First Offshore Deployment of Large-Diameter Pressurised Coring Technology in a Mature Waterflooded Field

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Abstract. This paper presents the operator's first offshore deployment of a pressurised coring system in a mature waterflooded oilfield. The objective was to acquire representative pressure-core samples from swept reservoir intervals in support of hydrocarbons remaining in place (HRIP) evaluation, log calibration, depletion planning, and EOR screening. A dedicated sidetrack targeted swept sands up-dip of a nearby injector. Thorough pre-job planning, integrated execution, and disciplined wellsite handling enabled safe deployment and full-length recovery on all six runs. Pressure-core handling, de-pressuring, fluid sampling, and laboratory analysis confirmed that representative remaining-oil saturation (Sor) data could be obtained under these conditions. The resulting measurements provided a reliable understanding of Sor under conventional water floor conditions in the reservoir rock of interest and direct calibration points for log-based saturation interpretation in swept intervals, demonstrating the value of pressurised coring where conventional methods may not preserve representative fluids adequately.

1 Reservoir characterization challenge and study objective

Mature waterflooded fields often retain significant hydrocarbons remaining in place (HRIP), but quantifying those volumes reliably is difficult once reservoirs have undergone prolonged depletion and sweep [1]. In this setting, uncertainty in remaining oil saturation directly affects depletion planning, recovery forecasting and the value assessment of enhanced oil recovery (EOR) opportunities. The main reservoir characterization challenge in this study was therefore to quantify remaining hydrocarbons behind the waterflood front in one of the main producing horizons of a large, mature offshore field.

This paper describes the operator's first offshore deployment of a pressurised coring technique from a Production, Drilling and Quarters (PDQ) platform to address that challenge. A dedicated sidetrack with a complex 3D trajectory targeted swept sands up-dip of a nearby injector. Although the campaign supported HRIP evaluation, the paper is primarily an offshore deployment case history covering method selection, planning, execution, and validation of representative samples and data. The paper first defines the technical requirements that drove method selection and the limitations of conventional approaches, then presents the selected pressurised coring solution, campaign execution and validation, and finally the lessons learned and reservoir implications.

1.1 Technical requirements for a successful HRIP measurement

A successful HRIP evaluation in this setting required foundational understanding of Sor under conventional water flood environment provided by direct determination of remaining oil saturation (Sor) and the supporting measurements needed to calibrate log-based saturation interpretation. In this study, pressurised core measurements provide direct remaining-oil saturation data at core scale for the sampled locations, whereas reservoir-scale HRIP estimates require integration of these measurements with petrophysical interpretation, geological context, and dynamic reservoir understanding. The integrated core analysis programme was therefore designed to determine remaining oil saturation directly by Dean–Stark extraction, while also providing the key inputs for resistivity-based saturation evaluation, including pore-water salinity and Archie m and n exponents. Because the reservoir had already been produced and waterflooded, measurements also needed to minimise fluid disturbance during coring and trip-out and to correct explicitly for mud contamination using unique oil- and water-phase tracers.

1.2 Limitations of conventional approaches and comparison of alternative methods

At the outset of the project, several HRIP measurement approaches were screened against the reservoir and

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operational context to identify a method capable of delivering representative remaining-oil measurements in a mature waterflooded reservoir. Post-production saturation logging without core calibration was not expected to provide sufficient confidence in these complex paralic sandstones, while appraisal-era saturation data no longer constrained present-day remaining oil distribution after prolonged production and waterflooding. Swept-zone coring for log calibration was therefore considered essential, and the available methods were compared for their ability to preserve representative fluids, manage contamination risk, and remain operationally deployable offshore. Methods were reviewed systematically for risk, value and cost [2].

Wireline-deployed rotary sidewall coring with pressure retention was rejected because of operational risk and limited data quality. The anticipated hydraulic overbalance (>135 bar / 2,000 psi) and expected permeability (10s–100s mD) made recovery uncertain, and the small samples would likely be flushed and heavily contaminated.

Drillpipe-conveyed sponge or liquid-trapping coring was evaluated to capture hydrocarbons evolved during coring and trip-out. When paired with downhole fluid sampling, these methods can estimate remaining oil in place, but the added operational complexity and uncertainty in sampling location, fluid recovery, and recombination were judged too high.

Partial pressure-retained drillpipe coring was also considered because it recovers rock and fluids from the same stratigraphy in a single run; however, expansion of fluids into multiple chambers would introduce uncertainty judged to outweigh the benefit of lower surface pressures.

Conventional full-bore coring (with mud tracing and wellsite plugging/preservation) has an excellent track record on the field. Optimised mud systems with oil- and water-phase tracers and extensive saturation analysis work well in virgin conditions, but post-production the method is less reliable once both phases are mobile and can be affected by de-pressuring and fluid exchange with drilling fluid during trip-out (Figure 1).

The required 3D trajectory drove selection of oil-based mud for lubricity, torque reduction, and wellbore stability. In that context, the main measurement risk was miscible interaction between remaining oil and mud filtrate during coring, followed by uncontrolled fluid redistribution during retrieval. Against the requirements defined in Section 1.1, full pressure-retained large-diameter coring (Figure 2) provided the best fit because it preserved core and fluids through coring, trip-out, and controlled surface de-pressuring, while also enabling integrated fluid sampling and subsequent laboratory saturation analysis. It was therefore selected as the preferred solution.

2 Selected pressurised coring solution

The selected pressurised coring technology is based on the Large-diameter Pressure Corer (LPC) core barrel system. It was chosen because it provides full pressure and fluid retention through coring, trip-out and controlled surface de-pressuring, directly addressing the principal limitations identified for conventional approaches in this mature waterflooded reservoir. The drill-pipe-conveyed system has already been deployed successfully in a range of applications with other operators in the Middle East [3, 4, 5].

2.1. Pressurised coring technique

The LPC core barrel is operated broadly like a conventional drill-pipe-conveyed full-bore core barrel. The principal differences between the LPC and a conventional core barrel are summarised below.

Wellsite preparation – The LPC is pre-configured in a designated pipe-deck processing area; inner-barrel spacing-out and most assembly tasks are completed before it is picked up.

Making up the BHA – On the drill floor the LPC requires only corehead make-up and crossover to the bottom hole assembly (BHA); the assembled coring BHA is then run in hole on drillpipe.

Coring operation – No flow-diversion ball is required to start cutting. After coring, the barrel is pulled to break core, an activation ball is dropped, the inner barrel strokes up inside the pressure vessel, and a flapper valve closes to seal the core.

Trip out of hole – Unlike conventional coring, no reduced trip schedule is required because the core is sealed; de-pressurisation is controlled at surface after laydown.

Surface handling – A secondary barrier is established by closing an internal top ball valve and installing a bottom sealing thread protector, reducing exposure to pressurised fluids during handling.

De-pressuring and wellsite processing – After transfer to the processing area, the LPC is vented in a controlled manner over several hours to characterise and sample evolving fluids before extracting the core for conventional handling and preservation.

2.1.1. LPC pressure core barrel system

The LPC incorporates a series of features that allow pressure-tight encapsulation of the core sample immediately after it is cut and separated from the formation (Figure 3; [6]). The process is initiated by a drop ball pumped down the drill string. Once the ball lands in the activation sub, an internal mechanism lifts the inner-barrel assembly into the pressure-vessel section of the tool. During this stroking sequence, the lower and upper valves close automatically, fully isolating the core sample. From that point onward, the core is sealed within a gas-tight pressure vessel, eliminating the potential for fluid or gas loss. The LPC system specifications are summarised in Table 1.

A critical component of the LPC is the integrated pressure regulation system (PRS; see Figure 3). The PRS is responsible for compensating temperature-induced pressure fluctuations during tripping out of the hole and subsequent surface handling procedures.

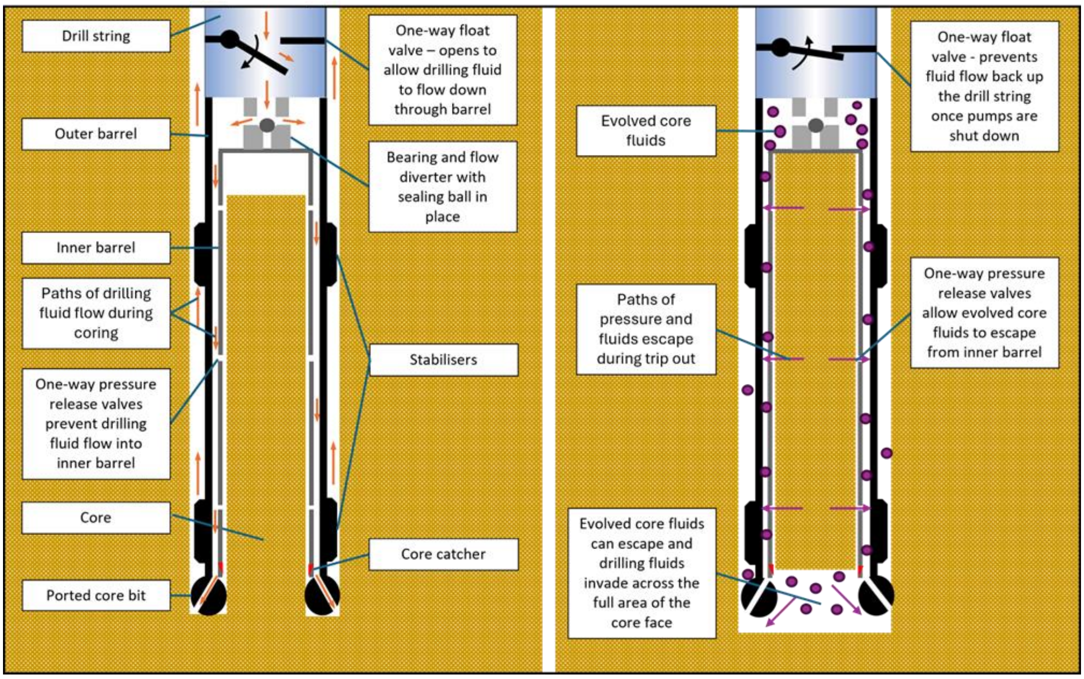

Fig. 1. Conventional core barrel – coring (left) vs tripping out (right). Note fluid pathways during coring and tripping out.

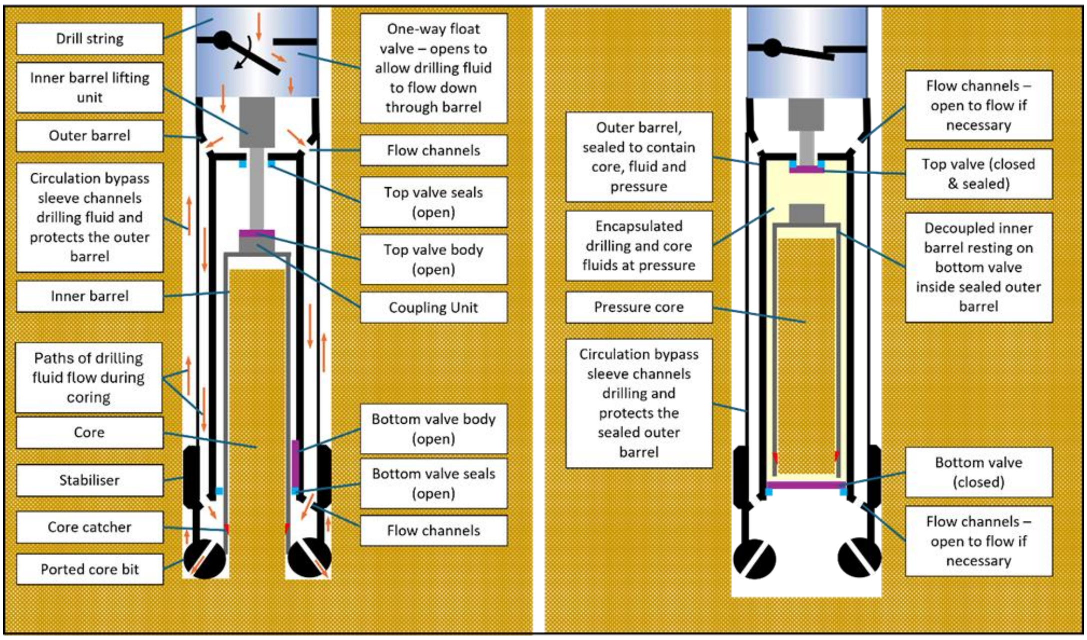

Fig. 2. Pressure core barrel - coring (left) vs tripping out (right). Note fluid pathways during coring and tripping out.

The PRS is a piston type accumulator that utilises a floating piston to separate a pressure control volume from the pressure vessel containing the core. The fluid within the pressure control volume is either an inert gas (e.g. nitrogen) or water depending on the selected operating mode of the PRS. The choice of the operating mode and the corresponding configuration of the PRS are determined on a case-by-case basis [7].

The two PRS configurations are:

1. Pre-charged configuration – For bottom hole pressures below 690 bar / 10,000 psi the PRS is charged with Nitrogen to a pre-determined and pre-set pressure. When pulling the sealed system out of hole the nitrogen in the PRS acts as a buffer to minimise pressure drop associated with the thermal contraction of the system as it cools. The final stabilised recovery pressure at surface (relative to the bottom hole pressure) corresponds to the isochoric cooling behaviour of compressed nitrogen from bottom hole temperature to surface temperature.

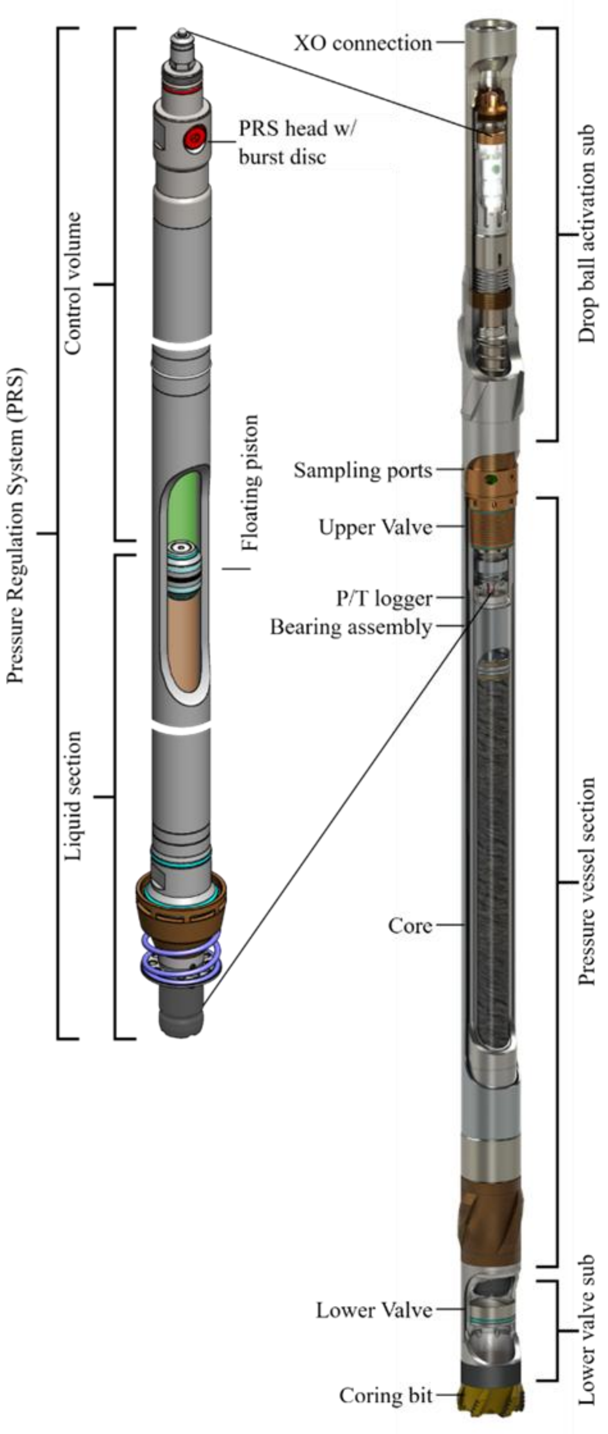

Fig. 3. Overview of the LPC and components [6].

2. HP (High Pressure) configuration – For bottom hole pressures exceeding 690 bar / 10,000 psi the PRS is filled with water, and a pressure relief valve is installed. This valve is pre-set to a relief pressure that remains within the LPC operational limits. During retrieval of the sealed system, if differential pressures exceed the set valve relief pressure, small amounts of water are discharged to prevent further pressure build-up. As a result, the system is recovered with a pressure that is equal to or below the pre-set relief pressure.

The PRS is in direct communication with the pressure vessel section of the LPC core barrel system and starts operating once the top and bottom valve of the system are closed.

The system is equipped with a pressure and temperature (P/T) recorder located at the top of the inner-barrel assembly. The P/T profile delivers valuable data on the operation and is read out once the core sample has been recovered from the de-pressurised core barrel system.

2.1.2 De-pressuring method, sampling and data acquisition

After laydown, the LPC is safety-checked, reconfigured to access the pressure-vessel section and PRS, and fitted with heating jackets, sensors, valves, and auxiliary equipment for controlled de-pressuring (Figures 4 and 5). PRS pressure is then measured to define recovery pressure at the prevailing temperature.

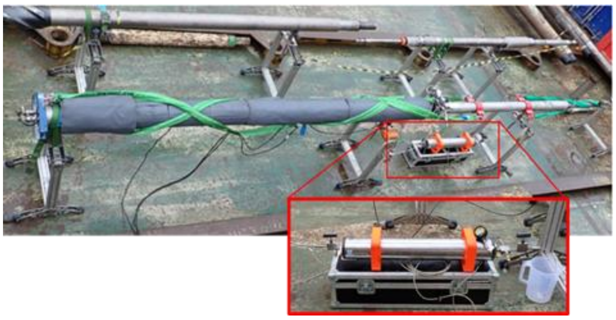

Fig. 4. LPC with heating jacket and sensors, valves, external accumulator (inset detail) and other auxiliary equipment hooked up for de-pressuring.

Fig. 5. De-pressuring and evolved gas monitoring system.

De-pressuring and degassing of the LPC – Pressure reduction continues by means of controlled extraction of gas from the produced core gas bubble which has collected in the upper part of the LPC in the previous step. The downstream gas pressure is reduced to approximately 5 barg / 70 psig for further processing.

Gas sampling and chromatography – Gas is collected in low-pressure cylinders while an inline chromatograph monitors composition to confirm sample quality and provide a real-time gas profile.

Determination of produced core gas volume – Downstream gas passes through a wet test meter (composition-independent) with continuous pressure/temperature monitoring; these data, together with sample volumes, are used to calculate total produced core gas.

De-pressuring by means of volume expansion of the pressure vessel section – An external piston accumulator is connected to the pressure vessel section of the LPC. The control side of the accumulator is pre-filled with water which is then released at a controlled rate. This results in a slow volume expansion of the live pressure vessel section and the intended reduction of internal pressure. At a certain pressure the core will begin to release gas which migrates to the uppermost part of the barrel and accumulates as a gas bubble (Figure 6). This de-pressuring process ends when the external accumulator volume is fully utilised, typically around 4.5 Liter.

Conclusion of de-pressuring – Once the system pressure reaches atmospheric conditions, and the gas production has dropped below 1 litre/hour the de-pressuring process is concluded, and the system is prepared for the extraction of the now de-pressurised core sample.

Extraction of the core sample – With the LPC pressure vessel section now at atmospheric conditions, the top is opened and the inner core barrel containing the core is retrieved. The P/T recorder is recovered, and all remaining liquids are collected for analysis.

Key field deliverables were preserved gas and liquid samples, total volatile gas in core (reported at STP), and the annotated pressure/temperature profile for each run.

3 Campaign planning and operational preparation

Thorough pre-job planning, aligned with the operator coring practice, combined the expertise of the new pressure-coring provider and the incumbent coring service company to enable safe and efficient deployment. Accessing the target interval required a challenging cased-hole sidetrack from a PDQ platform; the coring well was subsequently plugged back and re-sidetracked for injector completion. Planning began more than a year in advance to maximise the likelihood of success, with the key steps summarised below (Figure 7).

Selection of method – Options spanning logging, wireline rotary sidewall coring (conventional/pressure retained) and drillpipe coring (conventional, sponge/liquid trapping, partial/full pressure retained) were reviewed with subject matter experts (SMEs); full pressure-retained drillpipe coring was selected.

Selection and engagement of suppliers – Corsyde supplied the full pressure-retained large-diameter drill-pipe-conveyed coring technology, while Halliburton provided coring, wellsite tracing, plugging, and preservation based on its field and basin track record.

BOD (Basis of Design) – A common basis of design captured objectives, well design, geology, facilities, and constraints and served as the reference for multidisciplinary planning.

Integrated coring programme – Regular integration meetings developed a single programme covering drilling and fluids optimisation, coring, de-pressuring, processing, and analysis, together with equipment lists and clearly defined wellsite roles. Risk assessments and peer reviews involved platform personnel, sidetrack service providers, and laboratories.

Well optimisation – With no spare PDQ slots, a sidetrack from a redundant injector (Well A) was required to access the swept targets. Trajectory optimisation balanced wellbore stability, target access, and sticking risk, resulting in a complex 3D S-shaped path with a long 65° tangent, a 500 m drop section, and an 8 ½” × 10 ¼” underreamed interval (Figures 8 and 9). The underreamer was set back 46 m from the bit to provide a smooth, in-gauge tangent for coring initiation.

BHA modelling and optimisation – BHA dynamics modelling was used to reduce core-barrel loading, minimise torque and vibration, and maintain a safe coring RPM window. The analysis showed that stabiliser placement was critical because the LPC is less stiff than standard drilling components. Figures 10, 11, and Table 2 summarise the optimisation. The preferred design placed the lower string stabiliser as close as practical above the core barrel, reduced BHA weight by about 12 t to lower torque and slip-stick risk, and retained only the stabilisers needed to pass the casing window and maintain contact in the 10 ¼” section.

Corehead selection – A new corehead design for the LPC core barrel was developed based on local experience, with a particular focus on improving cutter placement to reduce core stress and optimising flow displacement to minimise core invasion.

DWOP/CWOP – In-person drill-and-core-the-well-on-paper sessions aligned the coring team, subsurface and wells teams, and key suppliers on platform constraints and the surface process plan.

Dry run – A full-dress rehearsal of de-pressuring and follow-on core processing was carried out at the Halliburton yard to test tools and refine the plan.

Rig visits – Key members of the core team made planning visits to the offshore PDQ platform to develop detailed and safe plans for pressure-core surface handling and processing with the platform crew on location. Sufficient core personnel were also trained as Performing Authorities to control the work in accordance with the platform safety management system.

RWI – Rig Work Instructions detailing well context, risks and operational steps were developed jointly by the drilling and coring team during the final stages of planning. RWIs were updated on a run-by-run basis throughout the operation.

Early mobilisation – The full package of coring equipment and team were mobilised early to allow equipment to be set up, operational plans and permits to be finalised, and to allow further crew team building and familiarisation.

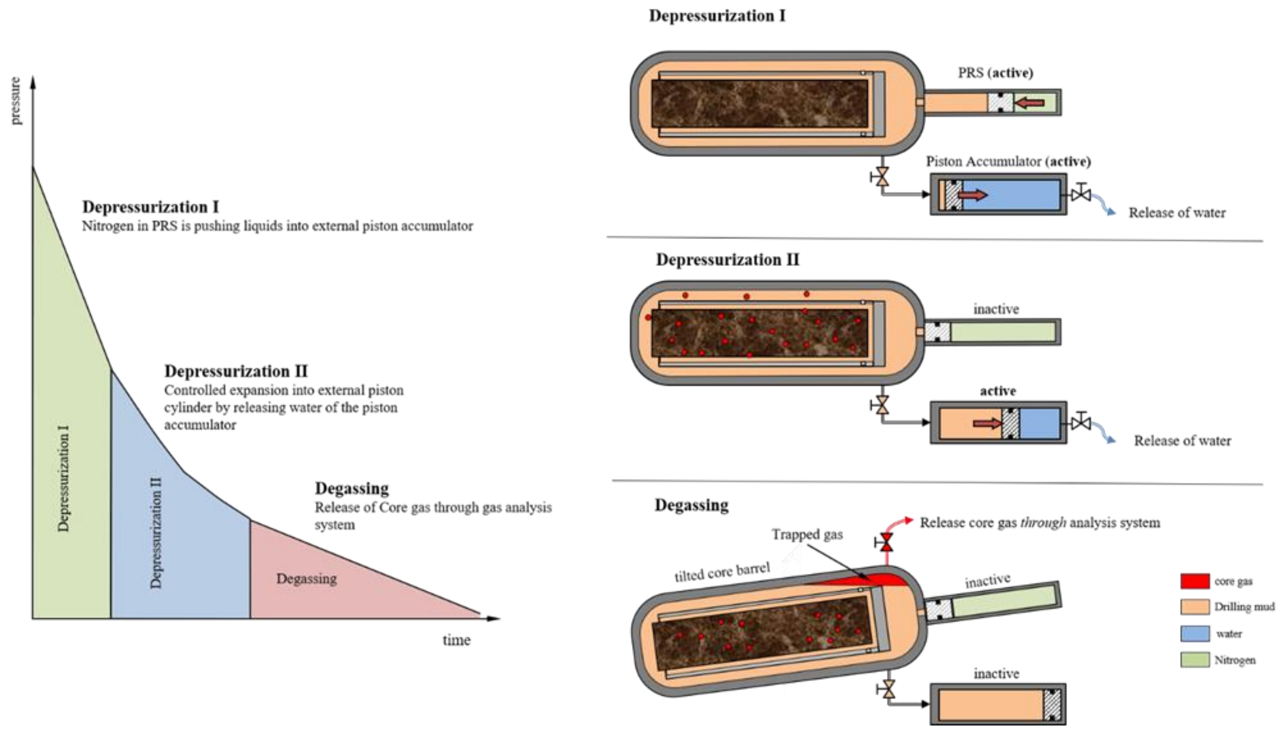

Fig. 6. De-pressuring and degassing sequence.

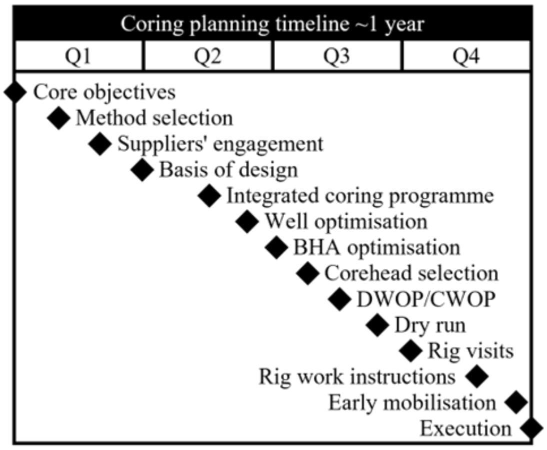

Fig. 7. Coring planning timeline and key steps. Many of the activities were progressed in parallel. See text for details.

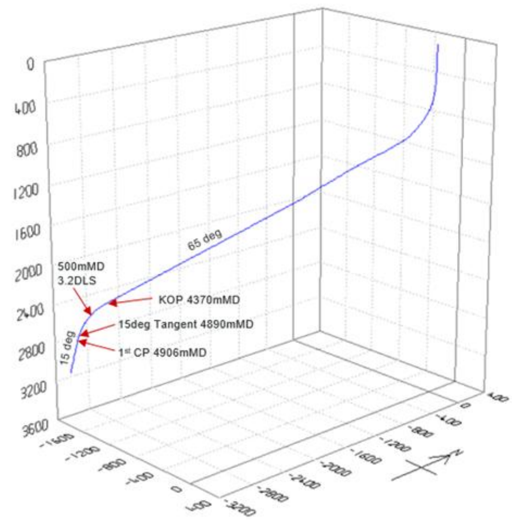

Fig. 8. Well A coring sidetrack trajectory.

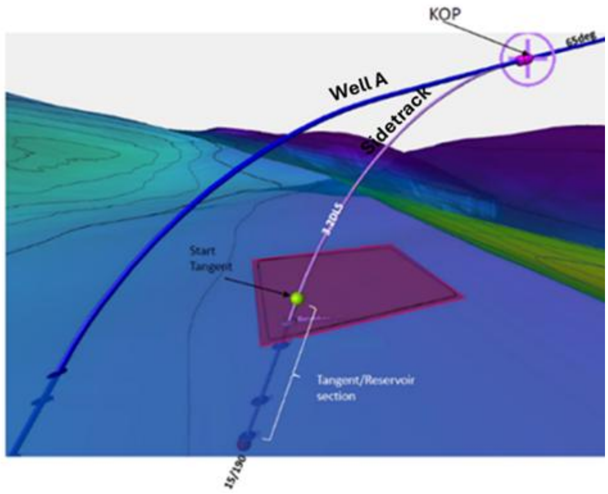

Fig. 9. Detailed view of main bore and coring sidetrack trajectory along with coring target box.

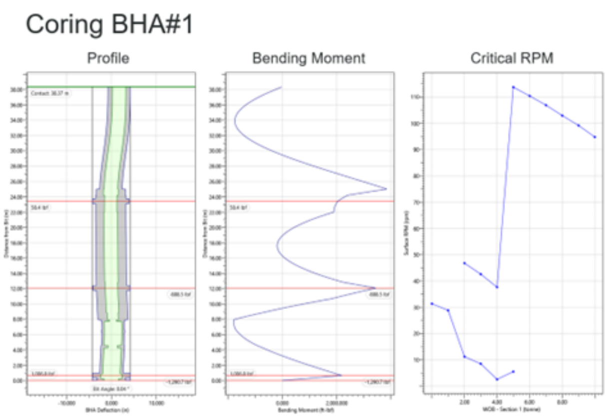

Fig. 10. Non-optimised BHA#1 with a maximum bending moment at the core barrel of 2,940 N-m / 2,170 ft-lbf and a poor operating window in terms of critical RPM.

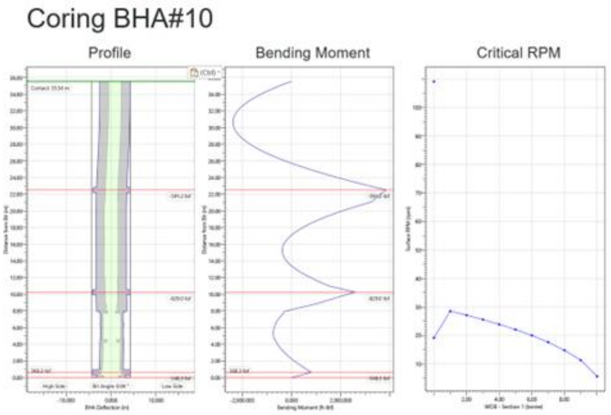

Fig. 11. Optimised BHA#10. Bending moment at core barrel has been reduced by a ratio of 3, while a large operating window in terms of critical speed has been achieved.

Table 1. Comparison of selected BHA configurations.

Options	Maximum Bending Moment [ft-lbf]	Maximum Surface Torque [ft-lbf]	Weight Below Jar [T]	RPM range	Remarks
BHA #01	2,170	34,500	25	bad	First String Stab too high in BHA
BHA #04	681	31,765	13	good	Recommended BHA - option 1
BHA #06	550	32,084	14	good	Extra Stab in BHA with limited gain, Contact point too close to 10 1/4" hole for first run
BHA #08	1,506	33,423	18	bad	2nd String Stab too high in BHA
BHA #10	736	31,728	13	good	Recommended BHA - option 2
Selected BHA #10: LPC / XO / Stab / Float Sub / 1x DC / Stab / 1x DC / CircSub / Severing Sub / Float Sub / XO / 18 x HWDP / Jar / 5xHWDP / Accelerator / 1 x HWDP / XO / 105 x 4"DPS / XO / 5"DPS					

4 Campaign execution

The offshore campaign was executed safely and efficiently, and all six planned coring runs were completed (Table 3).

The recovered material comprised three mudstones and three sandstones, with every run returning a full-length, intact core. Four runs retained full pressure to surface, including all three mudstones and one sandstone. Two sandstone runs experienced LPC seal issues during retrieval, resulting in one partially pressurised core and one unpressurised core at surface. These events were recorded as operational deviations and addressed in the subsequent sample-quality validation. Overall, campaign performance reflected extensive pre-job planning, strong multidisciplinary integration, disciplined offshore execution, and controlled use of management of change as the operation progressed.

Safety and COW – Pressure coring required 24-hour cover over a campaign lasting more than 30 days from set-up to rig-down. The team was sized for shift work, core personnel were trained as Performing Authorities, and permit-to-work documentation was prepared early to maintain producing-platform control-of-work standards.

Set up on deck – De-pressuring, fluid sampling, and analysis required a dedicated safe area and workshop in addition to standard core processing facilities. Deck layouts were agreed during rig visits and the dry run so equipment could be spotted, connected, and tested on mobilisation (Figure 12).

Mud optimisation and tracing – The synthetic oil-based mud was conditioned to minimise spurt loss and invasion, and traced with D2O in the water phase and 1-BN in the oil phase. Return-line mud samples were collected to confirm tracer levels and support later correction for contamination.

Core barrel make-up – Four LPC barrels were supplied so prepared barrels were always available for back-to-back runs. Complete build and preparation on the pipe deck enabled fast turnaround compared with conventional long-barrel systems.

RIH – Tight-hole and stuck-pipe events occurred over the drilling sections as the campaign progressed, probably influenced by the underreamed hole, limited flow rates, and mud properties. These issues increased elapsed time but did not appear to affect coring outcomes.

Coring – The 3 m barrel length increased the need for good hole cleaning and depth control in the S-shaped well. The team tagged bottom while rotating and monitored drilling parameters closely to confirm a clean bottom and coring initiation. All runs were brief and smooth.

Pressure vessel activation and POOH – A drop ball was pumped to activate and seal the LPC before pulling out of hole. Although the expected pressure signature was not always distinct, the mechanical stroke functioned on all six runs. A key advantage of pressure coring is that the barrel can be pulled out of hole without depressurisation restrictions because the core is sealed and protected from decompression. POOH was occasionally tight and required gentle rotation on two runs but was otherwise smooth and efficient.

Table 2. Pressure coring performance summary.

Coring performance	Core 1	Core 2	Core 3	Core 4	Core 5	Core 6	Total
Dominant lithology	Mudstone & siltstone	Mudstone & siltstone, thin sands	Mudstone & siltstone, thin sands	Sandstone	Sandstone	Sandstone	-
From (mMD)	x883	x886	x906	x952	x955	x958	-
To (mMD)	x886	x889	x909	x955	x958	x960.8	-
Cut (m)	3	3	3	3	3	2.8	17.8
Recovered (m)	3.01	3.08	3.14	3.02	2.93	3.03	18.21
Recovery (%)	100%	103%	105%	101%	98%	108%	102%
Pressured	Yes	Yes	Yes	No	Yes	Partial	4/6
Pressure (psi)	4640 psi	4640 psi	4814 psi	N/A	4930 psi	N/A	-
# wellsite plugs	6	3	4	5	5	6	29
# preserved samples	12	12	13	12	12	12	73

Core laydown – On reaching surface, the integrated top valve was closed and the corehead replaced with a safety plug to create a secondary pressure barrier before moving the LPC away from the drill centre. The LPC was then transferred to the pipe-deck processing area using the TFM and crane.

Surface process – A complete surface process was executed on each core to capture all required data and samples. Processes, equipment, cores and fluids were photographed throughout to support diagnosis and learning.

Core gamma – A core gamma scan was run along the pressurised LPC immediately after laydown to test whether net sand could be identified before de-pressuring and core extraction. The team recognised the response would be affected by multiple, variable metal thicknesses between the core and detector, but early lithology insight could support operational decisions. On this campaign, the scans were not reliable enough for decision-making. Comparison of scans inside and outside the LPC improved lithology interpretation. With improved calibration, this approach may be useful on future operations.

De-pressuring and degassing – The LPC was rigged with tethers to secure components, then fitted with the heating jacket and process connections to start de-pressuring, extraction, sampling and fluid analysis as described in Section 2.1.2. Excess gas was captured in a large-volume gas bag and disposed of in accordance with platform safety procedures.

Core extraction and fluid collection – After de-pressuring and fluid capture were complete, the inner barrel core was extracted and moved to the conventional processing area. All liquids remaining in the LPC were captured and sealed during extraction and throughout subsequent handling. The P/T recorder at the top of the barrel was recovered and removed for immediate data read-out.

Core marking, gamma scanning and cutting – The core top and bottom were inspected and the inner barrel depth-marked before repeating the gamma scan. The scan through the thin-walled inner barrel was much clearer than through the LPC and was diagnostic of lithology. The core and inner barrel were cut into 25 cm lengths (Figure 13) using a low-speed band saw to avoid sparks, vibration and heat damage. Depth-marked photos of cut faces were taken. These photos, the core gamma scan, plug end trims (see below) and selected core-face chip samples were used for stratigraphic navigation and correlation.

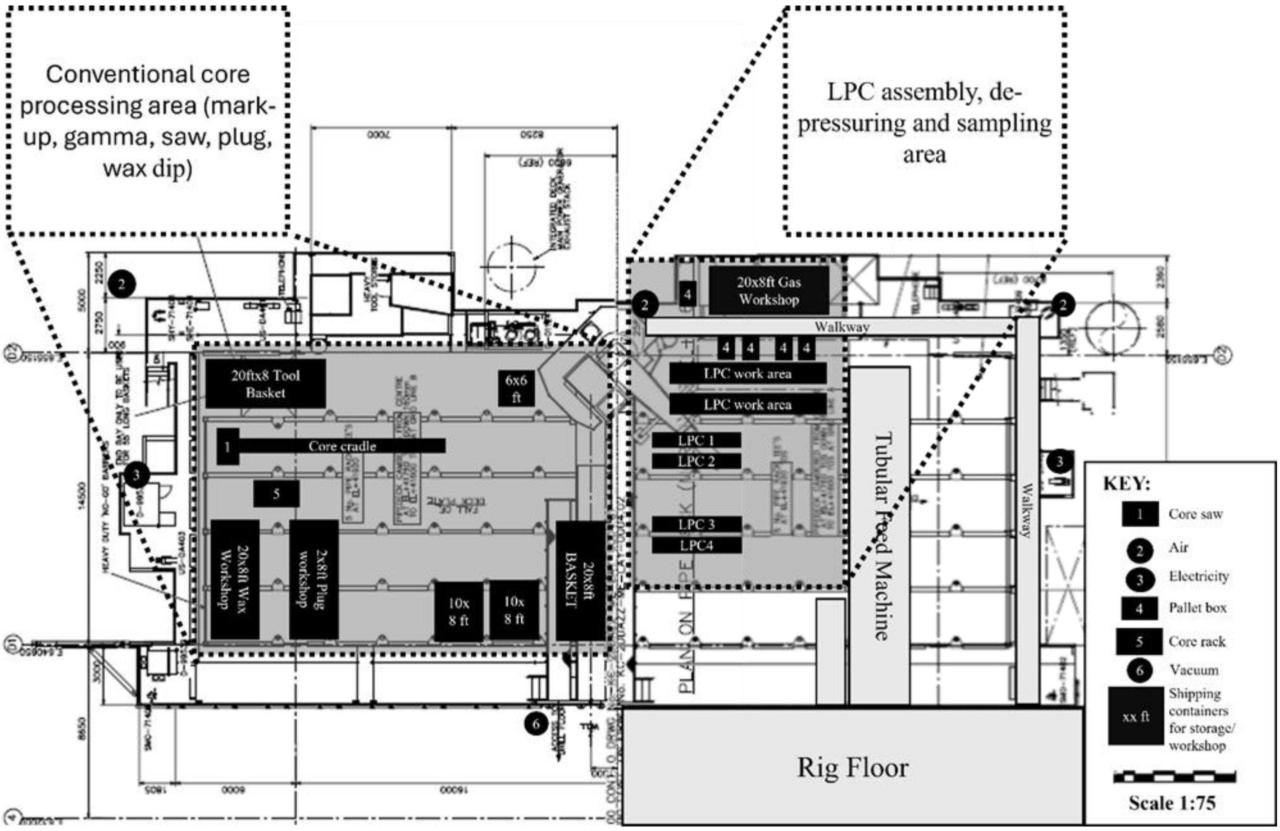

Fig. 12. Pressure coring and conventional core processing areas on the main pipe deck of the PDQ platform.

Core plugging – Plugs were taken across the core diameter at selected depths. Plugs were 1.5” diameter and cut using low-pressure nitrogen to minimise fluid displacement or alteration. Each plug was sawn into an inner, two outers and two end trims. End trims, together with selected core-face chip samples, were used for full lithologic description; inners and outers were sealed and packaged to preserve structure and fluid content.

Core wax dip – Each 25 cm sample was wrapped in plastic film and aluminium foil, then sealed by dipping in Coreseal™ wax.

The following validation step assessed whether the recovered pressure-core samples and associated fluid data were sufficiently representative for the study purpose, including the runs that did not retain full pressure to surface.

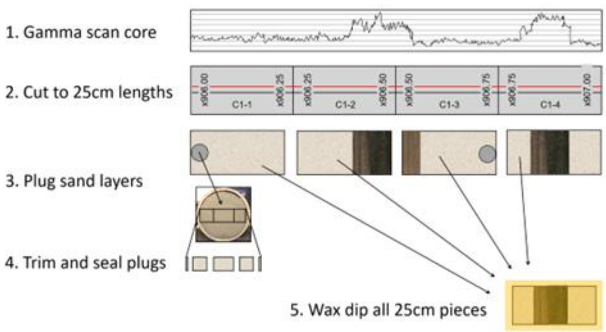

Fig. 13. Notional wellsite gamma scan, cutting, plugging and preservation process. Note: Any data in this figure are for illustration only.

5 Validation of sample quality and deployment outcome

The objective of the validation programme was to determine whether the recovered pressure-core samples and associated fluid measurements were sufficiently representative to support remaining-oil quantification and log calibration. Validation therefore focused on whether contamination could be quantified and corrected, whether oil-saturation measurements were consistent with independent log-based interpretation, and whether the runs that did not retain full pressure to surface still provided usable data. The samples comprised six whole cores preserved as 25 cm waxed sections, wax-preserved wellsite plugs, coring mud samples from the mud system return line, mud recovered from the LPC annulus, and wellsite-collected liberated gas samples.

All fluids and residues recovered from the core and inner-barrel sections were collected, sealed and shipped to the laboratory with the preserved core.

Validation measurements and sample use – Total liberated gas volume was measured for gas-oil-ratio (GOR) calculations and gas samples were analysed for C1–C5 composition for reference. The three LPC sandstone reservoir cores and associated samples underwent an integrated core-and-fluids programme (Figure 14) to determine remaining oil saturation directly (remaining core oil, corrected for mud filtrate invasion using tracers) and indirectly by providing Archie inputs (formation-water resistivity and Archie m and n exponents) for interpretation of deep resistivity while drilling. The three non-reservoir mudstone cores were reserved for non-saturation reservoir studies.

Core saturation measurements – The preserved 25 cm whole-core samples were Dean–Stark extracted, cleaned and dried to determine oil and water saturations. Water saturation values were considered non-representative of in-situ conditions because the water phase remained mobile and was susceptible to flushing during coring; they were therefore excluded from further evaluation. Oil saturation values were considered representative of in-situ immobile remaining oil saturation and were corrected for mud-filtrate contamination using 1-BN oil-phase tracer concentrations measured in both extracted core fluids and return-line mud samples collected during coring. Oil saturations were then corrected for shrinkage using formation volume factor, derived by combining offset PVT data with the gas-oil ratio estimated from liberated gas volumes and laboratory-measured ambient oil volumes after correction for mud-oil contamination.

Mud contamination considerations – Potential movement of core oil into the LPC annular mud volume between in-situ cutting and surface preservation was evaluated explicitly. Mud samples from both the return flow line during coring and the LPC annulus after recovery were analysed for 1-BN concentrations. If crude oil had leaked from the core into the annulus, the annular mud would have shown significantly lower tracer concentration than the return-line mud. The observed average difference was only 0.7%, which is below the analytical uncertainty of the method (1%). Any oil movement from core to annulus was therefore estimated at less than one saturation unit and judged insignificant.

Seal-failure implications for saturation uncertainty – The two sandstone runs that did not retain full pressure to surface were evaluated separately because depressurisation during retrieval could, in principle, bias measured saturation. No material adverse effect was identified within the resolution of the available validation methods. Measured oil saturations from these runs remained consistent with log-derived saturation estimates and with regional rock-property versus residual-oil-saturation trends established from laboratory core-flood experiments. These observations indicate that any saturation bias introduced by pressure loss was limited for the study purpose, although uncertainty for these runs remains higher than for the fully pressurised sandstone core.

Whole-core saturation results supporting sample representativeness – Whole-core oil saturation values were determined for each 25 cm sample and plotted against depth separately for each 3 m LPC core recovered from sandstone intervals. Within each core, the individual measurements were reasonably consistent and fluctuated around a mean value, although the average saturation differed between the three sandstone pressure cores.

Log-derived saturation results used for validation – Wellsite plugs were divided into two groups for measurement of formation-water salinity and Archie m and n exponents. These results were combined with deep resistivity data recorded while drilling to derive log-based water-saturation profiles across the cored intervals. Log-based remaining oil saturation was then calculated as $1 - S_w$ and compared with the core-analysis results.

Agreement between whole-core and log-derived saturation estimates – Comparison showed good agreement between the log- and core-based saturation evaluations within each core. Differences in remaining oil saturation between the pressure cores were attributed to variations in rock properties and waterflood sweep behaviour. Saturations derived from wellsite plugs showed some scatter but remained broadly consistent with the whole-core saturations from the same intervals (Figure 15). The pressure-core measurements reported here are direct determinations of remaining-oil saturation at core scale and therefore apply strictly to the sampled depths and lithologies. Their broader value lies in demonstrating that saturation data sufficiently representative for the study purpose can be preserved and in providing calibration points for log-based saturation interpretation. For cores that did not retain full pressure to surface, representativeness was assessed indirectly through contamination checks and comparison with log-derived saturation and regional residual-oil-saturation trends; these cores were retained in the interpretation, but with correspondingly lower confidence than the fully pressurised core. Reservoir-scale HRIP estimates remain dependent on the extent to which these calibrated log responses, together with geological and dynamic reservoir understanding, can be extrapolated beyond the cored intervals.

6 Lessons learned

This first offshore deployment of large-diameter pressurised coring demonstrated that samples suitable for saturation evaluation can be acquired safely and effectively in a complex mature-field offshore setting. All six runs recovered full-length core. In the three sandstone reservoir cores, oil saturation results were judged sufficiently representative for the study purpose, including—with lower confidence—the two runs where downhole seal integrity was lost, based on subsequent contamination checks and consistency with independent validation data.

Wellsite de-pressuring, fluid sampling and onsite gas analysis also provided actionable early insight for depletion planning and investment screening. A simple wellsite estimate of remaining oil saturation, combining evolved-gas volumes with GOR and porosity from adjacent wells, matched the subsequent laboratory results to within about three saturation units for fully pressurised cores.

Several operational and technical lessons were captured for future deployments:

• **Plan early and in detail** – Offshore PDQ pressurised coring is inherently complex and requires strong cross-team integration, dedicated wellsite supervision, and sustained focus on safety and risk management.

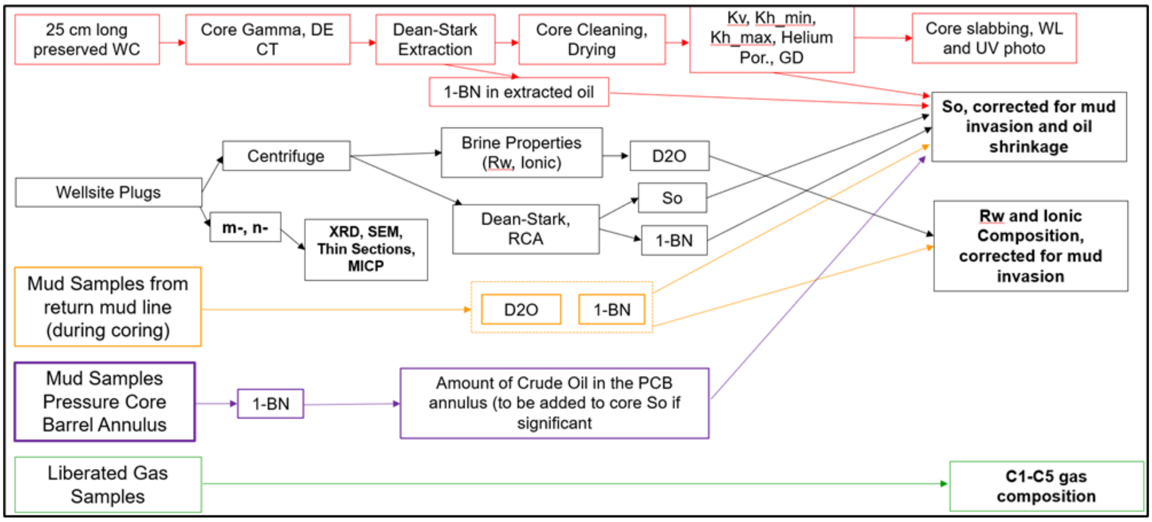

Fig. 14. Pressure core analysis study workflow.

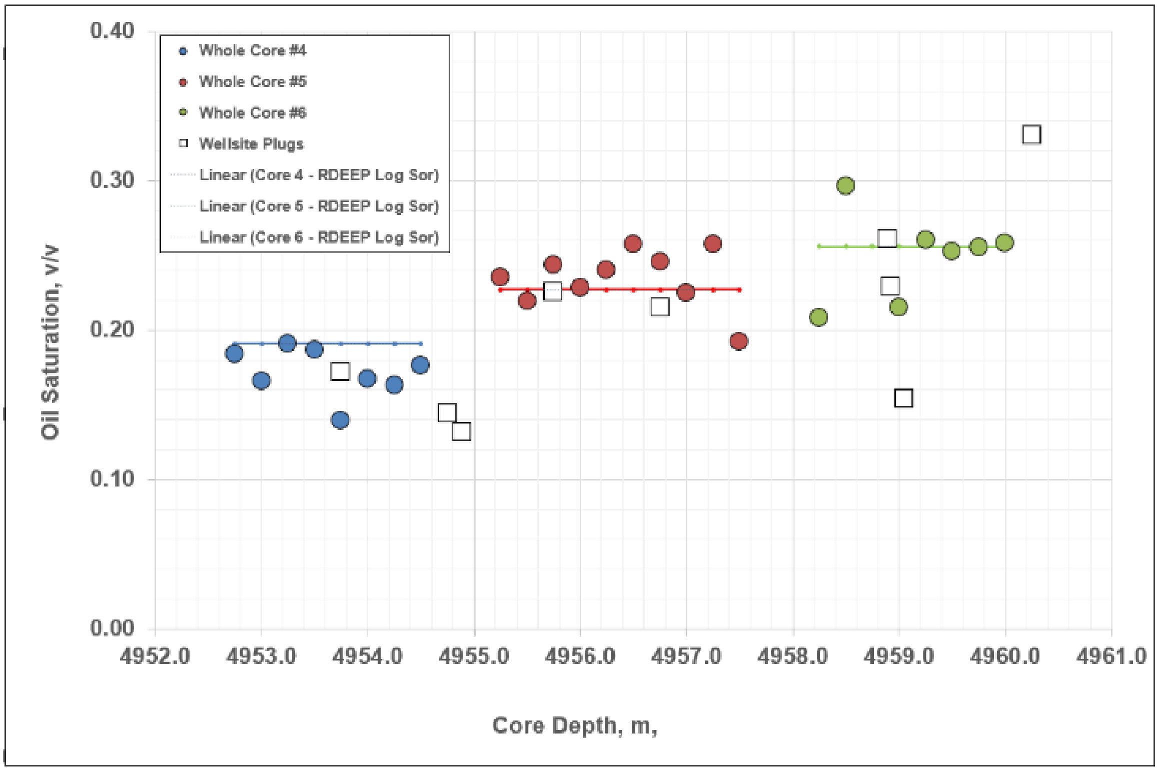

Fig. 15. Summary of the core analysis results.

• **Address seal reliability** – Two runs experienced downhole pressure-seal failures, one partial and one complete. Although the root cause was not conclusively proven, the evidence indicates hydraulic disturbance of an elastomeric seal during LPC activation. The seal design has since been modified to prevent displacement and leakage.

• **Improve core-catcher robustness** – One run experienced a primary core-catcher failure, but the secondary catcher activated as designed and enabled full core recovery. Investigation suggests that initial contact with fill at hole bottom displaced and deformed the primary catcher. The catcher and pilot shoe have since been redesigned to prevent this mechanism.

• **Reduce geological uncertainty at core point** – Three of the six recovered cores were predominantly mudstone rather than target sandstone. Higher-than-expected stratigraphic complexity, difficult core-point selection, and the short 3 m barrel length all contributed. Pilot-hole and/or sidetrack coring should be considered to improve target confidence in similar campaigns.

• **Strengthen depth-control practices** – Accurate depth control was difficult in the complex 3D S-shaped well because of drag, rotation-related string-length effects, and occasional fill. Close driller–coring engineer communication, low-speed tagging, and real-time trend tracking were effective mitigations; simpler well geometry and, where feasible, a longer pressure-core barrel would help future campaigns.

• **Mitigate hole-cleaning and stability risk** – Tight-hole, pack-off, and stalling occurred while tripping with the core barrel, with likely contributors including the long high-angle step-out, the underreamed section, and limited BHA flow rates. A cycling circulating sub and higher permissible BHA flow rates should be considered to improve hole cleaning and reduce trip risk.

• **Link deployment design directly to HRIP uncertainty reduction** – Pressure coring is most valuable when the acquisition, de-pressuring, fluid sampling, mud-tracing, and laboratory programme are designed as one integrated measurement system. In mature waterflooded reservoirs, the core-scale saturation result is not a standalone HRIP estimate; its value comes from preserving representative remaining-oil measurements, quantifying contamination and pressure-loss uncertainty, and providing defensible calibration points for log-based saturation interpretation and reservoir-scale HRIP assessment.

7 Conclusions: reservoir insights, impact and implications

This study demonstrates that large-diameter pressurised coring can be deployed safely and effectively offshore in a complex mature-field sidetrack and can deliver samples sufficiently representative to quantify remaining oil saturation at core scale. An additional impact was to provide direct calibration points for log-based saturation interpretation in swept intervals, improving confidence in remaining-hydrocarbon assessment where conventional methods were expected to be less reliable. Although the resulting measurements are not standalone reservoir-scale HRIP estimates, they materially strengthen the understanding of waterflood performance and underpin depletion planning and EOR screening when integrated with geological, petrophysical, and dynamic reservoir understanding. More broadly, the work indicates that pressurised coring is a practical measurement solution for mature waterflooded reservoirs in which preservation of in-situ fluids is critical.

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References

[1] T.W. Teklu, J.S. Brown, H. Kazemi, R.M. Graves, A.M. Al-Sumaiti, A Critical Literature Review of Laboratory and Field Scale Determination of Residual Oil Saturation, SPE 164483 (2013).

[2] D. Saucier and K. Sincock, 2023. An operator view on trends in core acquisition. Geological Society, London, Special Publications, **527**, 17-42.

[3] J. Ekpe, A.Y. Al-Shehab, A. Al-Othman, S. Baijal, K.L. Nguyen, R. Al-Morakhi, M. Dasma, N. Al-Mutairi, N. Verma, R.B. Quttainah, M. Janem, T. Deutrich, D. Wunsch, T. Rothenwänder, E. Anders, P. Mukherjee. New Methods for Cutting Pressure Retained Cores from Deep Unconventional Reservoirs in West Kuwait – First Ever Successful Pressure Coring Operation in the Najmah Kerogen. SPE-214638-MS (2023).

[4] P. Mukherjee, J. Peres, L. Hayat, E. Anders, M. Al-Rashaid, D. Wunsch, T. Rothenwänder, J. Al-Kandari. First-Ever Large Diameter Fully Captured & Retained Pressurised Core and In-situ Analysis with Slow Depressurisation – Pilot Case on Giant Burgan Reservoir, Kuwait. SPE-193021-MS (2018).

[5] K.L. Nguyen, R. Al-Morakhi, M. Dasma, M.F. Shehab El Dein, N. Al-Mutairi, N. Verma, R. Quttainah, J. Ashby, C. Verret, C. Rilling, J. Ramoin, J. Antia, D. Wunsch, T. Rothenwänder, E. Anders, T. Deutrich, P. Mukherjee, M. Janem. Precise Determination of Reservoir Fluids in Jurassic Kerogen from Pressurised Cores: Challenges to Success. URTeC 3853382 (2023).

[6] D. Wunsch, T. Rothenwänder, E. Anders, T. Deutrich, D. Brown, J. Ramoin, C. Verret, P. Mukherjee. Re-inventing pressure retained core acquisition for advanced reservoir property determination. SPE-216724-MS (2023).

[7] D. Wunsch, T. Rothenwänder, E. Anders, T. Deutrich. Pressure retained coring technology in comprehensive data acquisition campaigns – Recent advancements and potential fields or applications. DGMK/ÖGEW spring conference, Papenburg, Germany (2025)