Where's the Data? Acquisition and Processing of Seismic Data in the PNG Highlands*

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Introduction

Seismic exploration in the PNG Highlands (Figure 1) poses many challenges both in the acquisition and in the processing of the data. The seismic method is limited by both operational and technical constraints. These constraints push established seismic techniques to the very limit of their underlying principles.

Operationally, the remote location, rugose terrain, weather, and local stakeholder issues are some of the numerous factors that make operations both difficult and, at times, dangerous. Technical issues include the complex sub-surface structure, karstified limestone, velocity inversion, and extreme topography.

The operational issues and the geophysical effort needed to address the technical issues result in the cost of acquiring seismic data being very high, with seismic costing in excess of $250,000 per kilometre. This high acquisition cost makes 3D data uneconomic meaning that highly complex 3D structures have to be imaged on 2D data only.

The seismic data acquired in the PNG Highlands is amongst the most difficult in the world to process. A primary reason for this is that the signal-to-noise ratio of the acquired data is very poor making many established processing techniques difficult to implement. In order to process the data it has been necessary to rethink many conventional approaches and come up with unique and novel techniques.

Seismic data quality within the Highlands has always been an issue, and on a “non-fold-belt basis” the data would be considered of poor quality. The quality of the final processed data, although still poor when compared to other areas, has been continuously improved over many years.

Seismic Acquisition

As shown in Table 1, many different 2D production parameters have been used to acquire data in the Highlands. In the years through to the early 1990's recording equipment limitations imposed restrictions on the number of channels, fold, and maximum offset that could be recorded. In later years, as equipment improved, these limitations were largely addressed meaning that the data acquired was no longer restricted by the available technology.

Despite the advances in acquisition technology, the quality of the recorded data, although improved from earlier years, remains poor in comparison to other areas of the world. The main cause of this is the karst limestone that covers much of the highlands and, in some places, is a more than a kilometre thick. This karstified layer, combined with the extreme terrain, both attenuates and scatters the seismic energy at both the shot and receiver ends of the travel path resulting in data that is extremely noisy with a very low signal to noise ratio. A typical shot record (Figure 2) is dominated by noise with little visual reflection energy apparent.

Many experimental surveys have been performed since the late eighties using different parameters, techniques, and hardware to see what can be done to acquire data that gives a better image of the subsurface. Examples of what has been tested include:

i. Different source depths, intervals, charge sizes, and hole patterns
ii. Different receiver intervals, arrays, and depths
iii. Single geophones cemented into place
iv. Swath line shooting
v. Crooked line acquisition on the top of limestone ridges
vi. Extremely long offset data subsequently processed using specialised algorithms
vii. Passive seismic surveys
viii. 3C data using MEM's sensors
ix. Cable free node based recording

Other techniques, such as 3D surveys or cross-spread arrays, that may be expected to give an improved subsurface image, are so costly using currently technology that they cannot be economically justified even for experimental purposes.

Results from these tests have shown that there is, as yet, no "magic bullet" that gives a big lift in data quality. However, by incorporating the results from the tests, the recorded data quality has been improved in small incremental steps. An example of these improvements on the final subsurface image is shown in Figure 3 that compares data before any improvements, to data after all the incremental improvements.

Seismic Data Processing

Processing is an area where significant improvements in data quality have been able to be realised. Using an integrated methodology that uses all the available data such as surface attributes (lithology, dip and azimuth, fault locations), well attributes (dips, azimuths, etc.) and strontium dating for base limestone prediction the Processing geophysicist, working iteratively with the Interpreter and Structural Geologist, has been able to produce data that is much improved from that which was previously possible. In addition, advances in processing algorithms have recently made possible increased use of pre-stack imaging techniques that were previously not successful due to the low signal to noise ratio of the data.

A typical post-stack imaging processing sequence used over many years on highlands data is shown in Figure 4. Due to the low signal to noise ratio of the data this sequence does not utilise any pre-stack imaging algorithms but rather utilises post-stack migration as the key imaging tool due to the much improved signal to noise ratio of the stack data.

This sequence produces subsurface images that are of reasonable quality in many areas of the highlands despite its simplistic flow and reliance on the flat layer assumptions of conventional NMO and Stack. The 2005 seismic section shown in Figure 3 is an example of data with this sequence applied.

Recent advances in processing technology particularly related to noise attenuation and imaging algorithms have allowed pre-stack imaging sequences to be more successfully used on highlands data.

Many conventional strategies increase the fold and signal quality at the expense of horizontal resolution. The entire processing may be based on coarse CMP binning grids that are initially defined. Similarly, the stacking velocity analysis most often requires a temporal combination of several CMP gathers in supergathers in order to obtain well-defined and meaningful stacking velocities. This combination of neighbouring CMP gathers, however fails to improve the stacking velocity analysis in case of strong dip. The same limitations are found for flexible binning techniques that may be used in order to close some data gaps.

Hence, in many situations, coarse processing grids are not adequate for pre-processing of dip information and horizontal resolution.

In the imaging of sparse data, however, a significant dip enhancement and noise suppression can be achieved using the alternative strategy of Common-Reflection-Surface, or CRS imaging. This technique is successfully applied to highland data in recent processing techniques to enhance the imaging by increasing S/N ratio and resolution.

Figure 5 shows the example of conventional processing sequence and Figure 6 shows the result after using the conventional processing sequence.

Figure 7 shows the example of CRS processing flow and Figure 8 shows the result after using the CRS processing sequence.

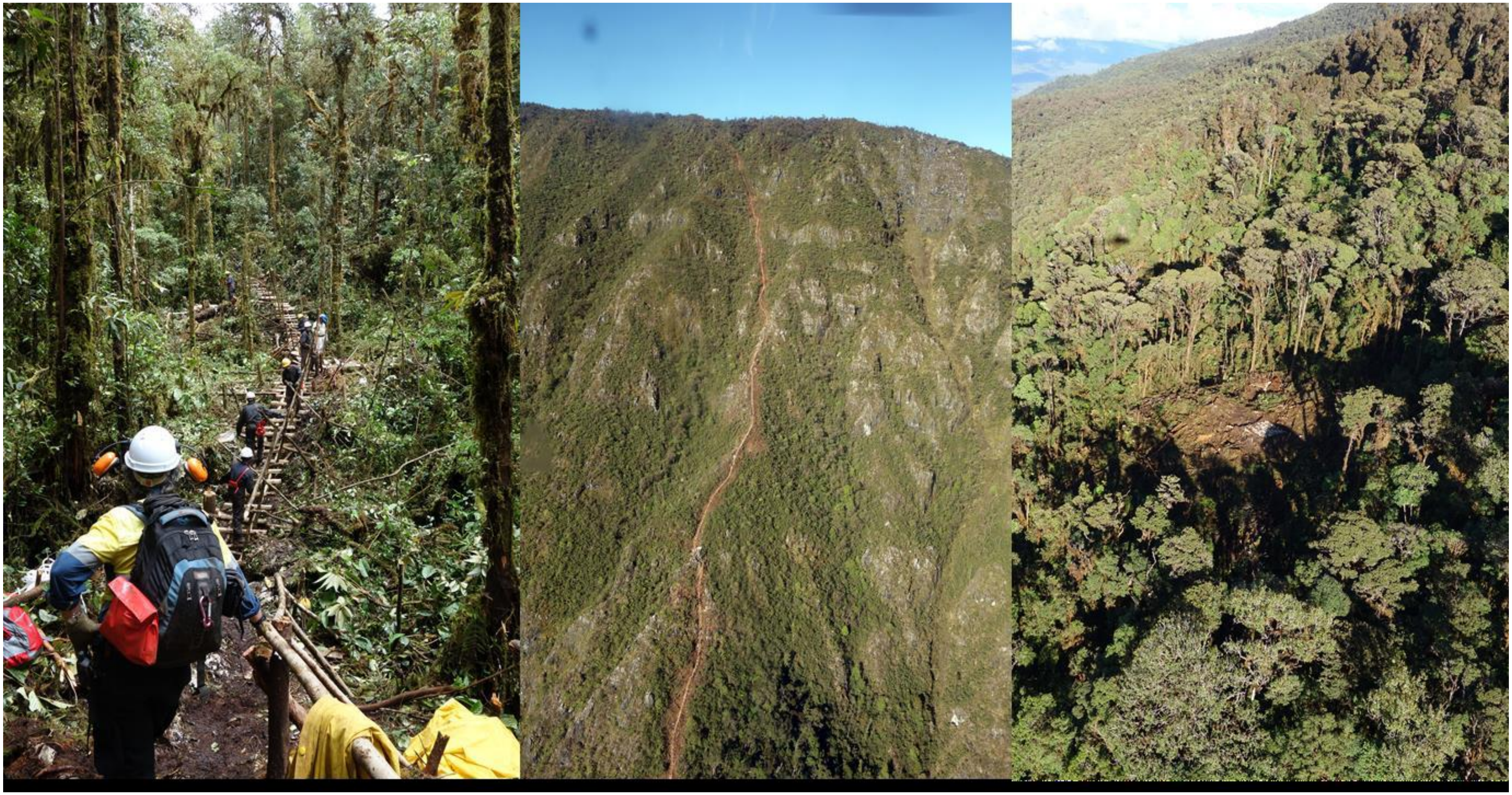


Figure 1. PNG Highlands: extreme terrain.

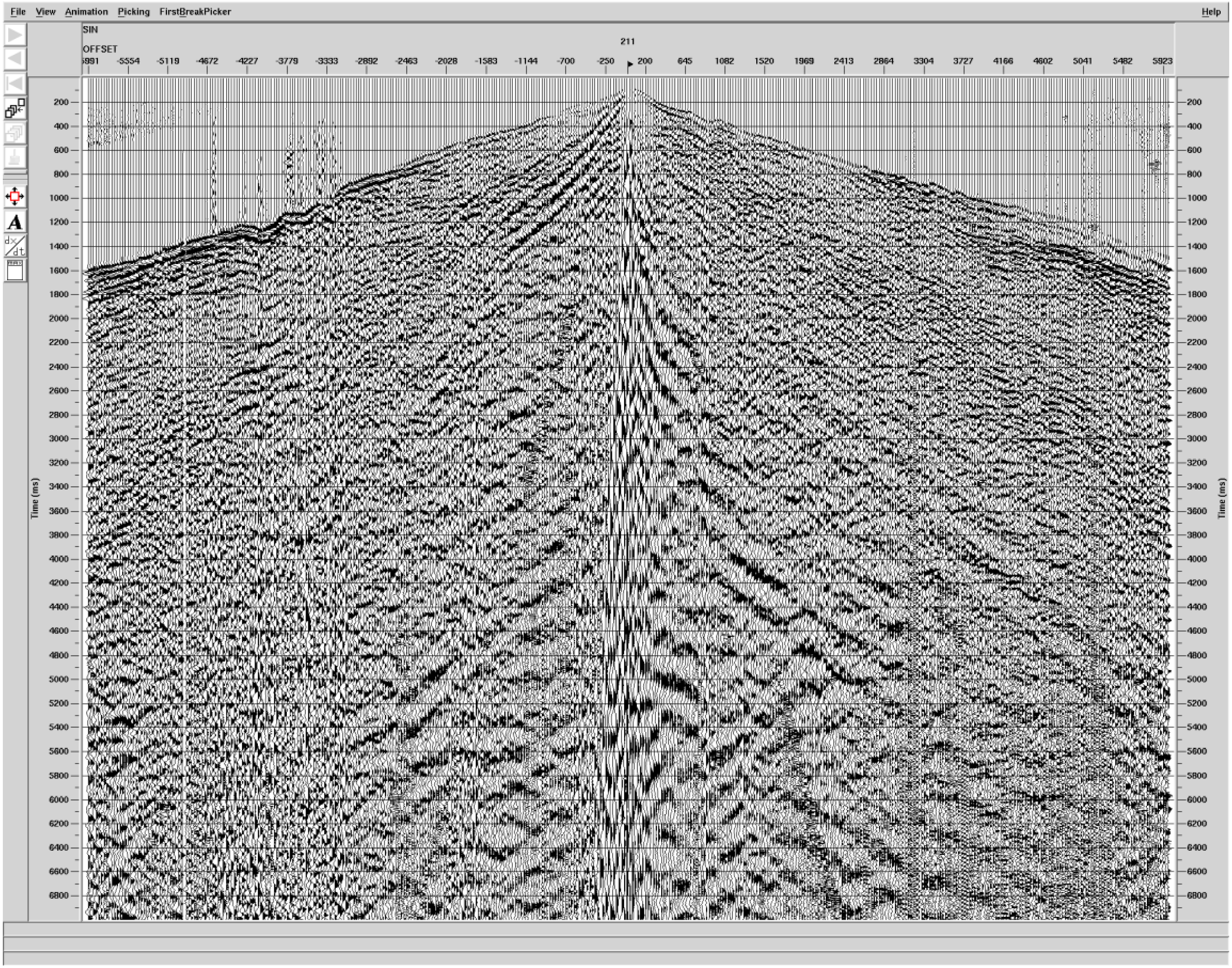
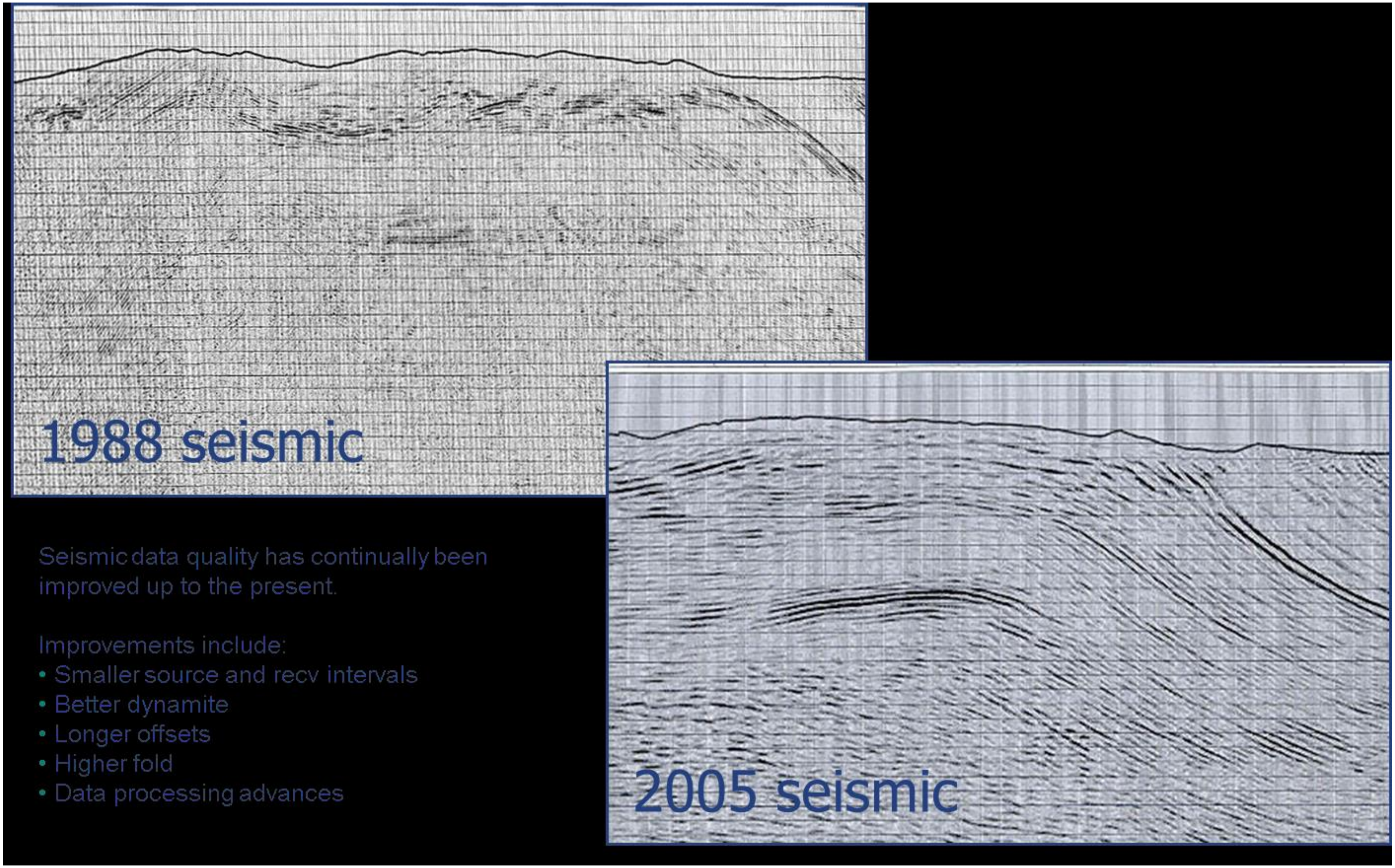


Figure 2. Example highlands shot record (AGC applied).



1988 seismic

Seismic data quality has continually been improved up to the present.

Improvements include:

- Smaller source and recv intervals
- Better dynamite
- Longer offsets
- Higher fold
- Data processing advances

2005 seismic

Figure 3. Data comparison between 1998 and 2005 acquired data.

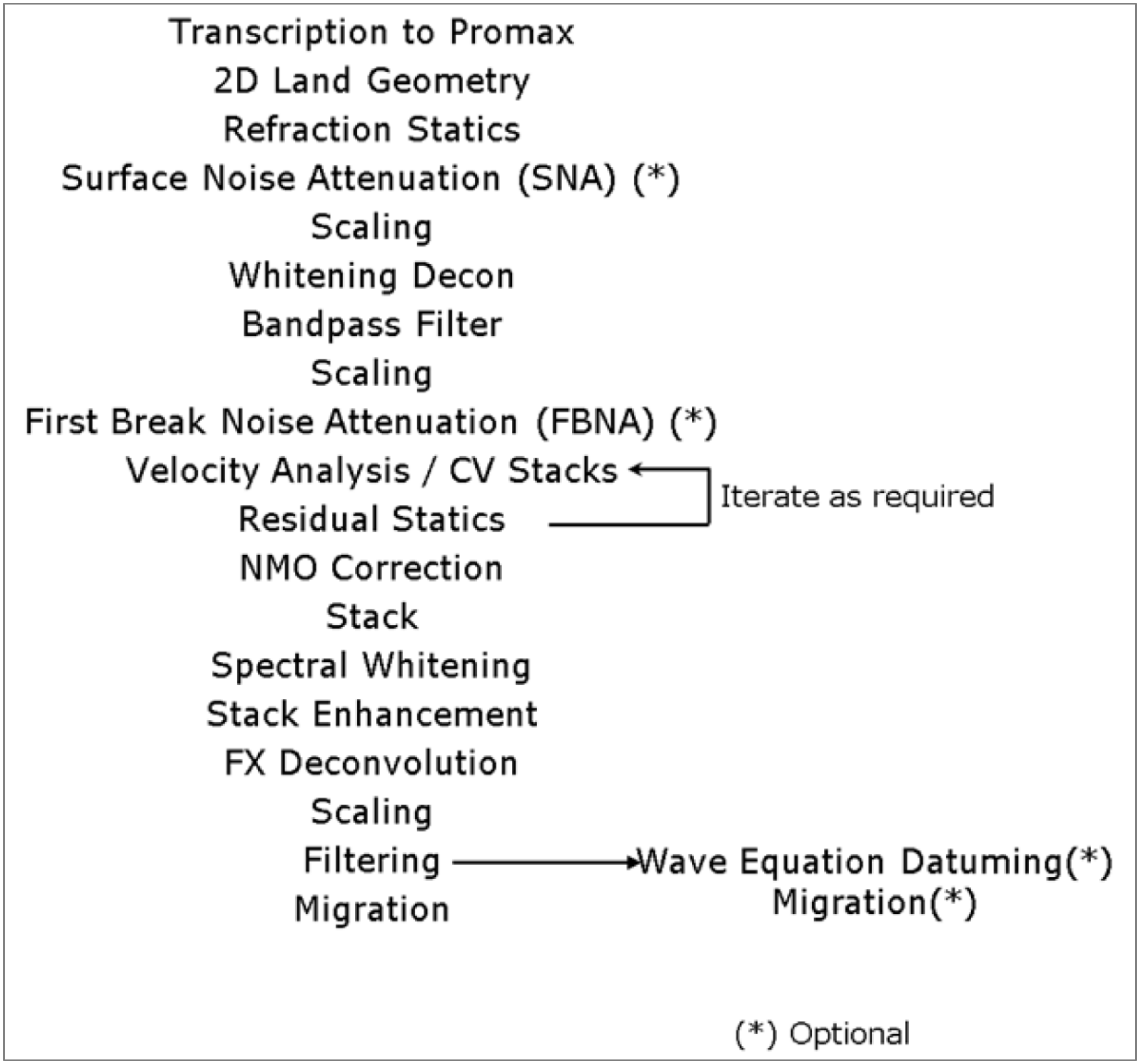


Figure 4. Processing sequence using post-stack imaging.

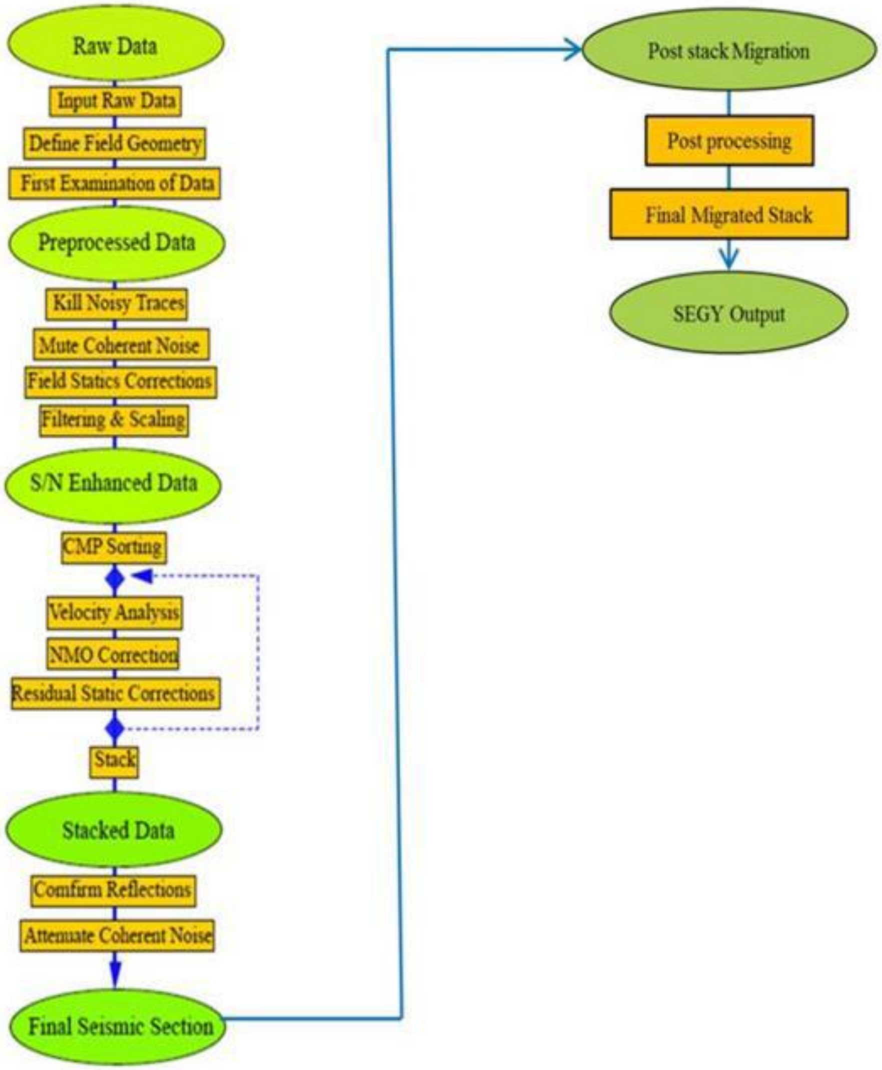


Figure 5. Post-stack Conventional Processing Flow

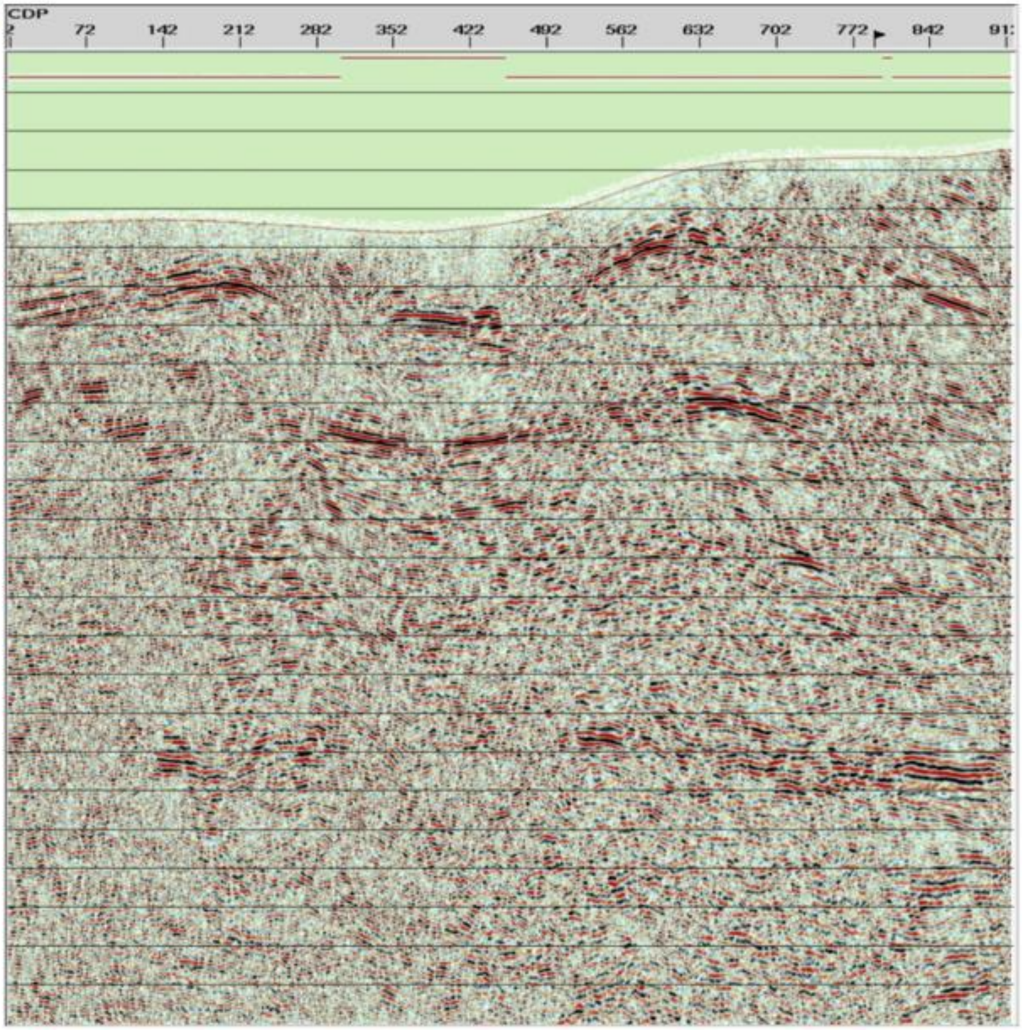


Figure 6. Unmigrated Stack using conventional post stack processing flow

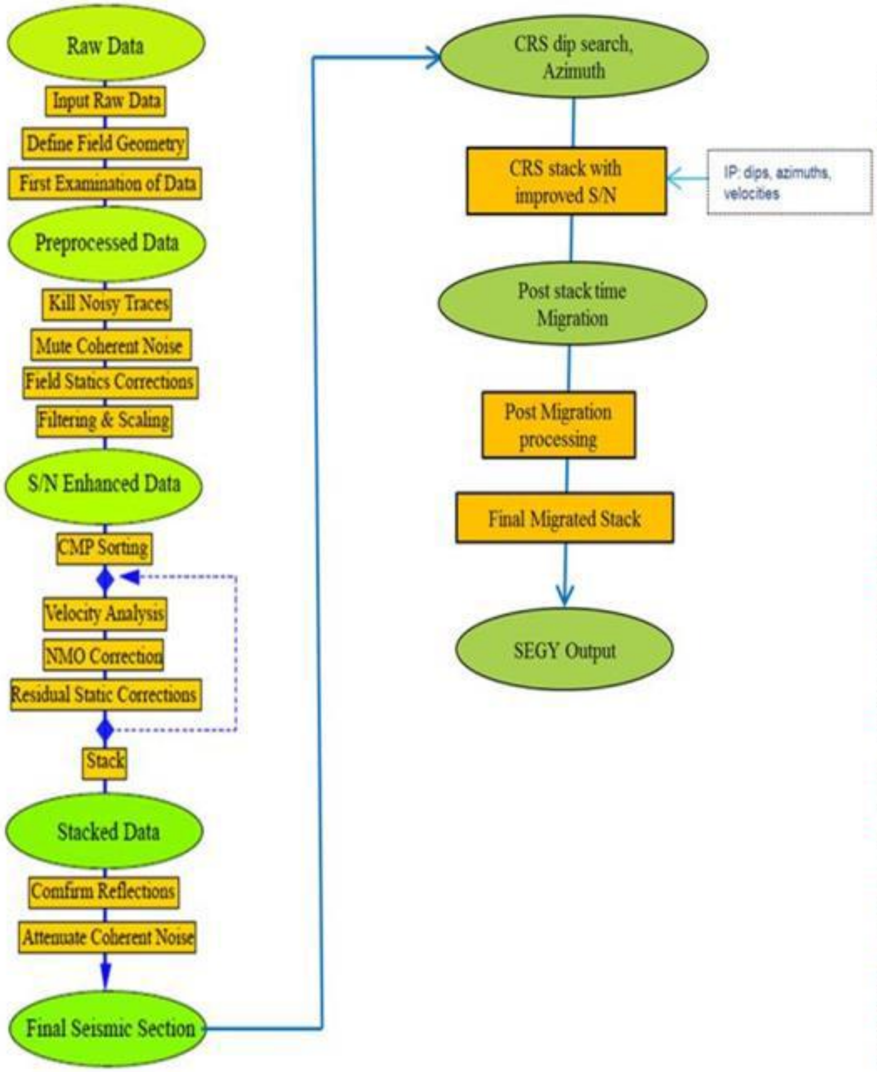


Figure 7. Post Stack CRS Processing Flow

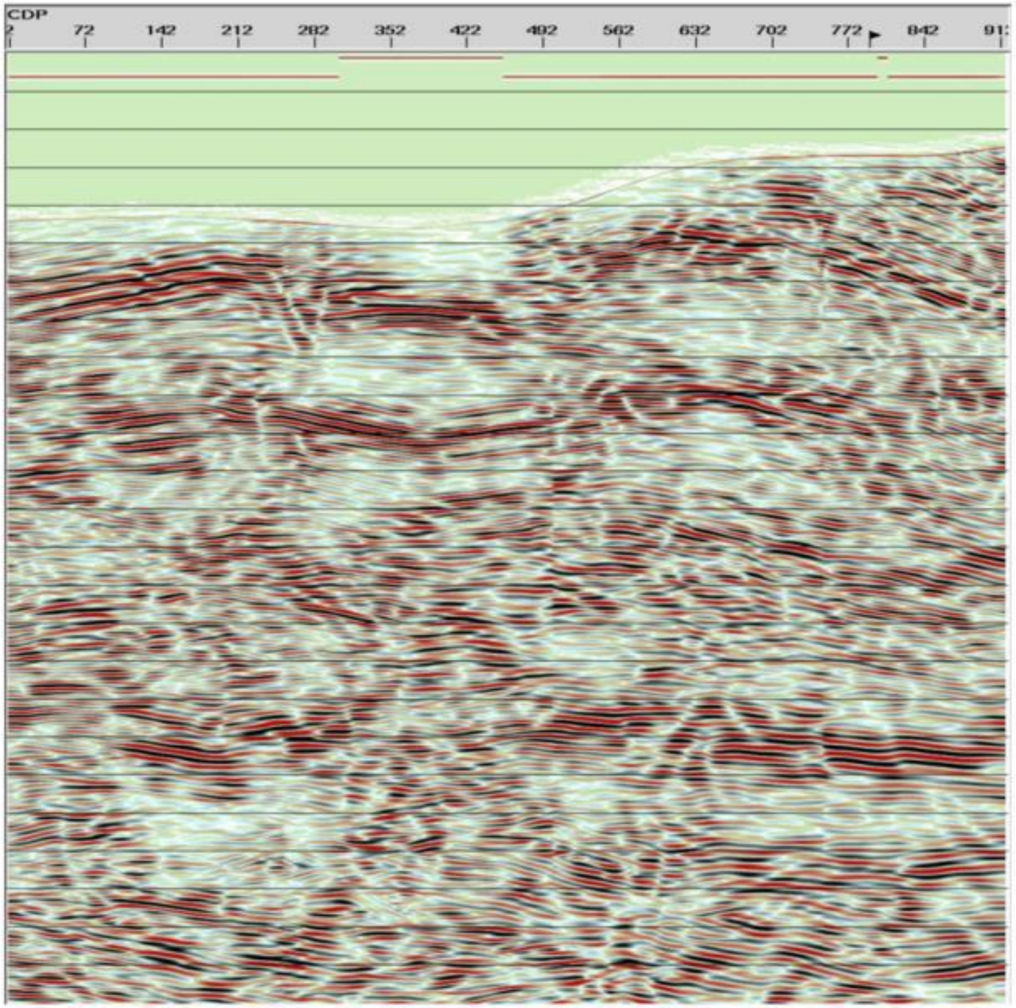


Figure 8. Unmigrated Stack using post stack CRS processing flow

YEAR	Recv. Int.	Recv. Array	Num. Recv.	Max Offset	Src. Int.	Fold	Souce
1970's	45.7	Unknown	48	1120	91.4	6	Unknown
1981	50	12xGeo Inline	96	2400	50 / 100	48 / 24	Seismex 3x0.5 kg(?)
1984	25	12xGeo Inline	96	1270	50 / 100	12 / 24	Dyn 1x7kg
1990	25	12xGeo Inline	292	3650	75	48	Powergel
1991	25	12xGeo Inline	292	3650	75	48	Powergel 4-12kg
1996	30	1xGeo at 4 m (Cemented)	504	6500	30 / 60	126 / 252	Dyn 1x12kg at 15m
1999	30	12xGeo Inline	622	9315	30 / 60	155 / 311	Powergel 1x5kg at 10m
2000	30	12xGeo Inline	400	6000	30 / 60	200 / 100	Powergel 1x5kg at 10m
2004	30	12xGeo Inline	Variable	Whole Line	30 / 60	Variable	Pentoseis 1x3kg at 10m
2005	30	12xGeo Inline	Variable	Whole Line	30 / 60	Variable	Pentoseis 1x3kg at 10m
2007	30	12xGeo Inline	400	6000	30 / 60	200 / 100	Pentoseis 1x3kg at 10m

Table 1. Historical listing of key acquisition parameters.