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Full-Cycle Iterative Processing: When is “Good”, Good Enough? A 4D North Sea Case Study

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Summary

In this presentation we examine the benefits of full-cycle iterative processing and its impact on both quality and turnaround using a North Sea 4D case study. We show that by providing interpretation ready volumes from an early stage of processing, and at various stages during subsequent processing, we reduce risk and improve quality in a cost neutral approach. We also show that these early deliverables can potentially be used to make business decisions ahead of the delivery of final products from processing.

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In this presentation we examine the benefits of full-cycle iterative processing and its impact on both quality and turnaround using a North Sea 4D case study. We show that by providing interpretation ready volumes from an early stage of processing, and at various stages during subsequent processing, we reduce risk and improve quality in a cost neutral approach. We also show that these early deliverables can potentially be used to make business decisions ahead of the delivery of final products from processing.

Introduction

In this paper we present a case study of the use of a "full-cycle iterative" approach to management of processing projects, referred to here as evolutionary iterative processing. Traditionally processing projects are run sequentially, occasionally with a fast track workflow executed in parallel to obtain deliverables early and help steer the course of the main track processing. In the approach, we take the idea further and produce end-products (i.e. stacks or amplitude-versus-offset (AVO) products allowing the generation of key attribute maps) at each processing step within the main track processing. This allows us to make more informed decisions, revise the processing flow and move onto the next steps. The early versions of the end-products are referred to as "EVO" products henceforth. This approach requires some initial parameterisation for the subsequent processing steps as well as an initial serviceable velocity model for imaging, if an EVO product is required prior to velocity model building. This kind of iterative approach to product delivery, often referred to as the Minimum Viable Product concept, is well established in other fields such as software development where so-called Agile working practices are employed (Sutherland & Sutherland, 2014).

We identify three main areas of value derived from this approach: (i) more effective quality control (QC), (ii) reduced project cycle time, and (iii) early delivery of data to clients. The approach permits the processing team to determine the effect on the end-products of any processing step, allowing them to avoid costly errors where a given processing step might adversely affect the end-product in a way not immediately obvious from the QC of intermediate products (e.g. pre-migration gathers). Processors are also able to determine which processing steps have little impact on the end-products, and so redirect resources to the testing of other more important parameters. Multiple alternative processing flows may be tested in parallel to aid decisions about which tools to run in production. Whilst this is more computer and human resource intensive, this more effective QC may also help to reduce overall project cycle time. Furthermore, the approach delivers early versions of the end-products to the customer geoscience teams who could use them for earlier decision making and feedback early findings to the processing team. It might even be possible to stop a project and use the current EVO product as the "final" end-product if appropriate. We will discuss such early delivery of end-products as well as describing the benefits to QC of this approach in relation to the case study.

Case study area

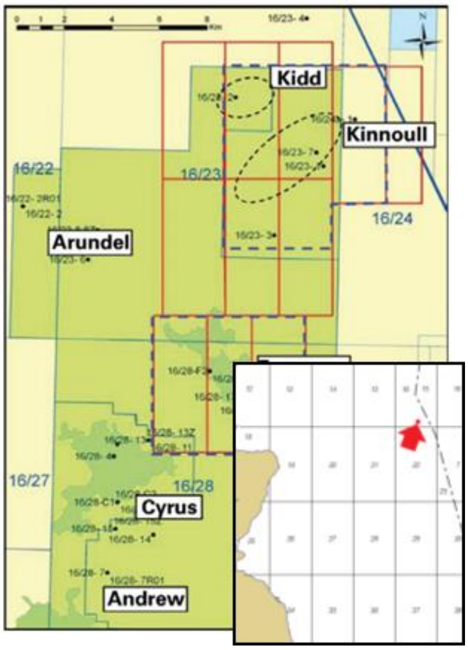

Figure 1 A location map for the Kinnoull field.

The case study we present is a 4D processing on the Kinnoull oil field, which is located 100km east of Aberdeen in the central North Sea (Figure 1). It comprises Palaeocene aged turbidites and has been producing since 2015 from three producers. Figure 2 shows a full-stack section through the reservoir. An OBC survey was acquired over this field in 2009 by RXT (Padmos et al., 2010). It provided excellent stack and AVO products (Figure 2). These permitted both delineation of the sand fairway, using a gradient volume, as well as mapping of fluid contacts using a fluid volume. Gradient and fluid extractions over the field are shown in Figure 3. Note how the gradient defines the sand fairway and the fluid the oil water contact within it.

By early 2017, with the recent shut-in of one of the producers on the field and PLT data acquisition, it was determined that oil sweep on the field was not fully understood and could be heterogeneous. Thus, it was decided that a 4D monitor survey would be acquired. This would provide cost effective full-field surveillance and help to inform further development, possibly including well work and infill drilling. An OBN monitor survey was shot during late 2017. Prior to acquisition of the monitor survey, a modelling project was carried out. Due to strong aquifer support, negligible pressure (and hence AVO gradient) response was anticipated in the field, but changes in fluid saturation were expected to have a strong influence on the full stack response (which is close to the optimal extended elastic impedance (EEI) χ angle for fluid discrimination).

The baseline survey was acquired in 2009 using 4-component ocean bottom cables with 375m cable separation and 25m receiver inline separation, with a 50x50m shot grid. The same source and receiver geometry were repeated for the 2017 monitor, which used 4-component nodes-on-a-rope system. The source in both surveys was towed at 6m and the source array for the monitor was designed to match that of the baseline. Repeatability of the monitor survey was very good: 98.6% of nodes and 99.6% of shots were located within 10m of their intended position. Both surveys were acquired in a north-south orientation.

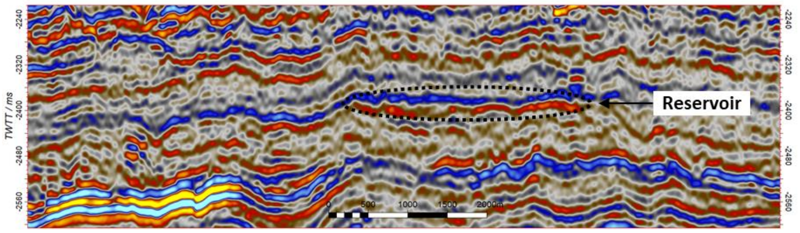

Figure 2 *Full stack section through the Kinnoull field, with reservoir annotated.*

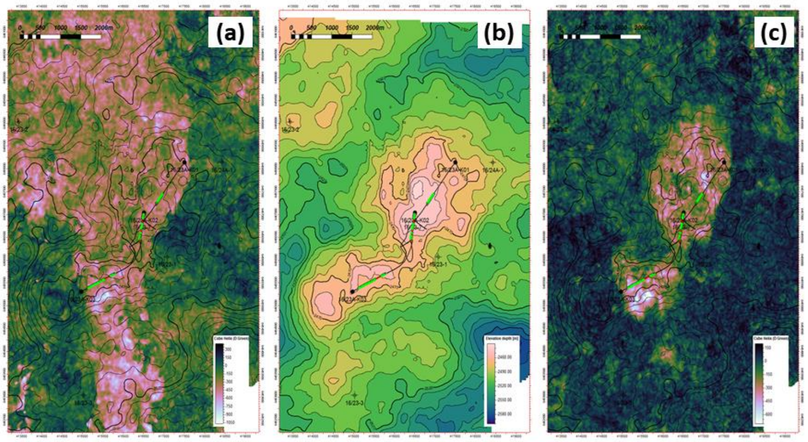

Figure 3 *(a) Colour inversion extended elastic impedance (EEI) gradient volume showing sand fairway. (b) Top reservoir structure map. (c) Colour inversion EEI fluid volume showing conformance of oil water contact to the sand fairway.*

Processing

The production processing flow and a timeline of testing of the different processes, showing the points at which EVO products were delivered, are shown in Figure 4. The flow and timeline are considerably simplified for clarity. The EVO products comprised monitor, baseline and difference stacks only. They were generated using all the processing steps up to pre-stack depth migration, with parameters tested to different degrees of maturity depending upon the point at which they were generated, as indicated in Figure 4. EVOs 1-7 were migrated using RTM-to-stack with smile trace rejection, but with no further post-processing applied. EVO 8 was migrated using a depth TTI Kirchhoff algorithm with no further post-processing applied. A TTI velocity model had been built in the original 3D processing of the OBC data, and this model was used to migrate EVOs 1-4. A new velocity model was built using this as an initial model, which was used to migrate EVOs 5-8. The evolution of 4D difference maps over the reservoir interval derived from the full-stack EVO products (monitor-baseline) throughout the project is shown in Figure 5. This difference shows clearly the hardening response associated with advance of the waterflood.

Figure 5 demonstrates that the quality of the end products systematically improved throughout processing in terms of coherent and incoherent noise content on the 4D differences. The largest improvements were seen early in the flow, between EVO 1 and 2, and between EVO 3 and 4. In the former case improvement to the PZ summation greatly reduced non-repeatable 4D noise. In the latter case, the optimised removal of the water layer multiple (using ‘model-based water-layer demultiple’ (MWD) and de-peg methods) significantly reduced non-repeatable multiple energy.

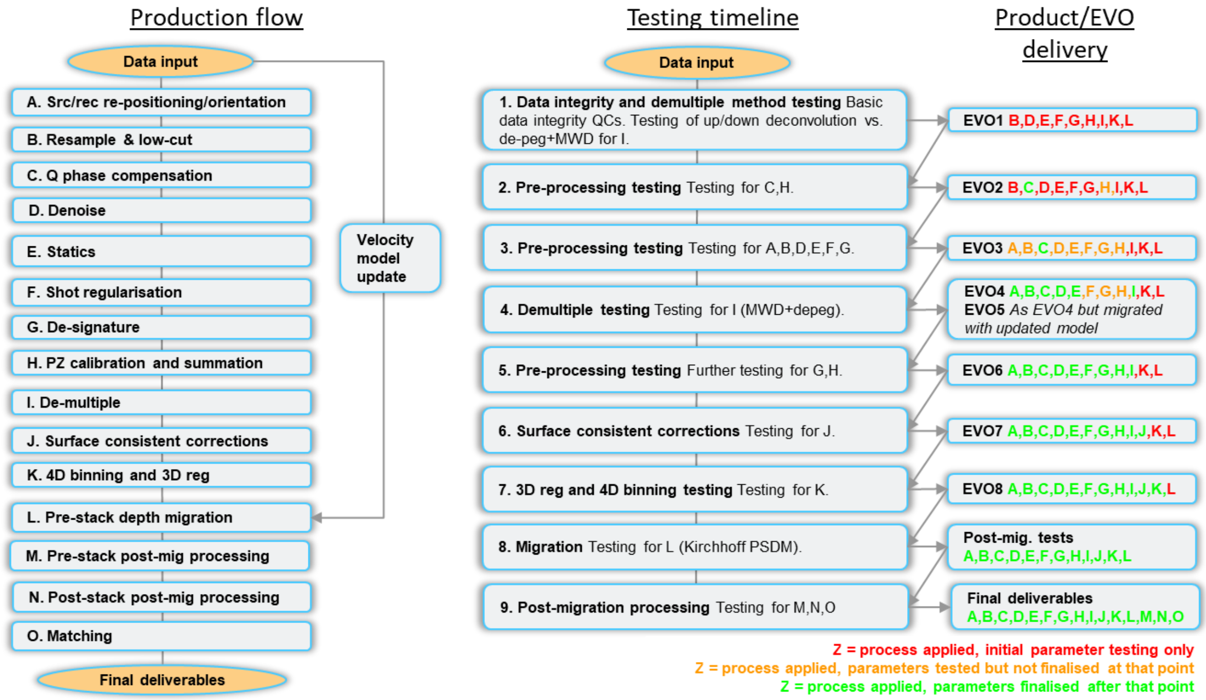

Figure 4 *(Left)The production processing flow. (Right) Timeline of testing applied showing where EVO products, post-migration tests and final deliverables were delivered.*

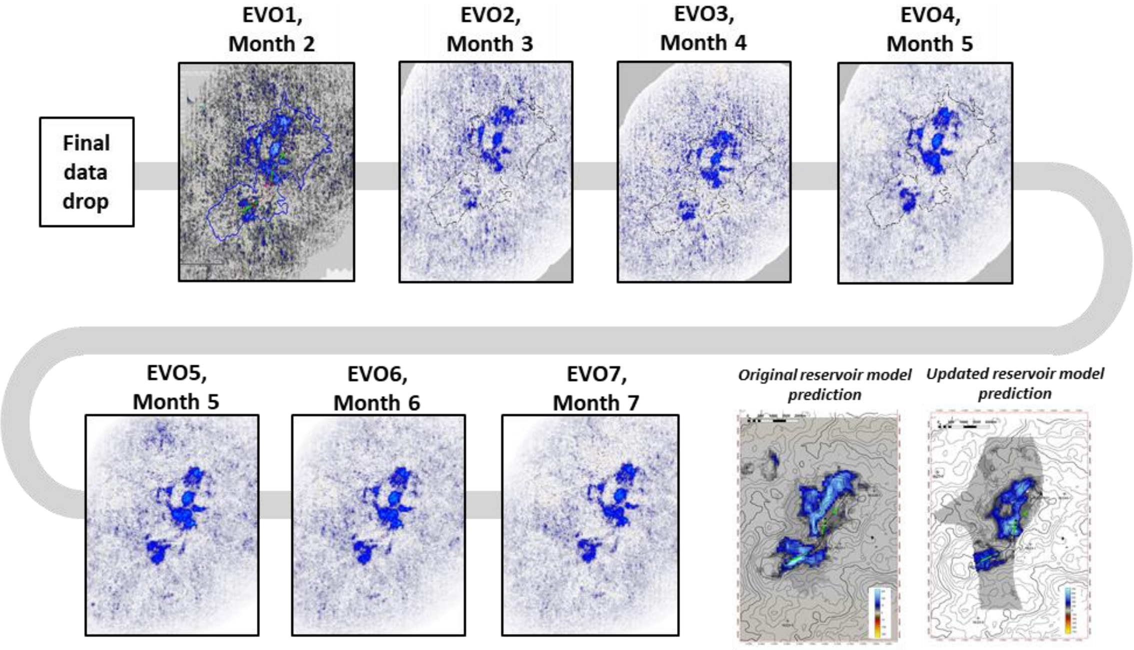

Figure 5 *Maps of sum of positive amplitudes extracted over the reservoir interval from the 4D difference volume calculated using the EVO full stack products. Note EVO 8 and final stack differences are not shown. Equivalent predictions made using the reservoir model prior to and after being updated using the 4D data as constraint, are shown for comparison.*

Figure 5 shows that sometimes refinement of parameterisations of processing steps had an adverse effect on end products. For example, between EVO 2 and 3, some “new” 4D noise is introduced. This was caused principally by a different shot regularisation parameterisation which had a less efficient denoise effect. This was then addressed in EVO 4 where the demultiple was optimised (addition of de-peg which had a stronger demultiple effect) alongside a milder denoise flow. The approach allowed processors to identify the processes which had the most impact on the end products and focus testing on these steps. For example, we can see in Figure 4 that the PZ calibration parameterisation was not finalised until EVO 6 as it was found to have a strong influence on the EVO products, whereas the Q phase compensation was rapidly tested, validated and confirmed by EVO 2. The EVO products were also useful for making decisions about which processing tools to use. For instance, the EVO 1 product was generated twice, first using the MWD plus de-peg demultiple flow and up-down deconvolution for demultiple. Although the up-down deconvolution showed some very promising results, it also amplified noise in the baseline vintage which was not easily removed. Thus, the more conventional MWD and de-peg demultiple flow was chosen for production. These examples demonstrate the QC power of the full-cycle iterative approach.

Looking at the 4D difference maps in Figure 5 (as well as the 3D full stacks used to generate these), it is arguable that we could have stopped processing early after the production of one of the EVOs since the end products do not seem to improve significantly after, for instance, EVO 4. The primary aim of processing in this 4D case study was to identify the waterflood to an accuracy sufficient for well planning. Using this criterion, the asset team did indeed agree that even the EVO 4 products would have been fit for purpose. Although we did not stop the project early, the early deliverables were used to decide to not drill a planned well, and instead plan intervention work on existing wells.

Compared to other processing projects, this case study's aim is limited in scope. For example, development style seismic projects might include the production of AVO and anisotropy products as primary aims. In this case post-migration processing becomes very important. This project also had a limited spatial scope: we knew the exact area and depth interval for which we wanted to optimise processing. This is not the case in exploration-style projects. If the project scope is large it may be more difficult to satisfy all aims at an early stage of processing. Also, if the project's aims are not well defined (i.e. the products may be used for different, perhaps unknown, purposes in the future) then it may be preferable to not deliver end-products early, and instead optimise all processing steps fully. Having a good pre-existing velocity model (or being able to update the model early relative to other processing steps) also helps to facilitate early delivery. For example, in this case study EVO 4 was considered acceptable as a final product despite being imaged with the existing legacy velocity model. The issue is to understand what useful further improvements can be gained from the subsequent processing effort. For example, in this case subsequent processing undoubtedly resulted in further incremental uplift in the 4D products as well as delivering pre-stack depth migrated data suitable for AVO analyses (EVO 4 was only available as RTM stacks). Herein lies the question: when is "good" good enough?

Conclusions

This case study demonstrated that a "full-cycle iterative" workflow is useful for QC and helps the asset team and processors to identify possible processing issues early. It also demonstrated that early deliverables from this type of workflow can be used to make highly valuable business decisions, which in this case was the decision to not drill a planned well. It is also possible that this framework could allow us to identify a point at which the project could be stopped early with products delivered which are fit for purpose. Such decisions would be more difficult for projects with larger scope or with less well-defined aims than in the study presented.

Acknowledgements

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