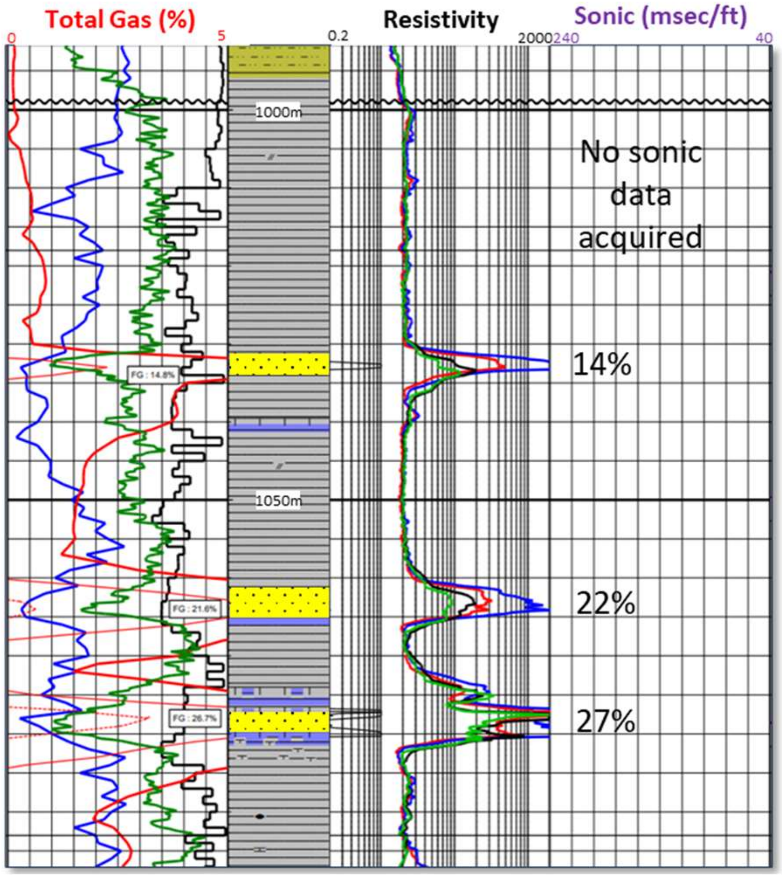
Gas max 25% C1, 2.5% C2, 1% C3

Excerpt from Well B Composite Log



Example 2:

Flow Zone 2

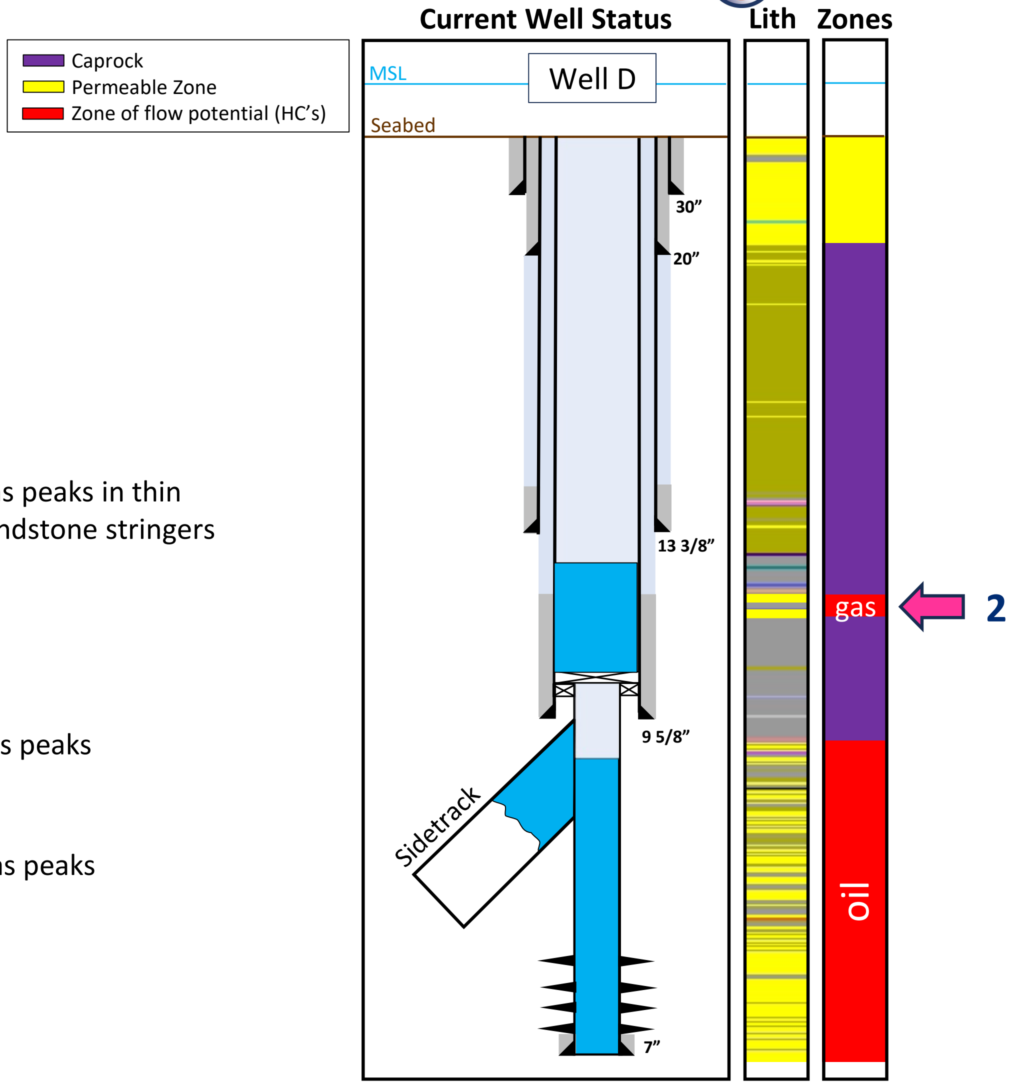


Excerpt from Well D Composite Log

Gas peaks in thin sandstone stringers

Gas peaks

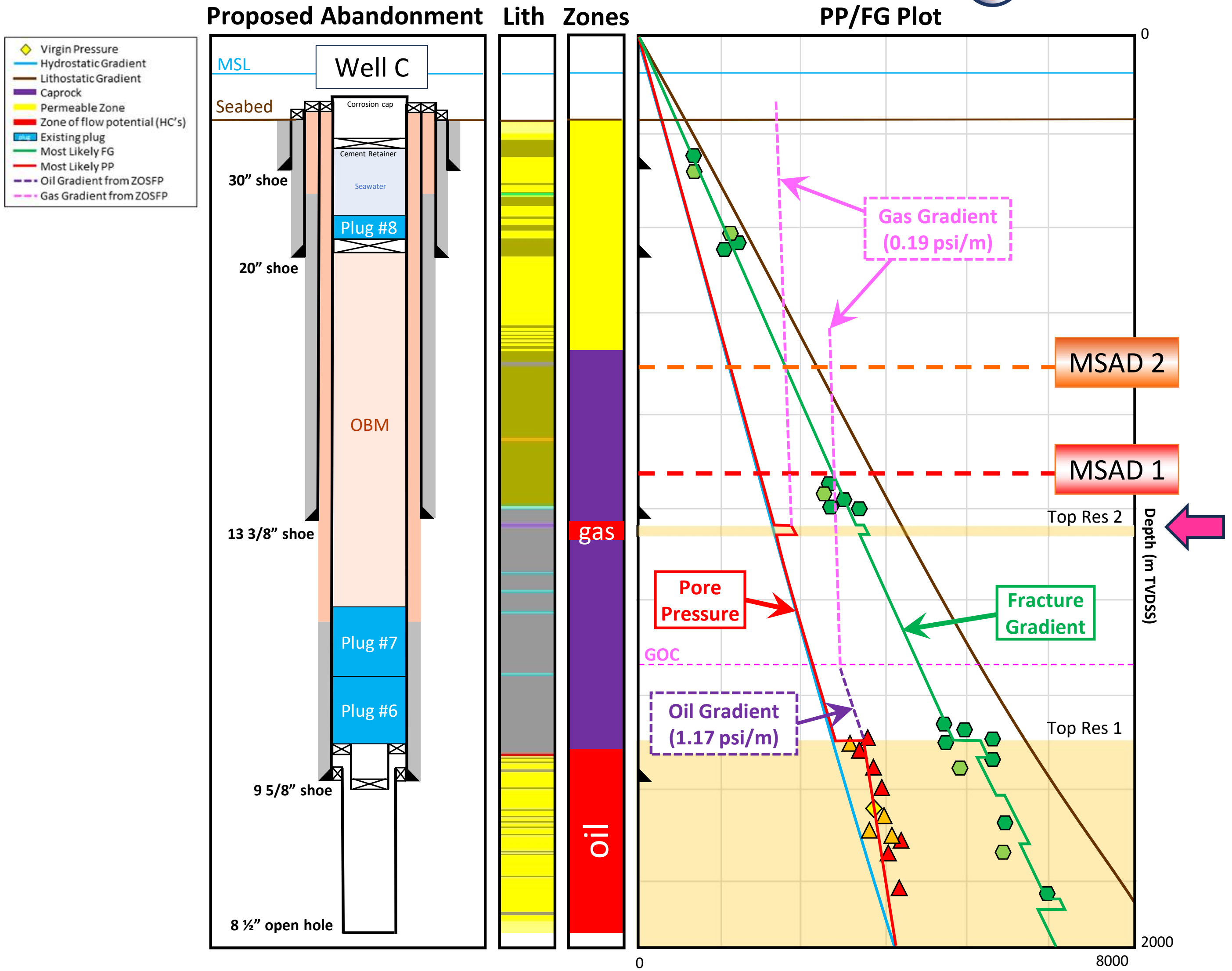
Gas peaks



Example 2:

PP/FG Models

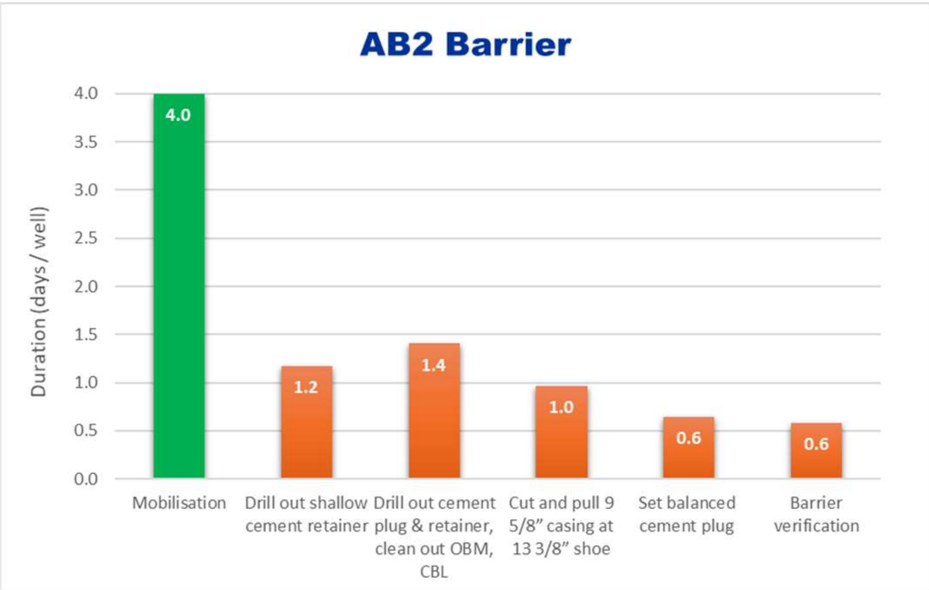
- Pore Pressure and Fracture Gradient models had accounted for this zone as a **field-wide** zone of flow potential requiring isolation

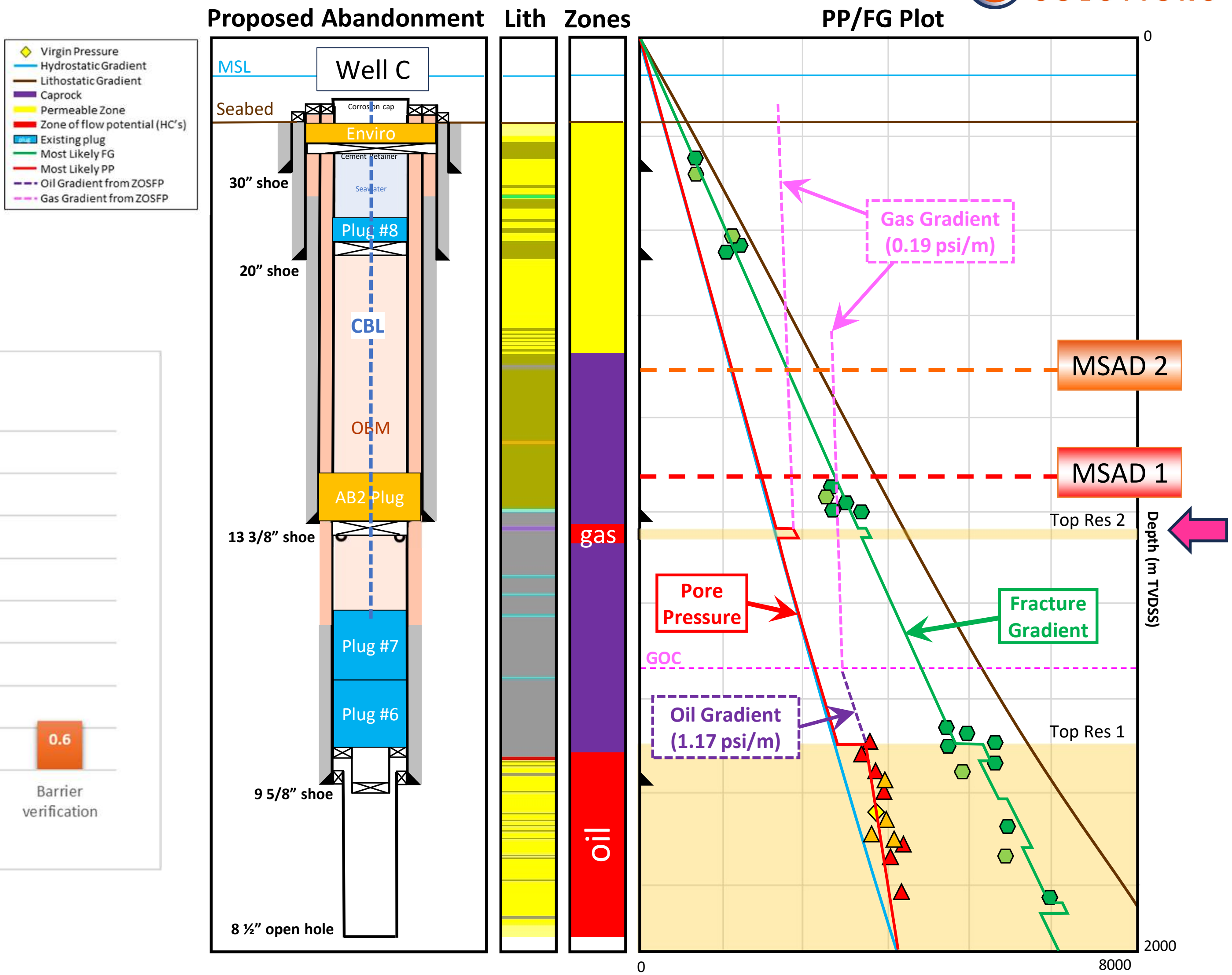


Example 2:

Operational Steps

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





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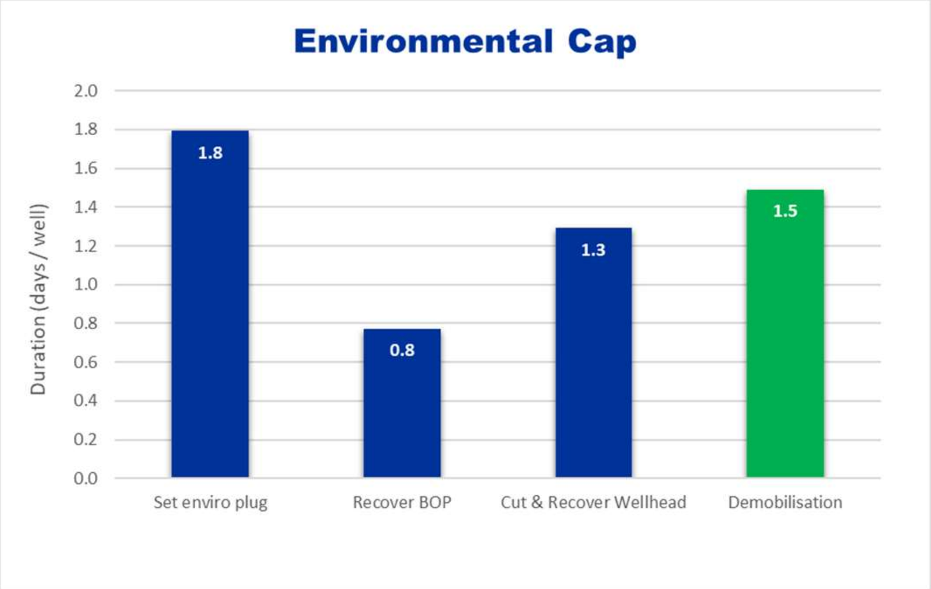
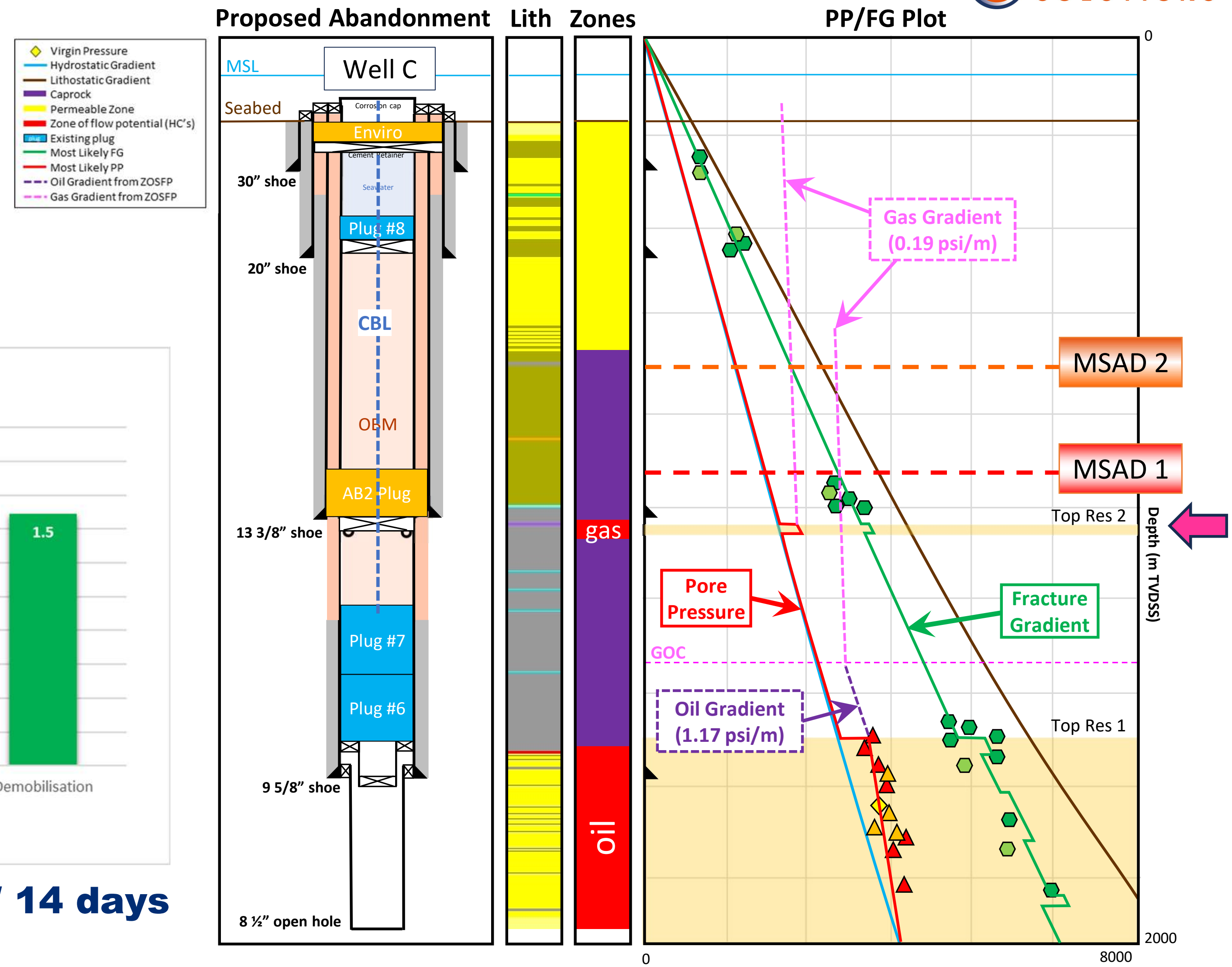


Overall Cost £4.27 mm / 14 days

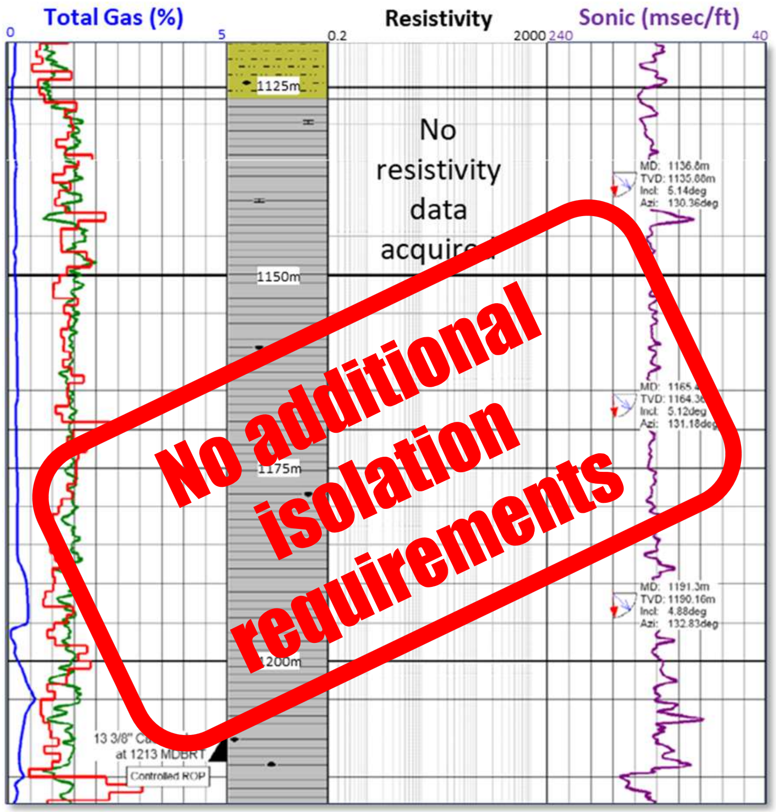


Example 2:

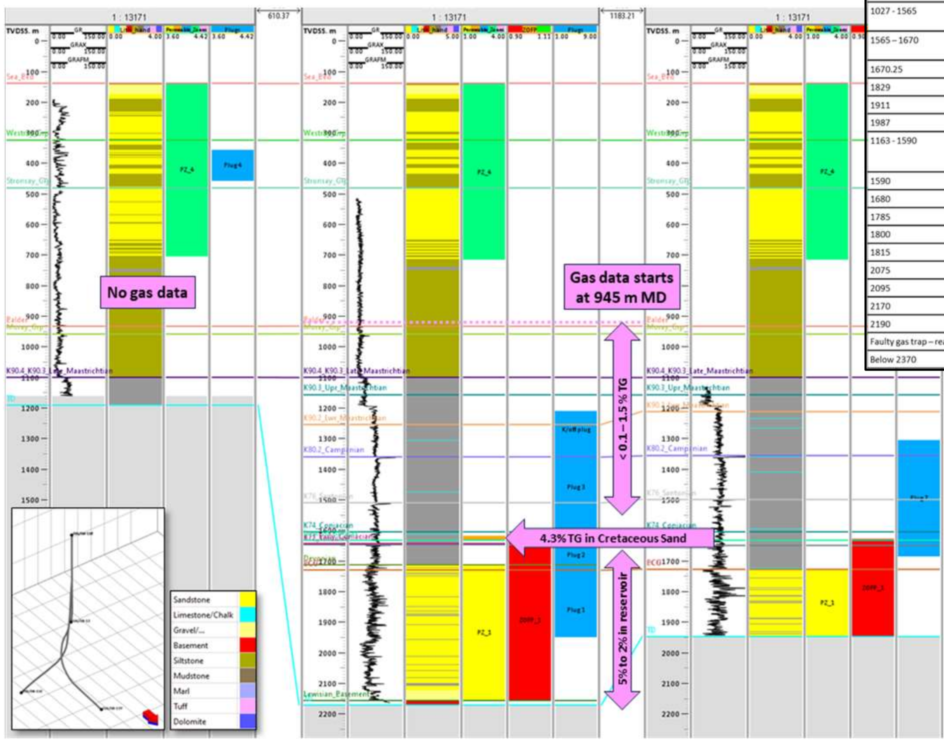
Subsurface basis of design for abandonment

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

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



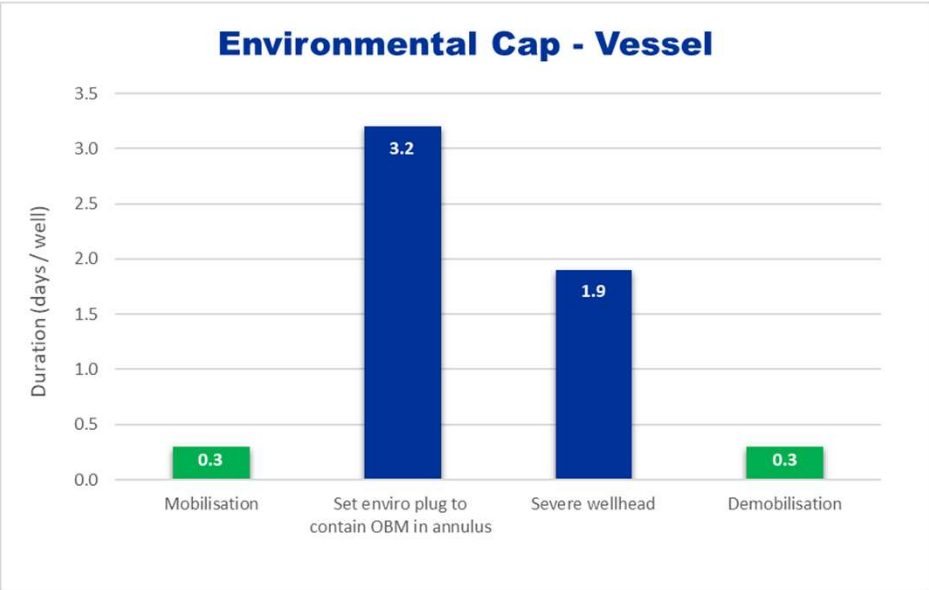
Well C



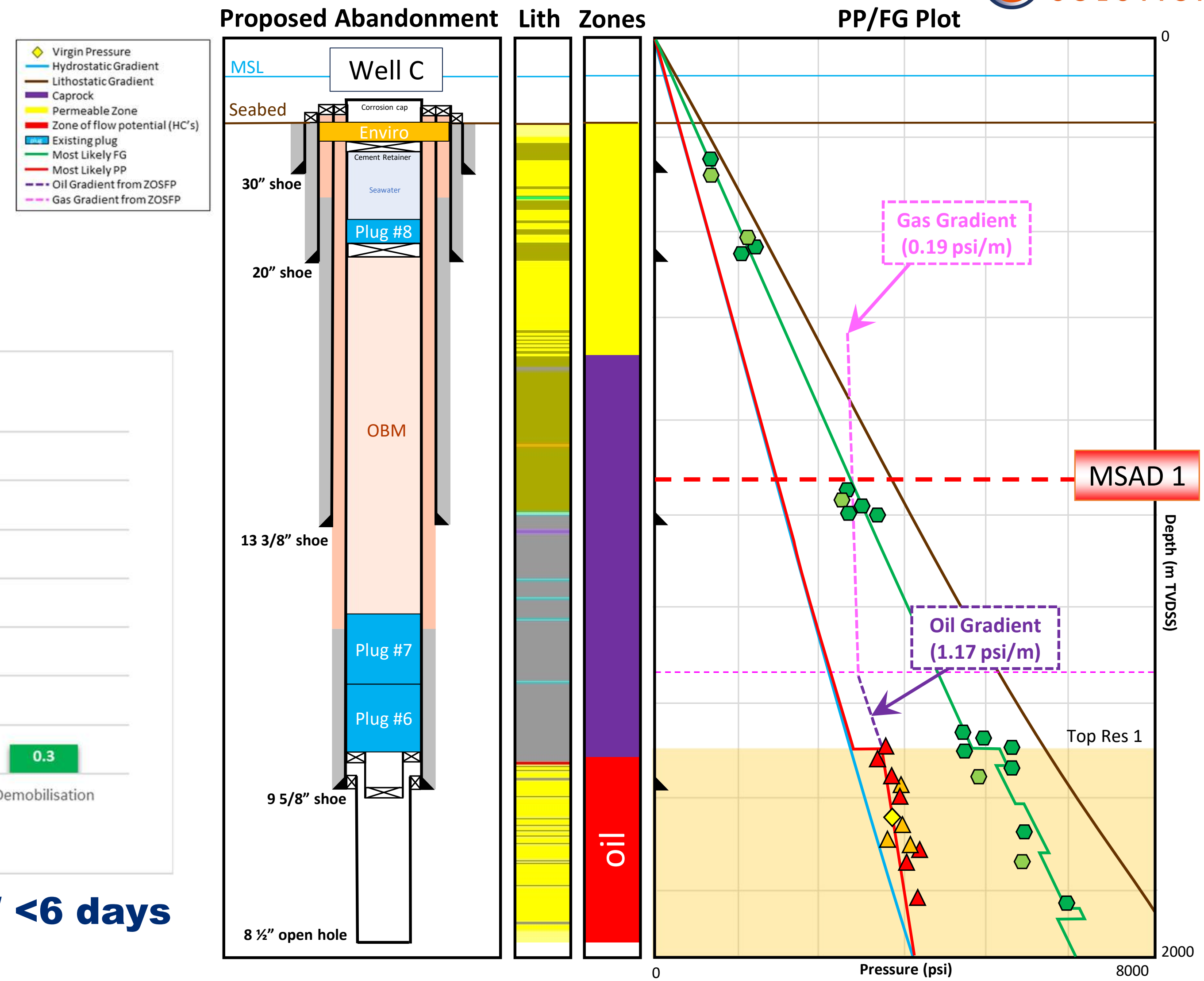
Example 2:

New Operational Steps

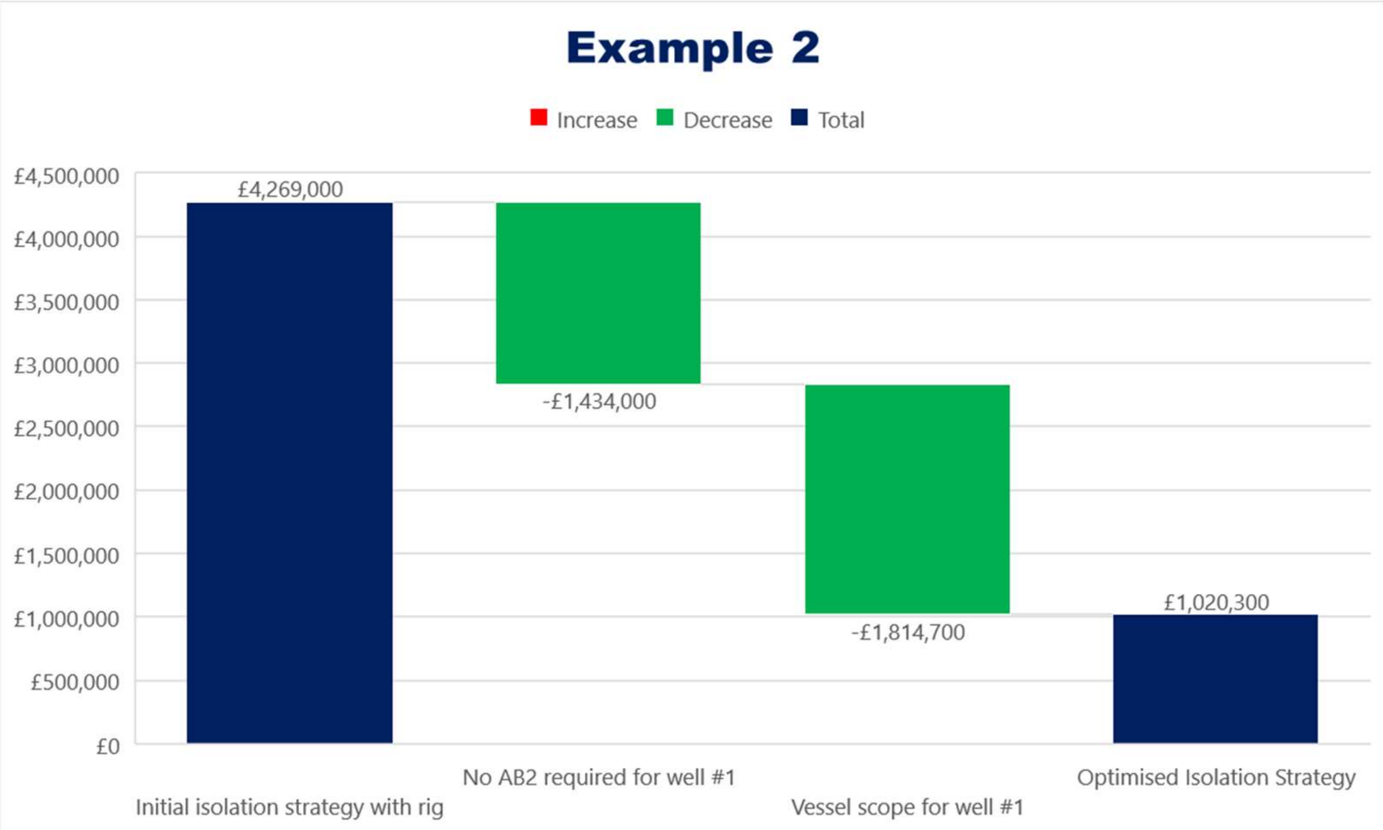
- Vessel rate: £179,000 p/d (campaign)
- No requirement for well control



Total £1.02 mm / <6 days



Time/Cost Impact



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

Example 3: "All models are wrong, but some are useful" (George Box)

How Recharge Assumptions Impact Cost & Complexity

Additional abandonment requirements / complexity

Crossflow risk

Un-isolated legacy well

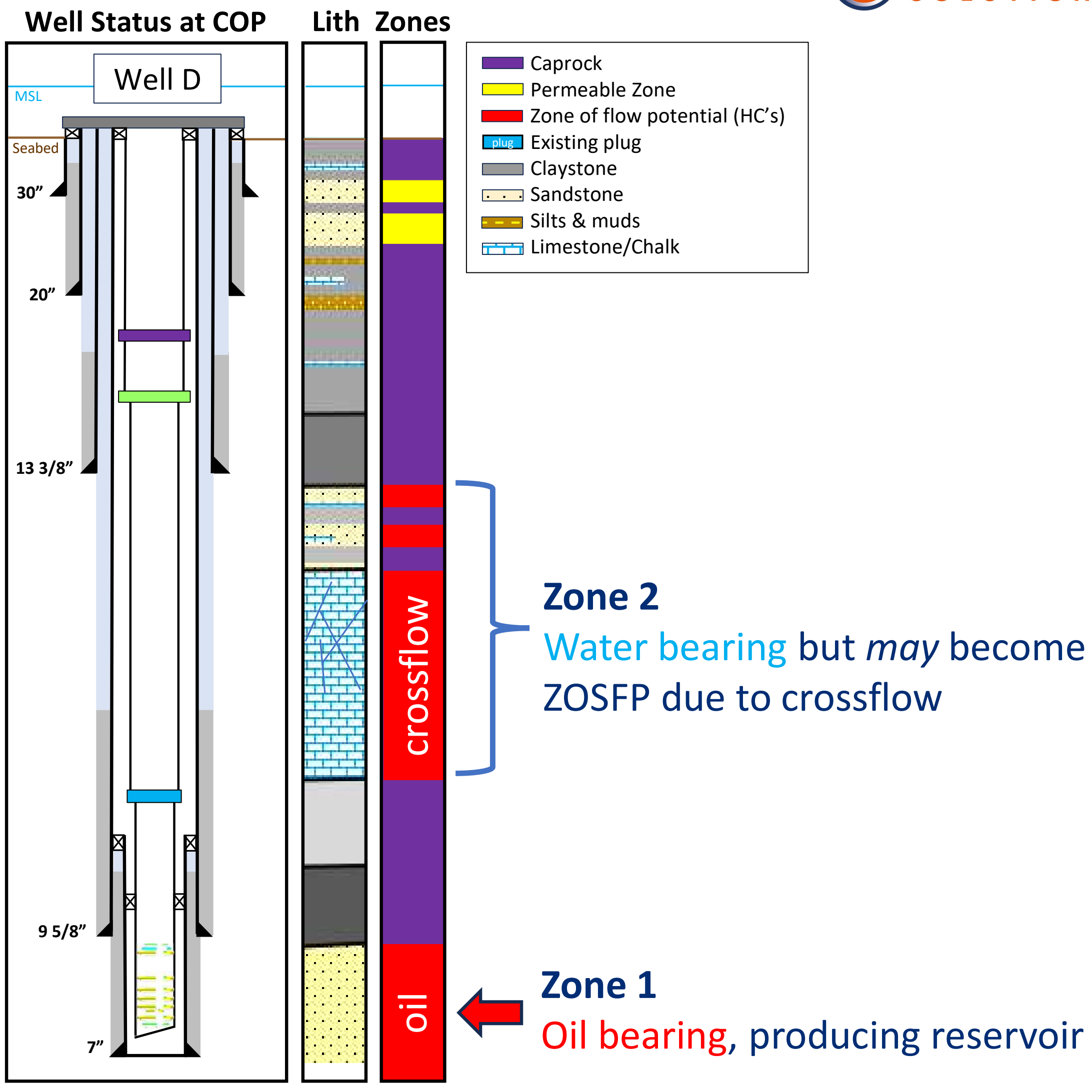
MSAD very deep – causing issues with execution

Recharge to Virgin Pressure Assumption

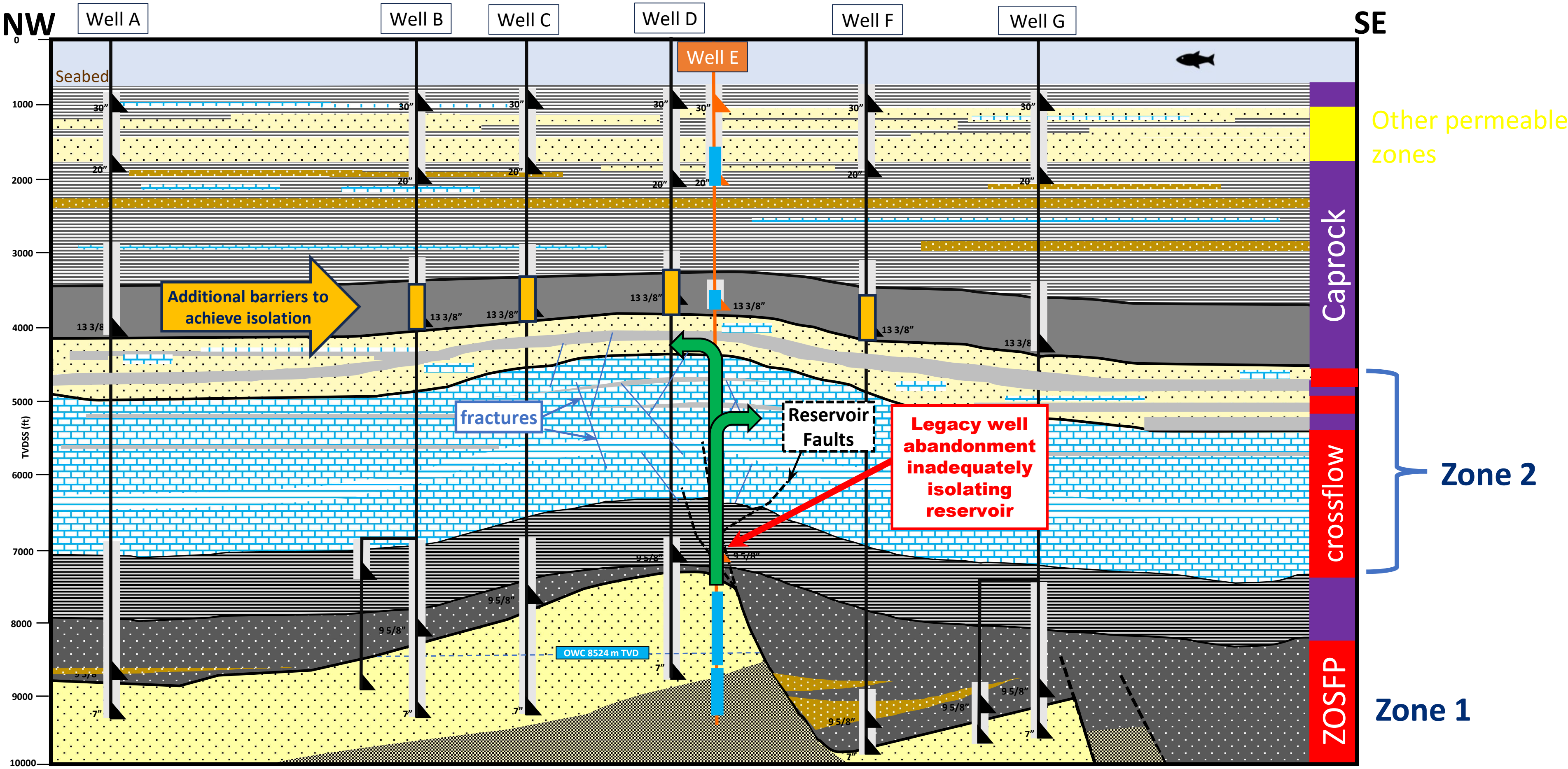
Example 3:

Subsurface Assumptions

- Field discovery in 1990 - COP reached in 2019
- 6 production wells, **1 legacy well (AB3)**
- Overpressured Middle Jurassic Sandstones – oil bearing (4569 psi @ 8217 ft TVDSS) **depleted** by c. 2644 psi
- Recharge assumption: **virgin (overpressured)**
- Fractured Chalk and Tertiary Sandstones may be charged through **crossflow**



Example 3:

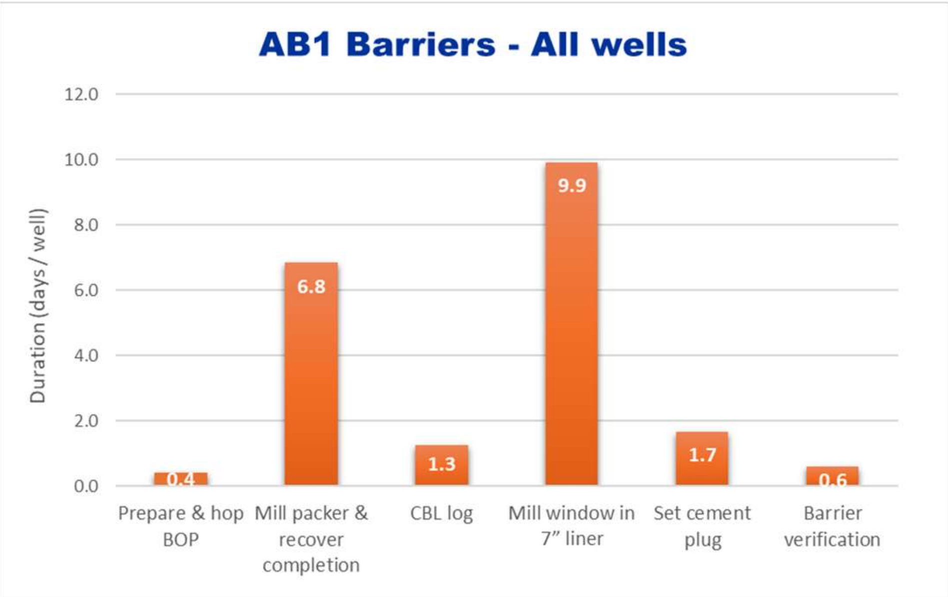


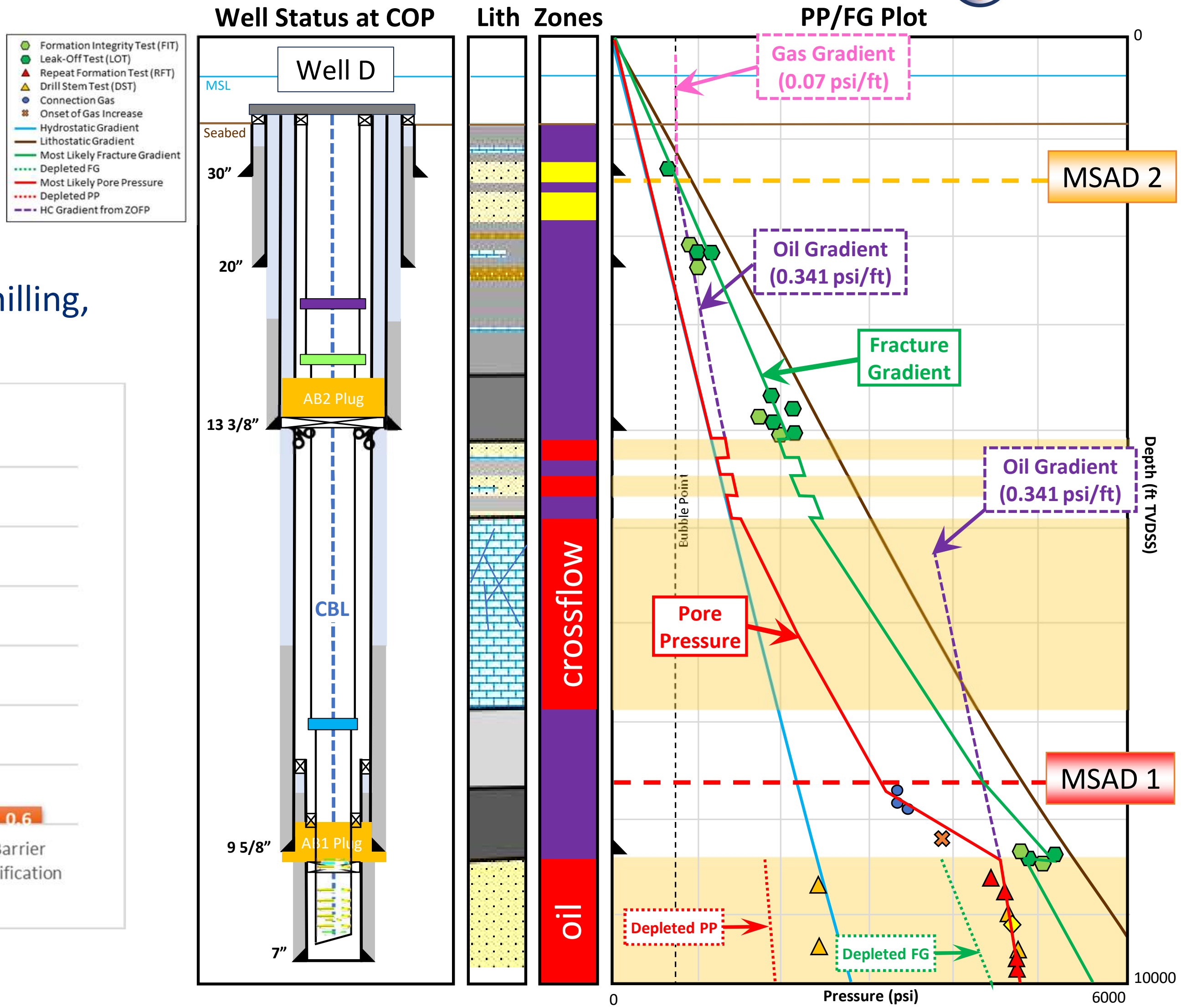
NW
SE
Well A
Well B
Well C
Well D
Well E
Well F
Well G
Seabed
Additional barriers to achieve isolation
fractures
Reservoir Faults
Legacy well abandonment inadequately isolating reservoir
OWC 8524 m TVD
TVDSS (ft)
Other permeable zones
Caprock
crossflow
ZOSFP
Zone 2
Zone 1

Example 3:

Well Status at COP

- Rig rate: £300,000 p/d
- 4 wells requiring additional barriers
- Risk of losses (field still sub-hydrostatic), milling, cutting & pulling





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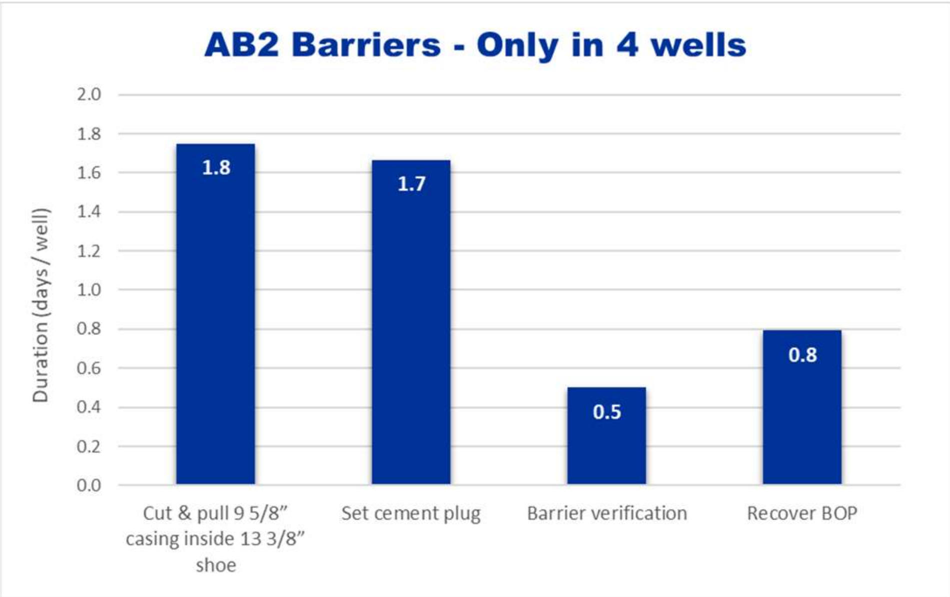
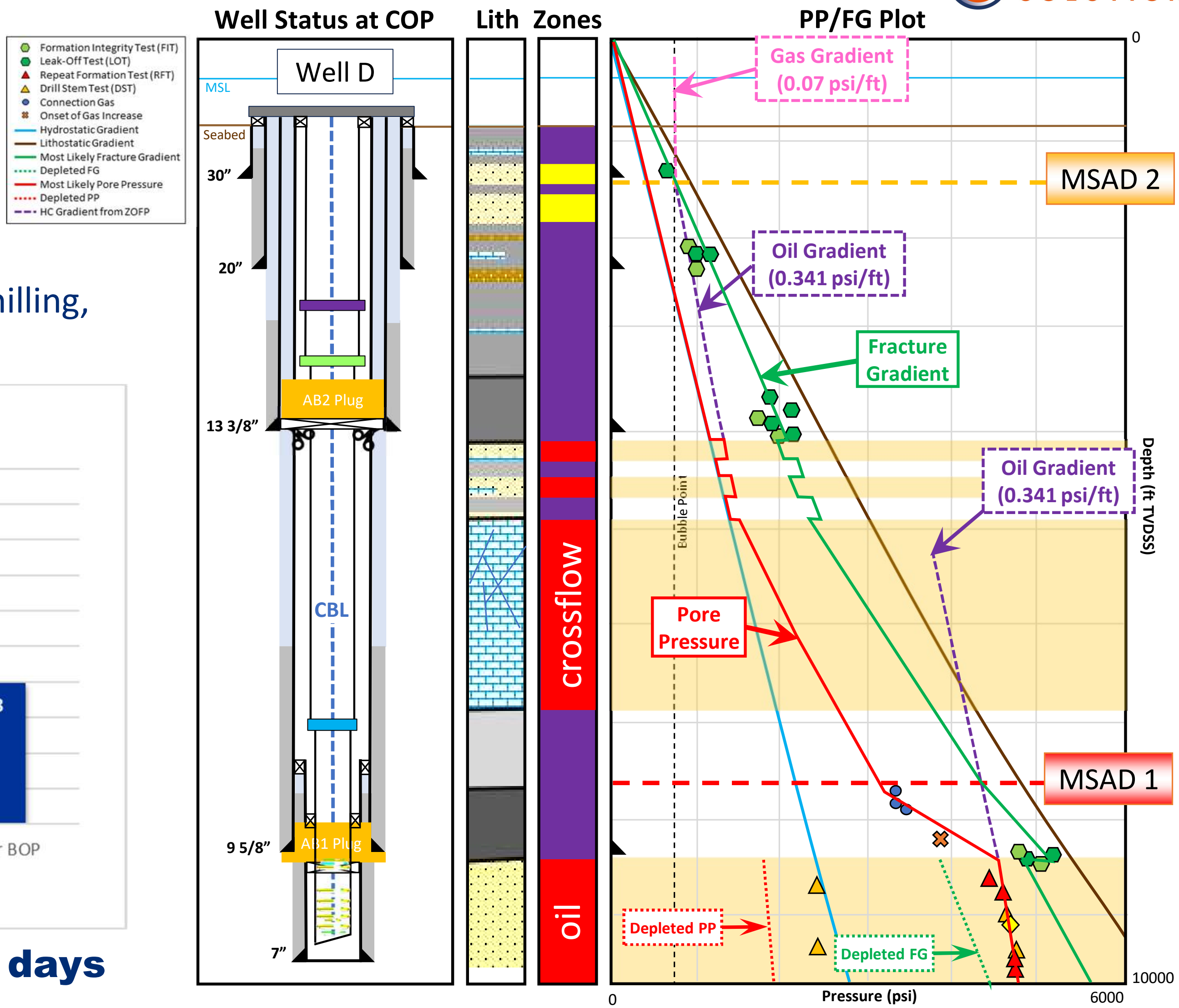


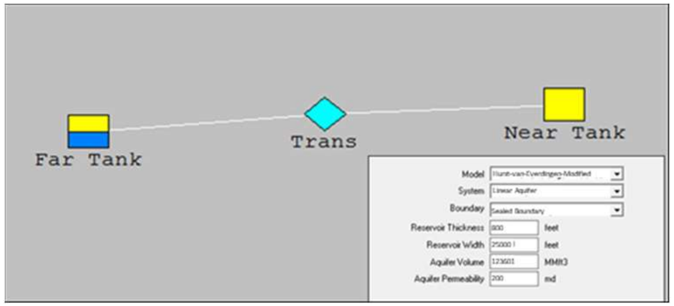
Total £41.15 mm / 137 days



Example 3:

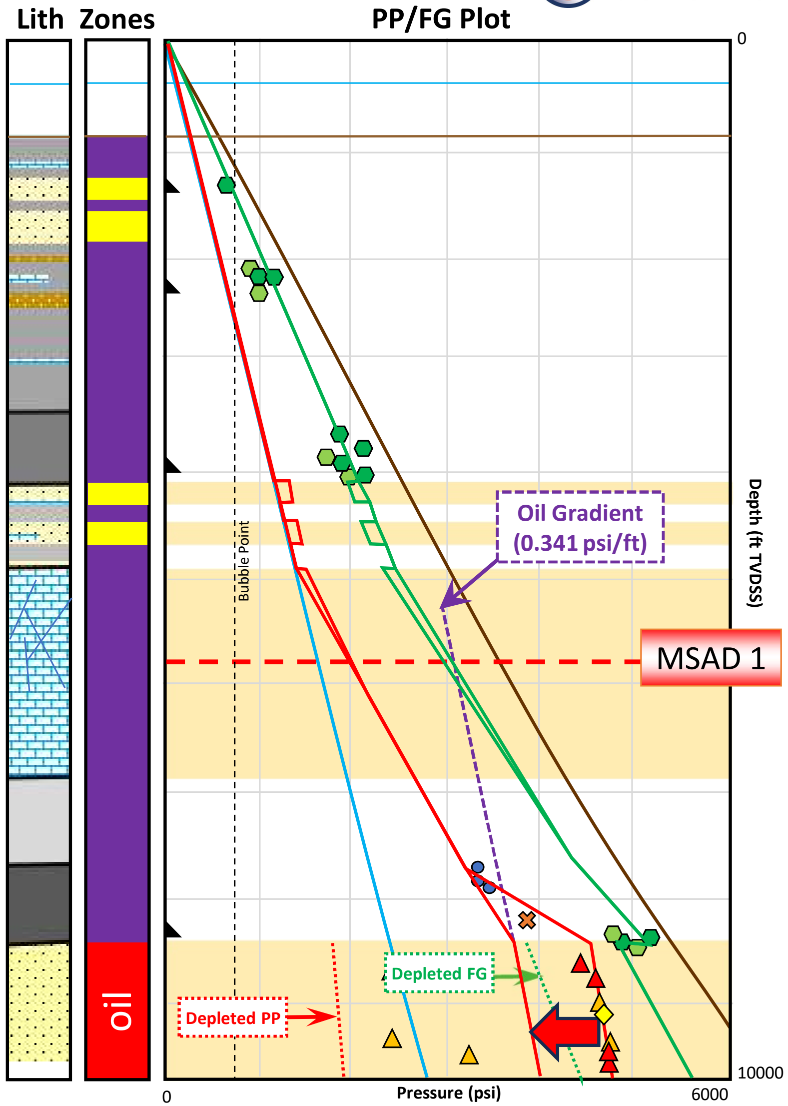
Reservoir Recharge Modelling

- Fault offset / horizon mapping on regional 3D dataset to define connected aquifer limits
- Regional pressure database created
- Thickness and properties of aquifer collated
- Aquifer size calculated at c. 3.5 bln m3 (smaller than predicted)
- A two-tank MBAL model created, incorporating offtake from nearby connected blocks
- Stabilised recharge pressures calculated: 3872 psi @ datum used as ML recharge pressure



Zone 2 Removed

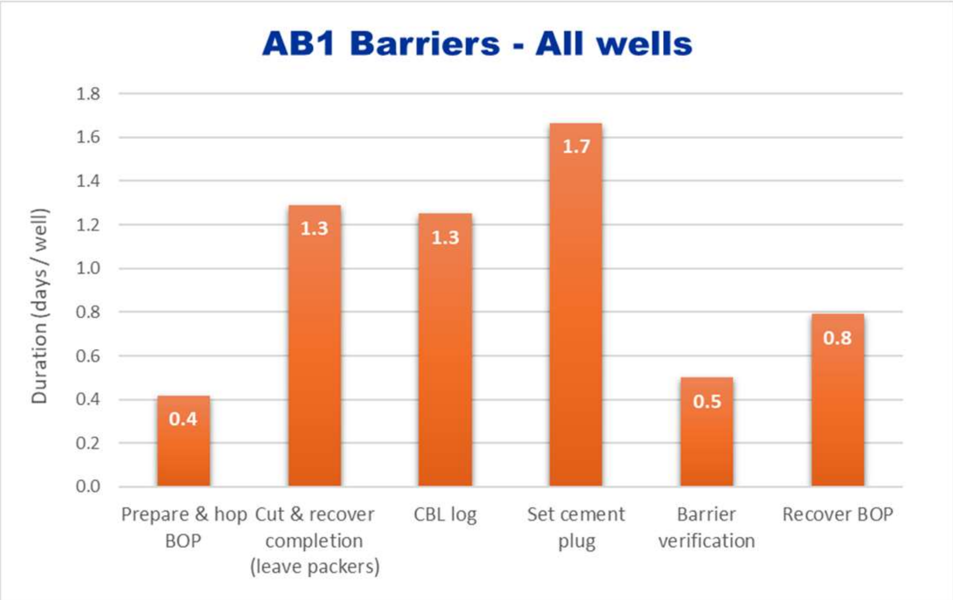
+ likely shale closure in short open hole section of legacy well



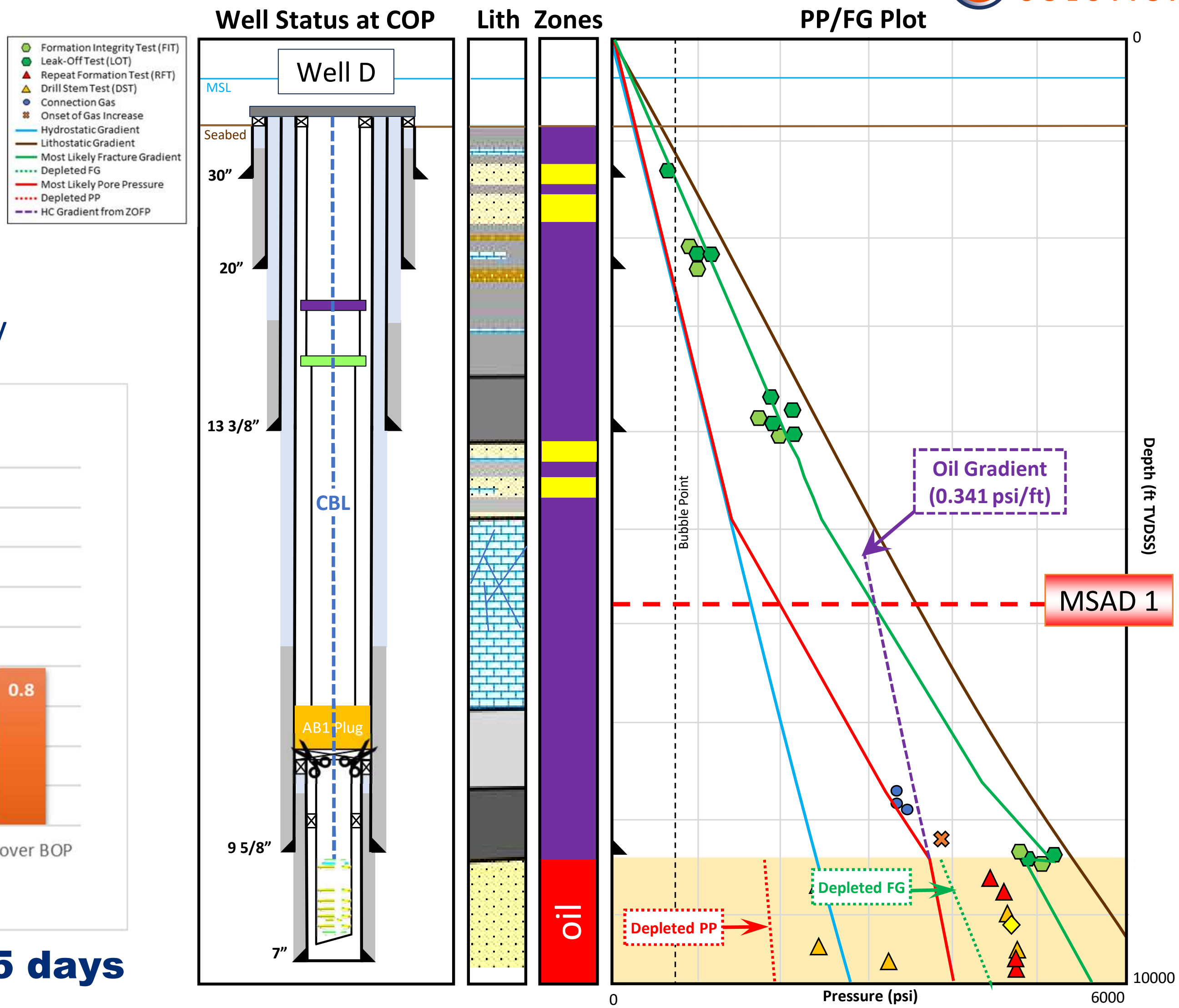
Example 3:

After Reservoir Recharge Modelling

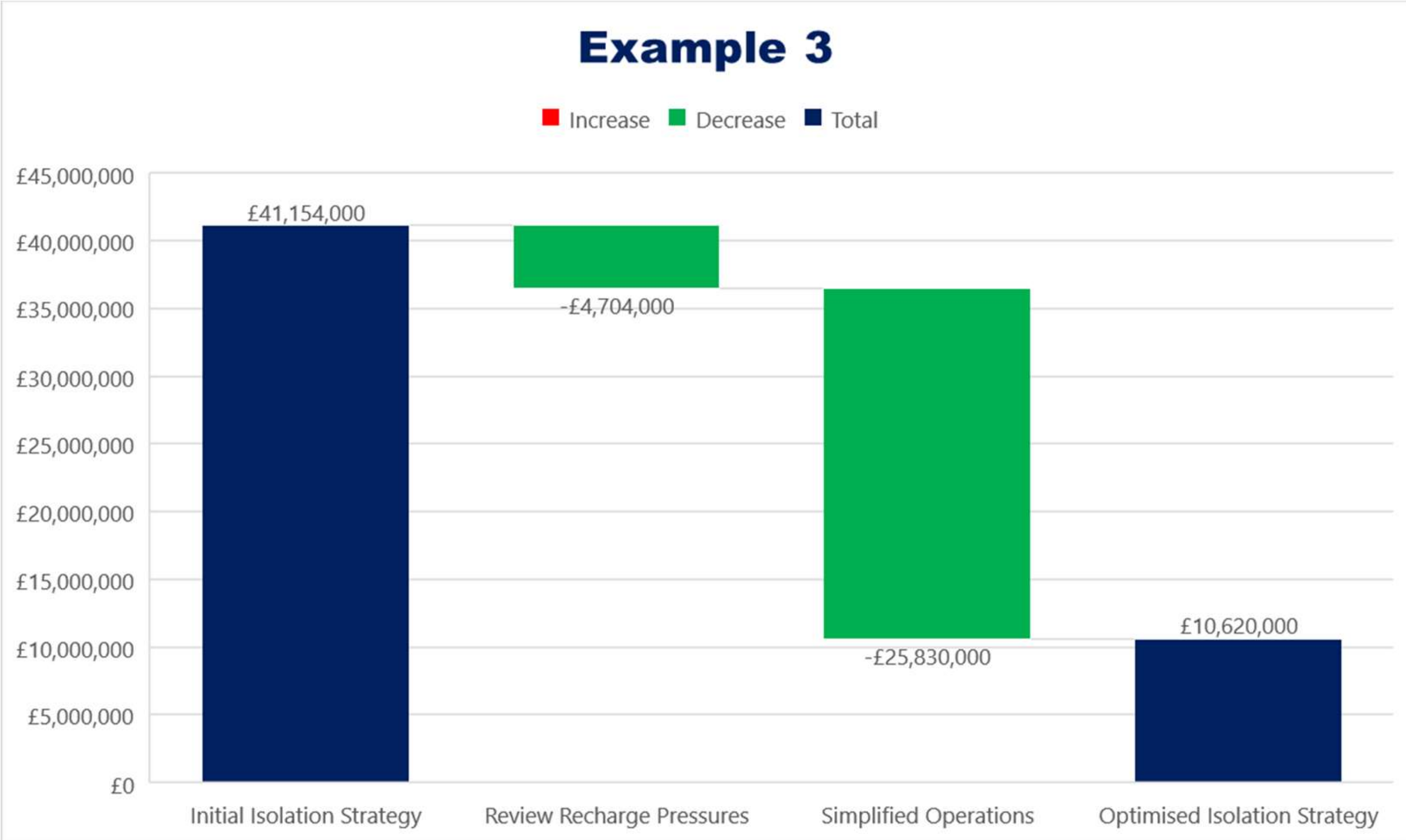
- Rig rate: £300,000 p/d
- No additional AB2 barriers required
- No milling under losses or packer recovery



Total £10.65 mm / 35 days



Time/Cost Impact



Saving from original strategy: - £30.53 mm / - 102 days

What do these example demonstrate?

Typical Subsurface BoD Workflow

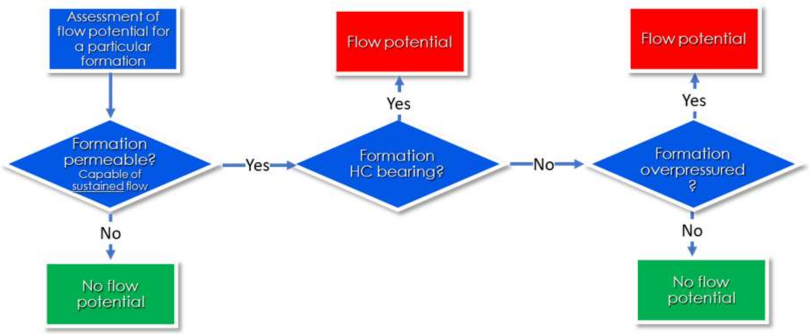
Workflow	Inputs	Deliverables
Data Review	Well & seismic data, scanned images, reports	QC'd database
Permeable Zones	Porosity, permeability, fluid properties, lithology	Identify permeable zones & caprocks
PP / FG Evaluation	Rock strength & pore pressure, fluid gradients	MSAD with uncertainty range
Zonal Isolation Philosophy	Crossflow analysis, reservoir pressure recharge models	Identify ZOSFP and isolation windows
Risk Review	Identify re-devel/re-use, well re-entry & subsurface risks	Risks Assessment & Opportunities Register
Well Abandonment Strategy	Stakeholder engagement, feedback and assurance	Develop fit for purpose abandonment

Permeable Zones — Understand the detailed lithology of each well & map formations aerially

PP / FG Evaluation — PP/FG plots need to reflect current pressures alongside predictions for the future

Zonal Isolation Philosophy — Assuming a return to virgin pressure conditions could add cost and risk

Whatever assessment style you choose…



Risk-Assessment Style (Numerical)

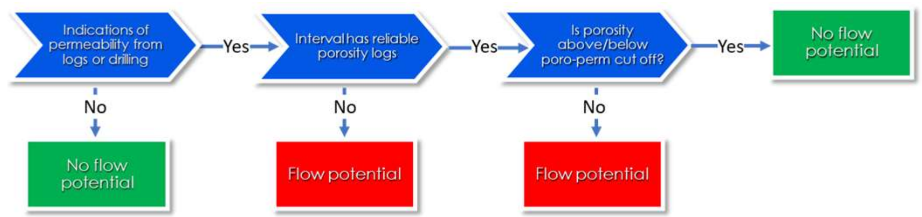
Zone / Formation	Permeability	HC Bearing	Overpressure	Low Fracture Gradient	Faults linking zones	Water Flow	Crossflow Potential	Flow Potential Assessment	Assessment basis/evidence	Requires Isolation?
3	3	2	2	5	1	5	1	2.7	GR only, annular pressure, seismic character	No
2	1	1	2	1	4	1	1	1.6	Logs, tight formation, no losses during drilling	No
1	5	5	5	3	4	3	5	4.3	Production, logs, cores, overpressure	Yes

Risk of Presence / Likelihood of Flow Potential

1	2	3	4	5
Very low	Low	Inconclusive / Not applicable	High	Very High

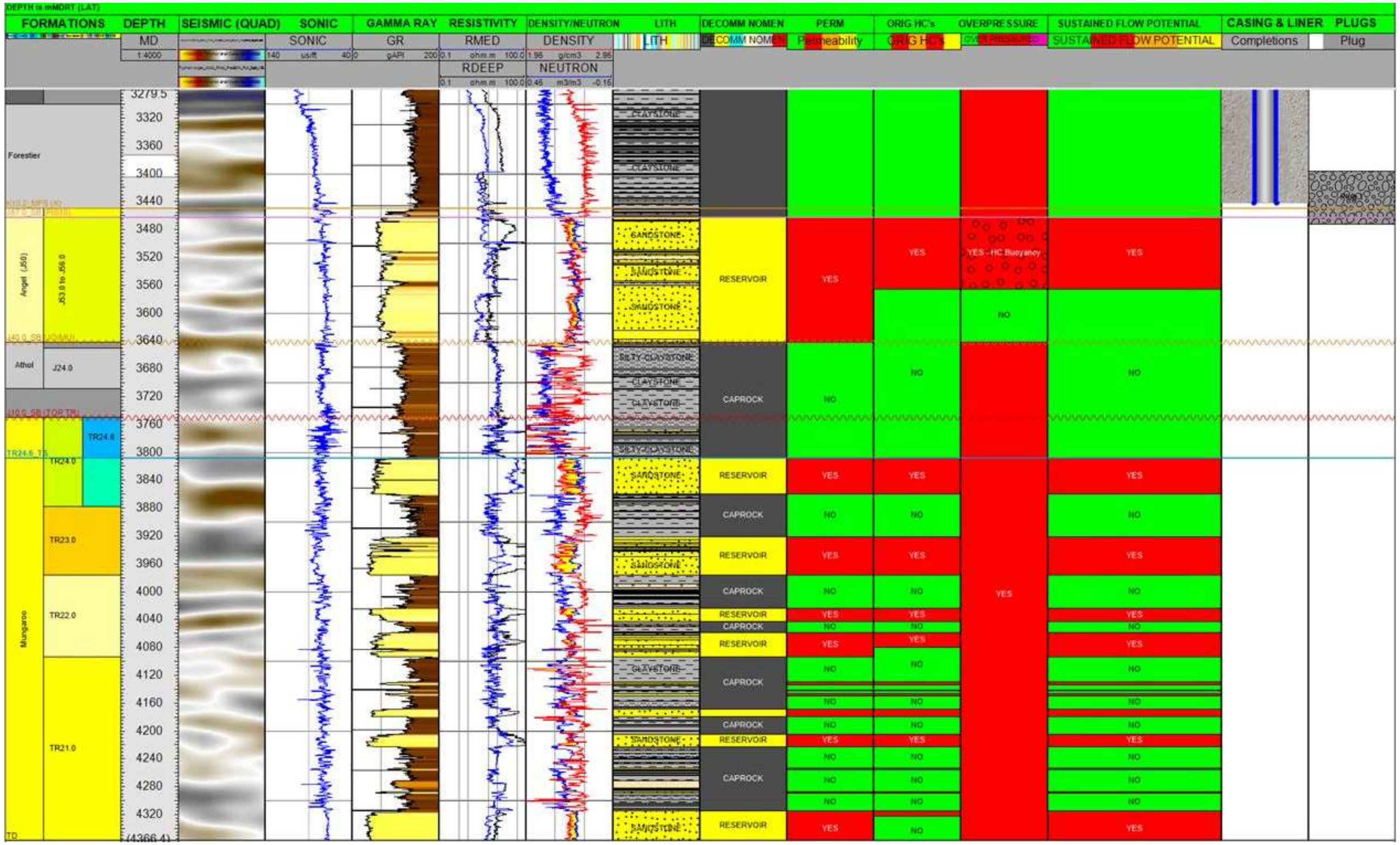
Evidence-Based Assessment (Non-Numerical)

Flow Potential Assessment	Criteria that led to flow potential assessment	Assessment Basis
No Flow	Section is hydrostatic and/or in communication with seabed – drilled riserless	Field Observations
	Section drilled underbalanced and no kick / influx reported	
No Flow	Section is hydrostatic pressure and/or in communication with seabed	Interpreted
	No permeable formations present based on petrophysical log assessment (good quality logs with high confidence interpretation)	
	Evidence from Well Completion Report describing no effective porosity or permeability in formation	
	No direct hydrocarbon indications or seismic anomalies identified in the seismic data on the well trajectory	
Possible Flow	Section overpressured and possible permeable formations present (poor quality logs, low confidence or no logs available)	Interpreted
Flow Potential	Section is overpressured and permeable formations are present (good quality logs with high confidence interpretation)	Interpreted
	Direct hydrocarbon indicators or seismic anomalies identified in the seismic data along the well trajectory	
Flow Potential	Kick / influx or losses reported during drilling operations	Field Observations
	Measured overpressured water or hydrocarbon in reservoir	



Be sure to incorporate the full data set

Emphasis on connected zonal volumes to quantify “sustainability” of flow potential!



In Summary

- Sustained flow potential relies on multiple factors – particularly understanding the connected zonal volumes
- We often lack data, time, and financial support to conduct further studies – prioritise those with the biggest impact
- A "fresh eyes" approach can be invaluable – reduces impact of confirmation bias
- Offset data is the key to unlocking uncertainties and providing context
- A multi-disciplinary approach, dedicated to P&A, is the key to optimised and cost effective well abandonment!

Thanks to:

Iain Whyte, Wayne Alger & all at Islay Petrophysics
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Vaughan Cutten of Woodside Energy

Thank you!