**Exploration Revival from Multi-Vintage Diverse Source Dataset**

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**Introduction**

It is now commonly accepted that the only way to unlock new hydrocarbon provinces is by investing in modern methods of seismic acquisition and processing. However, new data is not always available and in some areas may be prohibitively difficult to acquire. Fortunately the legacy of seismic acquisition over the last 50 years provides a resource base we can re-examine. Data that is often forgotten and overlooked can be re-processed using modern techniques to provide new insight into frontier geology.

The Bay of Biscay, offshore western France and Northern Spain, has been extensively covered by seismic from the late 1960’s to the early 2000’s. Oil and gas fields have been discovered and produced, but there has only been limited drilling in the basin, and all of that on the narrow shelf. Due to a lack of investment in new seismic data, the existing legacy dataset is a valuable resource that allows us to better understand this basin. However, it exists only as a set of individual datasets, each processed independently of the other with no thought of tying together. Unraveling the basin development has been hindered by these eclectic datasets. Our case study shows how, by re-processing of this dataset with modern seismic methods, and with the aim of outputting one contiguous dataset that matches in phase and time suitable for regional structural interpretation, the issue can be addressed.

**Geology and seismic acquisition overview**

The Bay of Biscay is dominated by the Pyrenean foreland basin, yet comprises a complex palimpsest of earlier rift basins including the Parentis and Aquitaine Basins to the east, and the Basque- Cantabrian Basin to the west. Source rocks are found from the Palaeozoic to Cretaceous, with the Kimmeridge and Barremian-Albian sequences being most prolific. Reservoirs are found from the Upper Jurassic to the Lower Cretaceous in both clastic and carbonate facies, and structures tested to date include extensional fault blocks, compressional folds/toe thrusts and salt diapir flanks.

Many thousands of kilometers of data have been acquired in the Bay of Biscay in many different surveys between 1968 and 2003, both commercial and academic, using several different seismic acquisition sources and recording systems (Figure 1). Over 12,000 km of these data, a subset of the total data available in the Bay of Biscay area, were selected for re-processing.

Re-processing of this legacy data proved challenging due to the poor quality of the support data supplied, and the large variety of seismic acquisition techniques used. A total of 15 different surveys were included in the project, acquired using 6 different source techniques, as detailed in Table 1 above. Each of these sources had specific methodology of analysis and preparation.

**Source technologies – short historical overview**

**Air gun** - The most commonly used marine source is the air gun. The source signature from an air gun array is nominally minimum phase. A far-field signature was extracted from the data by summing a series of near traces derived from an area of water bottom showing little geological influence.

**Watergun** - This produces a very high frequency mixed phase source signature. The far-field source signature was estimated from the recorded data in the same way as the air-gun far-field signature (Safar, 1984).

**Aquapulse** - While the source signature is nominally minimum phase, its timing can vary substantially. Consequently considerable effort is required to determine and correct any observed timing variations. Once again a far-field source signature was estimated from the recorded data.

**Vaporchoc** – A designature operator was computed by converting the mixed phase recorded near-field signature to its minimum phase equivalent with a Weiner filter, and applying this Weiner filter to each shot. This also accounted for timing variations for each shot.

**Maxipulse** - Bubble oscillations are recorded and used to compute a shot-to-shot minimum phase de- bubble filter.

![Figure 1: Map showing 2D lines re-processed in Bay of Biscay project, color coded by different source type and vintage.](image-url)

**Table 1: Acquisition parameters summary by vintage.**
In this way the data is converted to zero phase and timing variations are corrected (Wood 1978).

**Flexichoc** - This emits a very short pulse, rich in high frequencies, which allows for high resolution. As for the majority of the other source types, a far-field source signature was estimated from the recorded data.

**Pre-Stack Time Migration (PSTM) workflow**

An initial assessment of the data confirmed a wide variety in wavelet shape and phase, as expected, caused by the different sources. The pre-processing involved correctly identifying the source type and deriving a suitable zero phase designature filter for each (Figure 2 and 3). In some cases a suitable filter could not be derived, in which case a statistical zero-phasing would be performed post stack. Different source techniques presented a set of challenges in the imaging sequence based on their different frequency spectra and phase. The next challenge was to process each data type as similarly as possible but taking into account potential different responses to each step by reviewing frequency content at regular intervals.

At this stage we now have a set of pre-stack data of varying vintages and source types that have been matched to reference phase and amplitude level with phase being close to zero phase. This data was then processed through a standard, modern PSTM processing sequence, resulting in an improved data quality and final imaging of the Biscay region. Tailored suppression of coherent and random noise was performed in several stages of the workflow in various sorting domains. SRME as velocity independent de-multiple workflow is applied early in the sequence with minimal knowledge of the velocities. These lead to improved removal of predictable noise from the data and subsequently allow for improved velocity analysis and migration. Residual multiples were removed with tau-p deconvolution and radon. Diffraction and out-of-plane events are treated as noise and were suppressed in f-t domain with coherency amplitude threshold filtering. Automatic velocity analysis provides smooth, continuous velocity models that conform to geology. The subsequent residual NMO can improve the fine definition of faults and enhance horizon continuity. Key to the imaging was the emphasis on keeping the processing...
sequence for each vintage as similar as possible, in order to keep to a minimum any differences in the final data that may be attributable to the sequence. However, in some areas it was appropriate to apply different techniques; for instance, tau-p deconvolution methods were utilized in shallow water areas to remove persistent short period multiples, but this process is not effective in deep water.

Final phase matching
The final step in the processing flow was merging final velocity models and imaging stacks for all the datasets. A smooth 3D time domain RMS model that ties on all the lines can later be used as an initial model for future depth model building. For several vintages, zero phasing was difficult to achieve pre-stack so post stack phase matching was performed using a statistical method.

The most modern survey available was selected as the reference or base and, working across the area survey by survey, all other vintages were successively matched. Unmatched data was loaded into the interpretation software for additional mistie analysis. To achieve a level of statistical robustness, all intersections were examined and average values for matching vintages together were computed. Average phase and static shifts were computed and applied to each survey in turn. The result is a contiguous dataset consisting of multiple vintages that was not available previously in this frontier basin. (Figures 4 and 5).

Geological benefits of re-processing
The re-processed data has significantly enhanced the quality and interpretability of the data throughout the section, which in turn has identified many geological features with potential hydrocarbon interest. The result is better signal to noise ratio and clearly removed multiples. In the shallow shelf section this enables the distinction of structures and sedimentological features. Better imaging of continuous reflectors and structural geometries yields improved definition of faults and salt diapirism. Indeed both salt walls and salt rafts are imaged for the first time in this area. Deeper structures are better resolved giving more comprehensive understanding of the basin’s geological evolution and history as well as prospectivity of the area at source rock level (Figure 6).

Conclusions
Applying modern processing techniques to data acquired decades ago can produce stark improvements in imaging. However, these improvements require meticulous approach, and particular care in understanding the seismic source signal. Once this is correctly managed, a modern processing sequence which focusses on noise and multiple removal is particularly successful in enhancing the data, providing a consistent and coherent dataset for the basin for the first time. These techniques often remain the only method of obtaining enhanced data in areas now subject to strict environmental laws. In the Bay of Biscay, this has revealed new insights into the structures, plays and exciting hydrocarbon prospectivity of this basin. The reprocessed data is a tool for planning new acquisition and identifying new areas for exploration.

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References
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