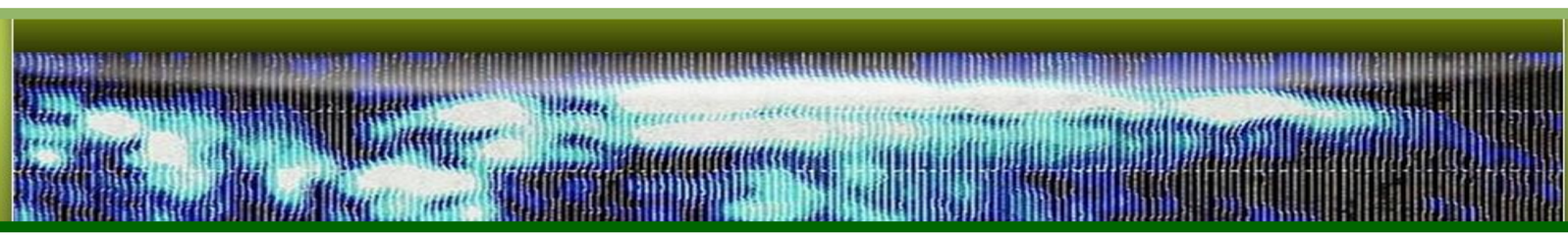
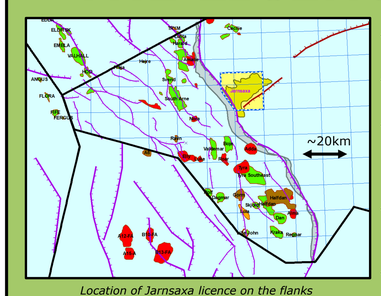
Jarnsaxa: Fractured Basement Play-Opener Offshore Denmark



A well is planned in 2019 to test a huge 250 km², 1 km closure prospect, as a play opener for Denmark

THE LICENCE & PLAY



Location of Jarnsaxa licence on the flanks of the Central Graben in Denmark (Tail-End Graben)

Core taken from the OMV operated Habban field in Yemen, showing a range of fractured reservoir lithologies contributing to production

- The 11/16 licence is on a six year term from April 2016.
- All licence commitments are fulfilled barring the exploration well drill/drop
- The well is planned for 2019 and Arden is farming down from it's 80% (Nordsøfonden 20%) – dataroom available.
- The two year work programme was completed with 3D PGS Geostreamer acquisition.
- It is a fractured basement play opener in the optimal location to test it.
- Globally the play is very active in Yemen, North Africa, and SE Asia, and modern techniques are helping to empower its efficient exploitation.
- In NW Europe, the greater Johan Sverdrup (Norway) and Lancaster areas (UKCS) involve large fractured basement complexes and are under ongoing development.

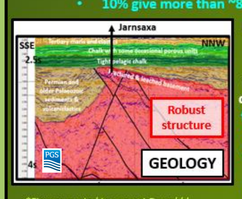
ONE-STOP SUMMARY

JARNSAXA
New 3D Broadband
Emerging NW Eur. play
Simple £11MM well
$NPV10 1.9 billion
>20% COS
Data to appraise effectively

We need four things to work for any hydrocarbon accumulation. Here we estimate:
1. Charge: 80% chance of success
2. Reservoir: 65% chance of success
3. Structure: 80% chance of success
4. Seal: 55% chance of success

All of them working them together here? 23% chance of success – better than 1 in 5 & nearly 1 in 4. Better than 1 in 6 from a dice…

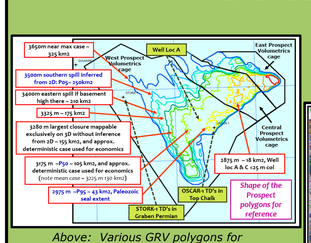
If we do get a hydrocarbon accumulation at Jarnsaxa, we've modelled a range of outcomes as to roughly how big it could be*. It could fall anywhere on the range, but:
- The average size of all the outcomes is ~370 million recoverable barrels of oil
- 90% of outcomes give more than ~30 mmbbl
  - 50% give more than ~ 160 mmbbl
  - 10% give more than ~850 mmbbl



Even discounting the future value of money by 10% per year, and costing the development needed, for 370 mmbo @ $60 oil, that's net profit $1.9 billion, a rate of return of 52% and a profit to investment ratio of 4.5

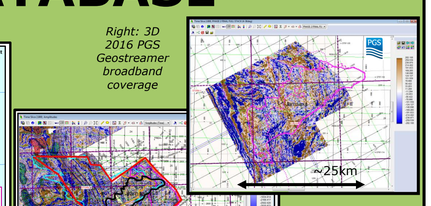
**Figures quoted to nearest 5 mmbbl.*

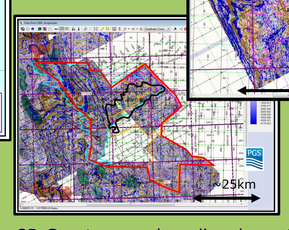
DATABASE



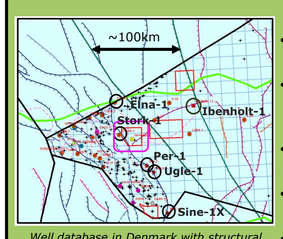
Above: Various GRV polygons for reference on database maps to right

Right: 3D 2016 PGS Geostreamer broadband coverage





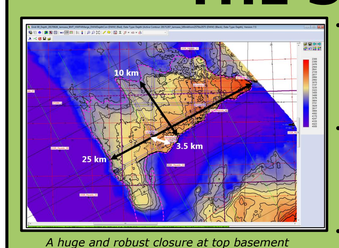
Left: 3D PGS Megasurvey coverage



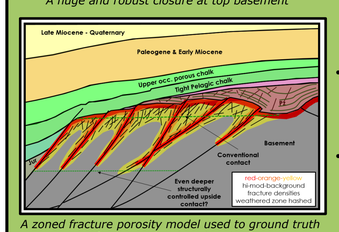
Well database in Denmark with structural framework, with most relevant basement and Palaeozoic penetrations circled

- 3D Geostreamer broadband acquisition by Ardent & PGS Geophysical - 90% of the prospect
- Remainder of the prospect and its regional context is covered by PGS's 3D Danish Megasurvey.
- Further regional context and well ties are provided by extensive 2D.
- All Danish well reports are held & utilised by Ardent
- Integration of all these datasets has been required to understand the prospect.

THE SIZE



A huge and robust closure at top basement



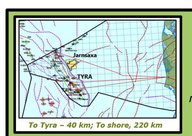
A zoned fracture porosity model used to ground truth fracture porosity estimates

- GRV, fracture porosity, and recovery factor are the "big three" variables which most influence volumetrics in this play.
- The GRV is an order of magnitude larger than Lancaster – which is estimated to have a more than 2 billion barrel STOIIP.
- The area is larger than Clair, with a 5 billion STOIIP, and the Jarnsaxa P10 HC column is around 900m.
- Fracture porosity assumptions are deliberately kept conservative at P90-P50-P10 0.2-0.9-4.0% (lognormal).
- Recovery factor is assumed to be 10-22.5-35% as per Lancaster CPR, but can be much better in fractured reservoirs.

OIL CASE	STOIIP mmbbl	Rec Oil mmbbl	Rec Assoc Gas bcf	Rec Res mmboe
P90	146	28	11	30
P50	739	157	61	167
Mean	1582	370	148	394
P10	3712	848	340	904

P50 STOIIP ~ 3/4 billion barrels, mean ~ one and a half billion, P10 ~ 3 & 3/4 billion barrels

THE REWARD



To Tyra – 40 km; To shore, 220 km

The economics are scoping in nature, designed to demonstrate a robust commercial viability in even lower case scenario outcomes

ASSUMPTIONS OF SCOPING DEVELOPMENT SCENARIOS & ECONOMICS

Appraisal Strategy	Early Production system - an initial exploration well which contingent on results of testing suspends or P&A's for later return & conversion to producer. Second appraisal well for conversion to producer, with location contingent on results of first. Full FDP formulated during EPS phase.
Exploration & appraisal well	2019, 2020
Well production	10k bopd, drawing on analogues from Lancaster CPR and Yemen.
Fluid assumptions	From offset accumulations, 38 deg oil, no H_2S, CO_2 400 scf/bbl, no gas sales
Aquifer & water cut	ESP (electric summersible pump) assumed for lift support, but may not be required. 0% water cut expected, but design for 20%
Export	Export rate of EPS of up to 30K bopd, with 85% efficiency
FDP commitment	2020
Development	FPSO with FSU capacity of 450 000 bbl, or shuttle tanker if ESP not required
Production start	2022
Economics objectives	Scoping exercise to demonstrate commerciality of lower end cases
Low case economics	Only western part of prospect charged, like Sunah analogue - 62.5 mmbo recovered, 2 subsea development wells
near P50 economics	Whole prospect charged, with 200 m column at exploration well, three development wells, 175 mmbo recovered
Mean case economics	Whole prospect charged, with 250 m column at exploration well, five subsea development wells, one failed producer, 370 mmbo recovered
Other cases	If much bigger, tie back to Tyra Platform (40 km) or shore (220 km) become options. If smaller, MOPSOU options may work.

SCOPING ECONOMIC METRICS	NPV_{10} $MM (to nearest 5)	NPV_{10} /bbl $	Discounted rate of return (DCF ROR_{10}) %	Profit/Investment ratio PIR	Discounted PIR_{10}	Payback month/year
62.5 mmbo Case (7% of P10)						
$60 oil	310	6.2	26%	1.0	0.6	Feb-2025
175 mmbo Case (21% of P10)						
$50 oil	715	5.1	32%	2.0	1.2	Oct-2024
$60 oil	910	6.5	36%	2.5	1.6	Jun-2024
$70 oil	1105	7.9	41%	2.9	1.9	Apr-2024
$80 oil	1305	9.3	45%	3.4	2.2	Feb-2024
370 mmbo Case (44% of P10)						
$50 oil	1540	5.2	46%	3.7	2.3	Jan-2023
$60 oil	1910	6.4	52%	4.5	2.8	Jan-2023
$70 oil	2275	7.7	57%	5.2	3.4	Jan-2023
$80 oil	2645	8.9	62%	6.0	3.9	Jan-2023

- Nobody is saying Jarnsaxa is without risk, but in a first-world fiscally attractive country at NPV_{10} of $1.9 billion, 62% ROR_{10} for $80 oil, for an $11 million well cost to check it out, it just might be worth it…

COMMERCIAL ASSUMPTIONS

General						Tax				Capex			
Oil price	Discounting	Inflation	Gas sales	Tariffs	Terms	Royalty	Corp Tax	HC Tax	With-holding Tax	PV tested & suspended Exploration well USDMM	PV appraisal well USDMM	PV well subsea USDMM	PV FPSO USDMM
Constant in real terms 2018	PV @ 10% mid year	2.5% p.a.	None	None, tanker export	Standard Danish royalty & tax	0%	25%	52%	0%	~25.5	~24.9	~28.0	~260

THE RISK

- The one stop summary shows a basic approach to technical risk.
- A more complex approach also took into account phase and other less likely scenarios thinking harder about the Palaeozoic section around the prospect, as shown below. Nothing changes much.

CHANCE THAT A DISCOVERY ON THE MODELLED VOLUME DISTRIBUTION CAN DELIVER SUSTAINED HC FLOW TO SURFACE FROM SOME LOCATION ON THE MAPPED PROSPECT

Jarnsaxa Model Description	Model chance	Source	Migration	Reservoir	Structure	Seal	TOTAL COS PER MODEL	MODEL WEIGHTED COS	Phase oil%/gas%	TOTAL OIL COS PER MODEL	MODEL WEIGHTED OIL COS
Preferred model											
Pz sediment is a seal to fractured basement reservoir; spill point controlled by top basement; Jurassic charge	0.90	1.00	0.80	0.65	0.80	0.55	0.23	0.21	90%/10%	0.21	0.19
Secondary models											
Pz sediment is a reservoir or waste zone sealed by chalk and Zechstein/Triassic; Internal late Pz geometry and fault seal controls spill point.	0.05	1.00	0.80	0.65	0.80	0.70	0.29	0.015	90%/10%	0.26	0.013
Either of above models with wholly Pz charge	0.05	0.10	0.90	0.65	0.80	0.55	0.03	0.001	10%/90%	0.003	0.0001
TOTAL ALL SCENARIOS	1.00						COS oil or gas all scenarios:	0.22		Oil, all scenarios:	0.20

THOUGHT EXPERIMENT : CHANCE THAT A TECHNICAL SUCCESS CASE IS CONCLUSIVE FOR COMMERCIAL SUCCESS EVALUATION

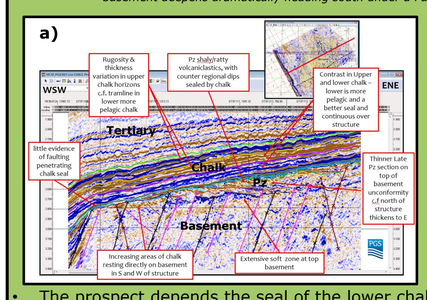
Risk element	Comments/caveats	Estimated Chance of Success, given a technical success at the well has already occurred
Presence of minimum commercial field size MCFS at the well location	Given the size of the prospect, it's not very sensitive to price etc, assumed MCFS ~ 30 mmbo	90%
Production profiles for producers can be sufficiently estimated from the early wells	This is the chance that well results aren't confusing or ambiguous - that the combined data sets are enough to empower development decisions, including understanding of both	85%
Production sweet spot tracking	Chance that seismic can be used to calibrate exploration well findings and fracture characterisation and enable targeting of optimal production "sweet spots" by extrapolating throughout	90%
Sub-horizontal appraisal & development drilling	Chance that horizontal well segments in the fractured basement are ultimately able to access targetted zones	95%
TOTAL		65%

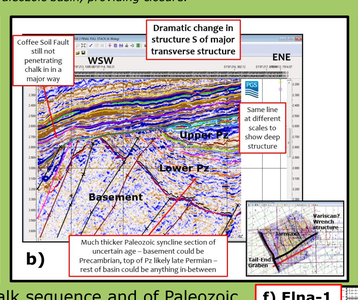
- Undesired in a fractured reservoir field, is a set of confusing well results that leave development plans risky
- The table at left considers some of the key elements for future investment decisions.
- It illustrates that if a success does happen at Jarnsaxa, the data sets present are likely to empower effective resource delineation and decision making for development.

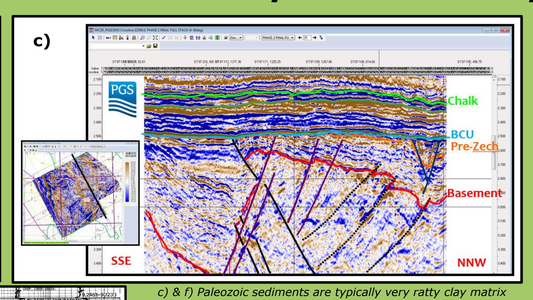
At mean STOIIP of 1.58 billion bbl, COS 23%, NPV_{10} $1.9 billion - for gross well cost $11 million, it's eye catching…

STRUCTURE, CHARGE, SEAL

a) & b) : Lines in the west of the prospect illustrate the complete chalk section required for seal, and how the basement deepens dramatically heading south under a Paleozoic basin, providing closure.

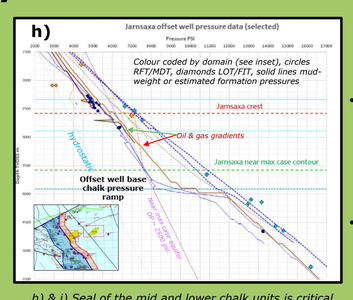






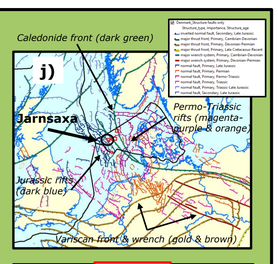
c) & f) Paleozoic sediments are typically very ratty clay matrix volcaniclastics likely to seal, wherever penetrated in the vicinity, and they are themselves sealed by chalk. Elna-1 (left) is fairly representative of the volcaniclastics and volcanics encountered in any Danish well east of the Caledonide thrust front.

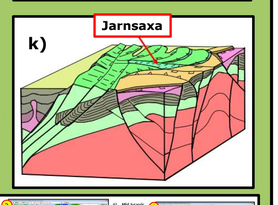
g) A zoom of d) showing the Paleozoic thrust system forming the eastern and southern margins, uplifting basement and defining closure



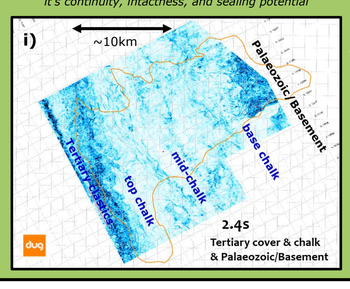
h) & i) Seal of the mid and lower chalk units is critical, but pressure data suggests that it is a sub regional seal in the nearby Tail End graben, and seismic attribute analysis in DUG software provides further confidence of it's continuity, intactness, and sealing potential

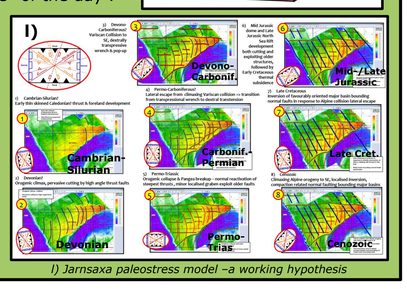
- Offset well pressure data illustrates 3000 psi of seal through the chalk in the nearby graben, and favourable conditions for max oil column retention.
- Seismic attributes in DUG software are providing further confidence in the continuity and sealing potential of the middle and lower chalk levels.
- The prospect has been in a tectonic "bullseye" since the Precambrian, generating many different fracture sets.
- Meaning some are likely to be dilatant whatever the stress regime "of the day".



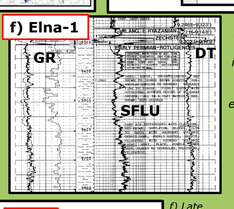


j), k), l), Precambrian basement assembly, Caledonide thrusting, Variscan wrenching, Permo-Triassic Pangea break-up, Jurassic North Sea rifting, and Cretaceous-Tertiary stress regimes, have all provided abundant opportunity for fracturing and dilatancy

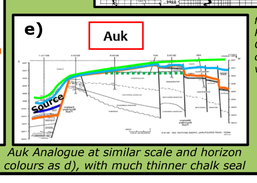




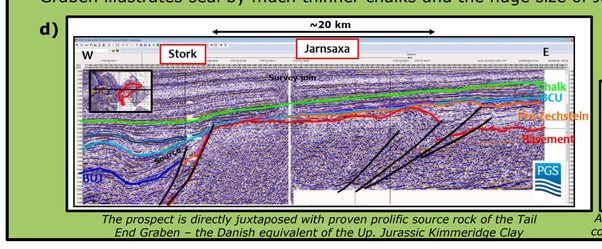
l) Jarnsaxa paleostress model –a working hypothesis



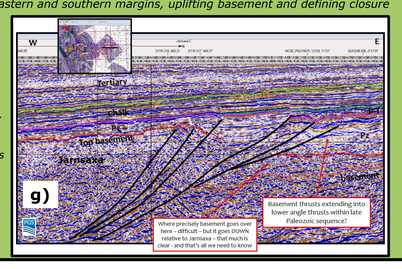
f) Late Permian seal: Consistently clay matrix volcaniclastics



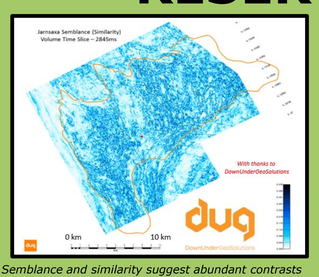
Auk Analogue at similar scale and horizon colours as d), with much thinner chalk seal



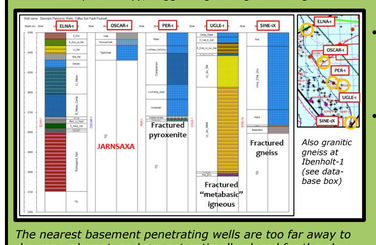
The prospect is directly juxtaposed with proven prolific source rock of the Tail End Graben – the Danish equivalent of the Up. Jurassic Kimmeridge Clay



RESERVOIR

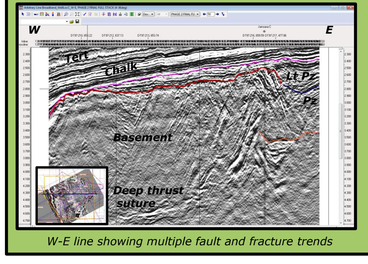


Semblance and similarity suggest abundant contrasts within the confines of the structure (outline mapped independently), suggesting strong fracturing



The nearest basement penetrating wells are too far away to be very relevant, and are not optimally placed for the play

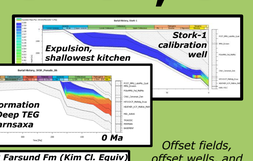
Also granitic gneiss at Ibenholt-1 (see data-base box)

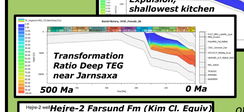


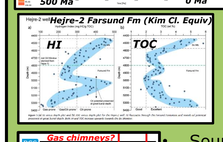
W-E line showing multiple fault and fracture trends

- The nearest basement penetrations to Jarnsaxa are over 30 km away.
- In a region with as many Paleozoic thrust terranes as this one, that makes them of dubious relevance.
- They are nevertheless fractured with a range of gneissic and meta-igneous lithologies.
- Basement at Jarnsaxa could be completely different, and variable.
- None of them penetrated basement for any significant distance, or in a location optimal for this play.
- Analogues from Yemen suggest that while basement lithology is an important secondary control on diagenesis and fracturing, it is the presence of dense open fractures that is the primary control.
- That means for Jarnsaxa that fault and fracture attributes from the broadband dataset are our best control on reservoir.
- They suggest it is pervasively fractured on many orientations, at least some of which are likely to be dilatant at any one time during the structure's history, including now.

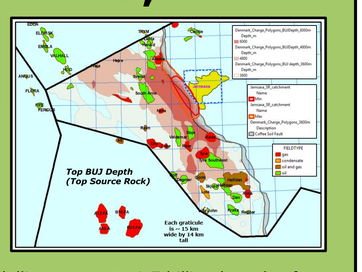
SOURCE, SLICKS, SEEPS

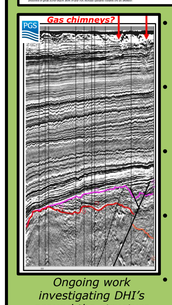






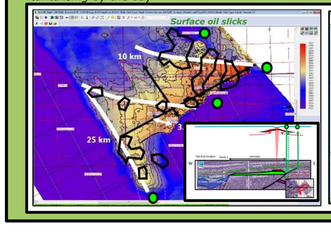
Offset fields, offset wells, and basin modelling of pseudo-wells, provide ample comfort regarding source rock and charge

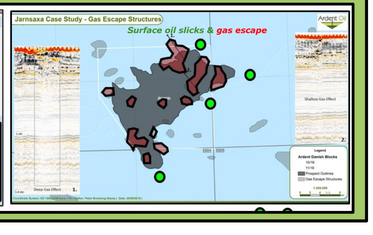




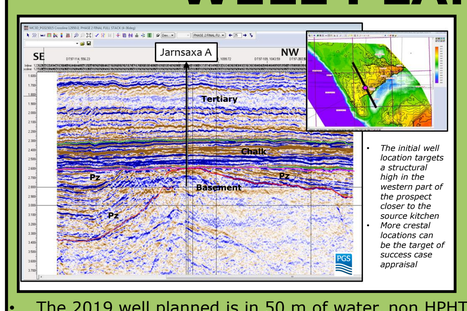
Ongoing work investigating DHI's around the structure becomes more tantalising by the day

- Source basin modelling suggests 4-7 billion barrels of expulsion in the catchment area immediately adjacent to the prospect, from the top 200 m of UJ source only.
- Calibrated by nearby source penetrations, basin models suggest expulsion began in the early Tertiary, and is ongoing today. Migration arguments imply 90% oil chance.
- Prospect risking and volumetrics is based only on the proven Farsund Fm (Kim. clay equivalent) source rock but other Jurassic and Paleozoic sources may contribute.
- Oil seeps concentrated around the periphery of the structure, and gas chimneys, are providing increasing evidence by the day of HC migration in the vicinity.
- Though work to understand these continues, and there are other possibilities, increasingly they are becoming hard to explain without a Jarnsaxa pool.

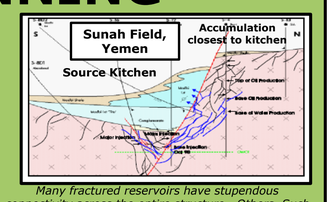


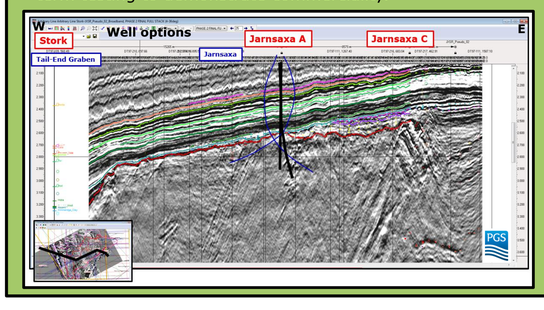
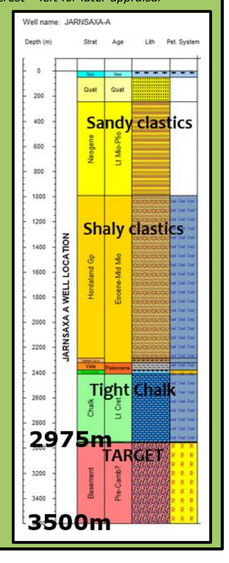


WELL PLANNING



- *The initial well location targets a structural high in the western part of the prospect closer to the source kitchen*
- *More crestal locations can be the target of success case appraisal*



Many fractured reservoirs have stupendous connectivity across the entire structure. Others. Such as Sunah in Yemen, are more restricted accumulations close to the source kitchen. Our well location therefore targets a local structural high in the western part of the prospect closer to the kitchen area, rather than the ultimate crest – left for later appraisal

- The 2019 well planned is in 50 m of water, non HPHT, and has estimated 40-45 days duration to a TD of 3500 m including ~ 500 m of basement penetration. Cost ~ $11 million dry hole.
- A 2002 well – Oscar-1 is located nearby above the prospect but penetrated only to the upper levels of the chalk. It provides good overburden control, suggesting a straightforward well.
- The exploration well location in this huge 25 km long prospect is near the source kitchen to mitigate against internal migration risk suggested by analogues like Sunah in Yemen.
- Success cases like to include sub-horizontal deviations and long term testing to demonstrate commerciality.