CHAPTER 5

Low Frequency Models

The seismic inversion process requires additional information in the low frequency range, as these are not present in conventional seismic data. As a consequence, the low frequency information is included by building a low frequency model (LFM). The basic concept and importance of LFM were discussed in CHAPTER 2.

The key elements were an ultra-low frequency model (ULFM) based on seismic stacking velocity information, and an initial LFM based on well log data. The main objective of making a ULFM was to capture velocity and density trend variations between wells, and only include data in the frequency range from 0 to 2 Hz. As part of the process, the ULFM was further calibrated to well log data information and combined with a well log based LFM, which only included data in the range from 2 to 10 Hz. These two models were constructed in parallel, and later merged to construct the final LFM. Low frequency models were constructed for acoustic impedance, shear impedance and density. Further details regarding the process of constructing the LFMs will be discussed in the following sections.

5.1 Ultra-Low Frequency Models

Seismic stacking velocity data normally contains data in the frequency range from 0 to 2 Hz. The data were received in a standard format, being root mean square (RMS) velocity values from the Beam PSDM processing conducted in 2014. The seismic stacking velocity data were transformed to interval velocity using Dix equation (Dix, 1955) as follows:

$$V_{int} = \left[\left(T_2 Vrms_2{}^2 - T_1 Vrms_1{}^2\right)/(T_2 - T_1)\right]^{1/2} \quad (5\text{-}1),$$

where V_{int} is interval velocity, T_1 and T_2 are two-way travel time of the upper and the lower medium (sample), respectively. $Vrms_1$ and $Vrms_2$ are the root mean square velocity in the upper layer and the lower medium (sample), respectively.

Seismic interval velocities were calculated at Well-A, Well-C and Well-D, and compared with sonic log data. It is assumed that the well log velocity data represent more reliable information, when compared to seismic interval velocity data at well location. As Figure 5-1, to match the seismic interval velocity with the behavior of the well log data, a simple linear function was extracted (y = 1.186x – 794.5) (red line), x and y represent the seismic interval velocity and sonic log velocity, respectively. The application of the function improved the calibration of the seismic interval velocity to follow the ideal function of x = y (black line). An arbitrary line as Figure 5-2 was used to show all processes in this chapter. The example of original and calibrated seismic interval velocity using relationships at wells were compared across an arbitrary line in the Figure 5-3.

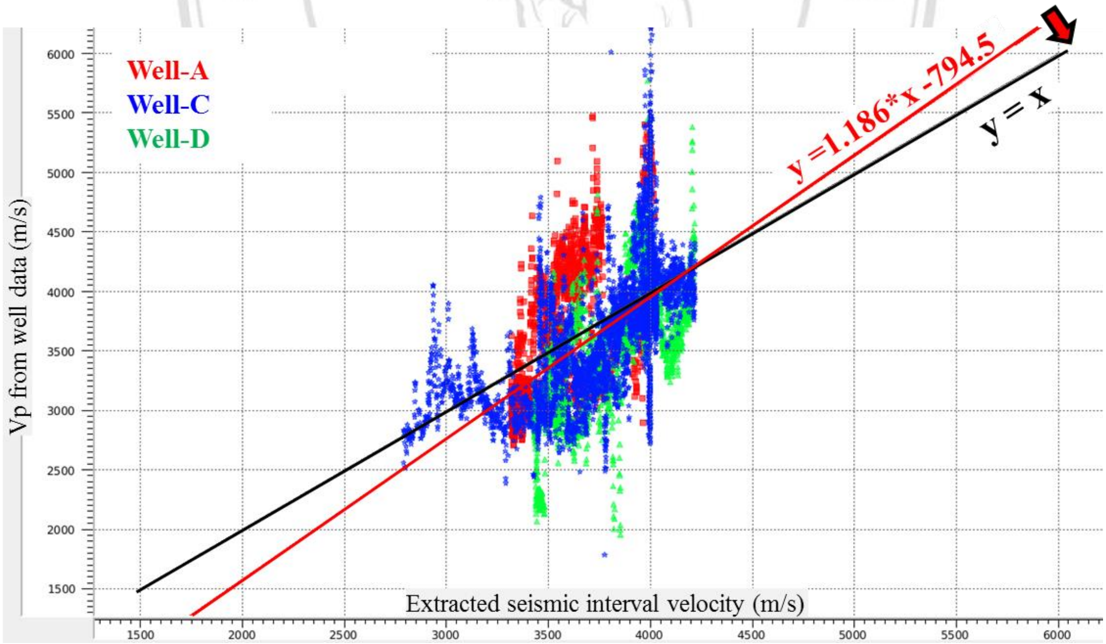


Figure 5-1 Crossplot of extracted seismic interval velocity versus Vp log using Well-A, Well-C and Well-D data.

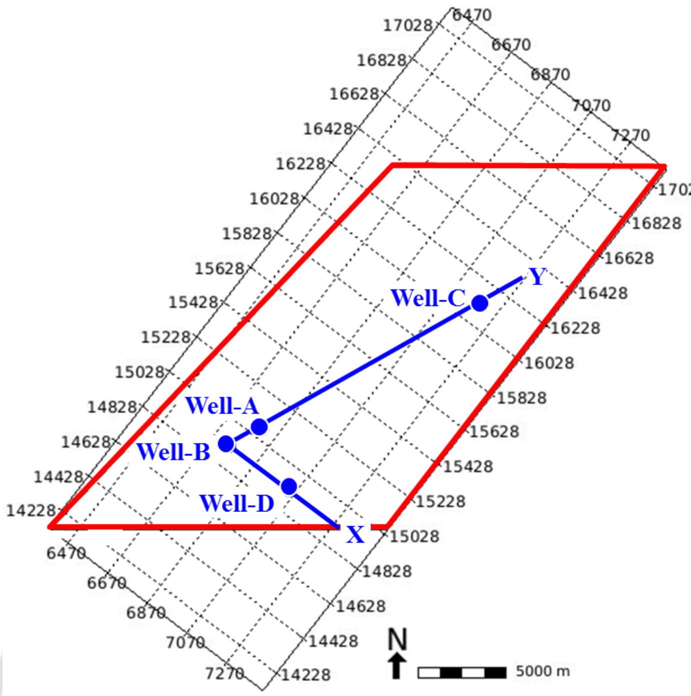


Figure 5-2 An arbitrary location to show the results in Chapter 5.

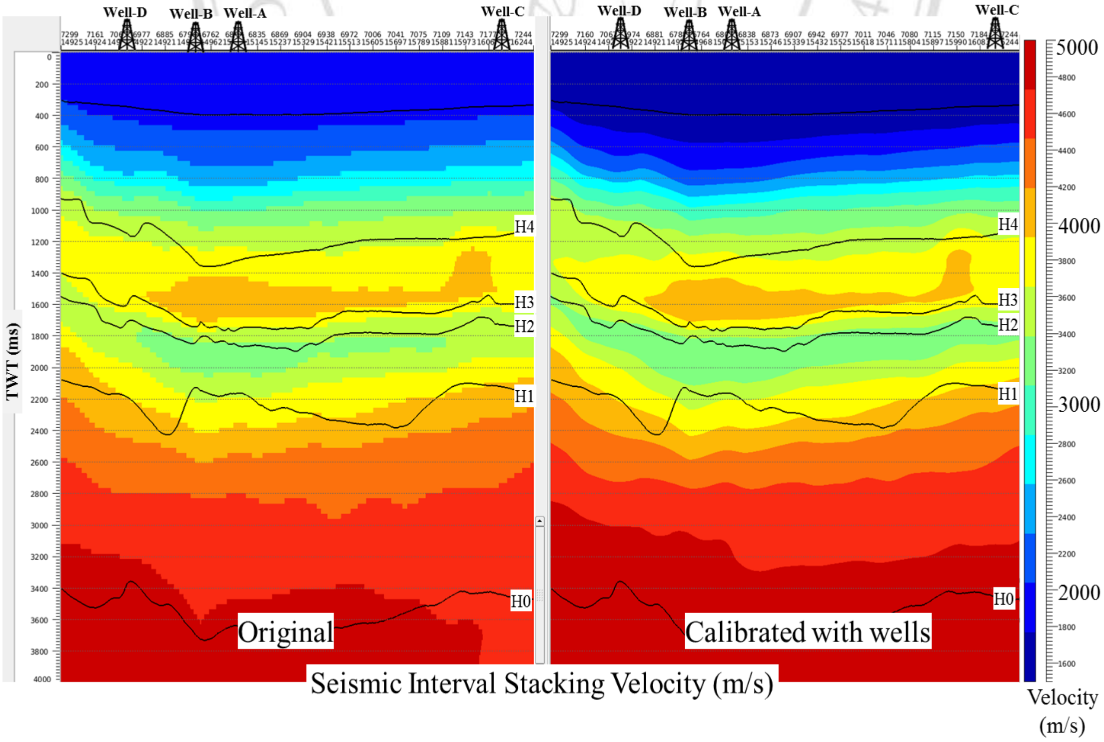


Figure 5-3 Comparison of seismic interval stacking velocity between original (left) and calibrated seismic velocities using relationships at wells.

Relationships between Vp and acoustic impedance (AI), shear impedance (SI) and density were established using well log data of Wells-A, -C and -D as shown in Figures 5-4, 5-5 and 5-6. The calibrated seismic interval velocity cube was transformed to the respective properties using the derived relations i.e. initial ultra-low frequency models comprising AI, SI and density.

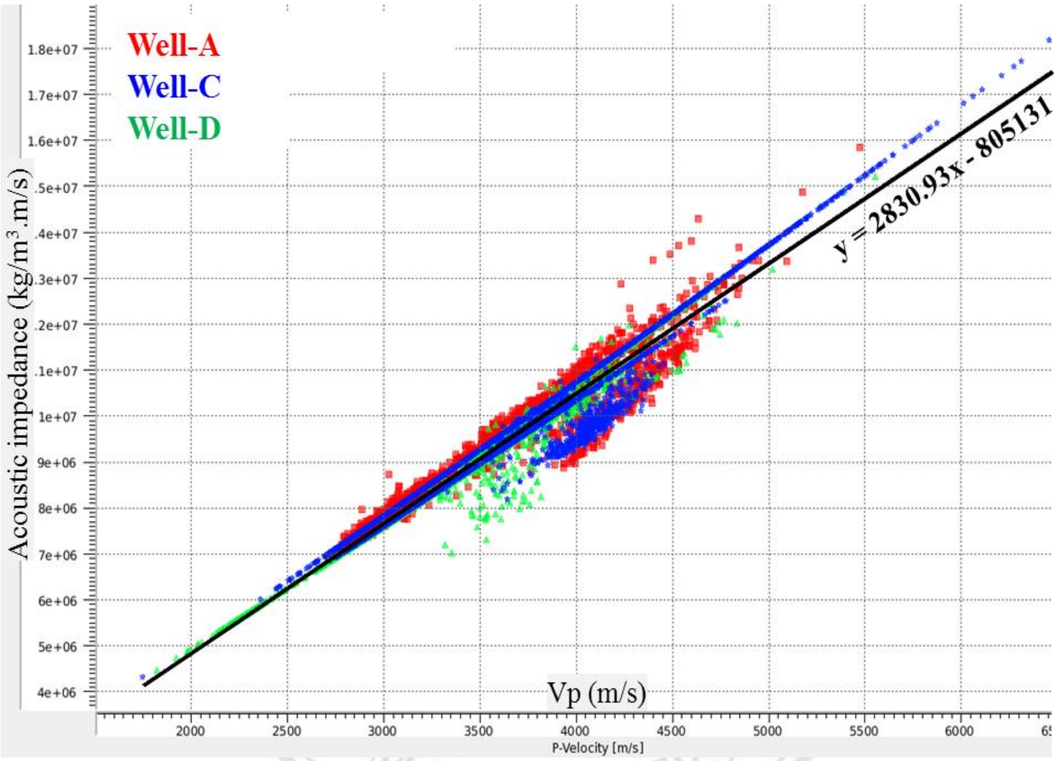


Figure 5-4 Vp and AI relations using well data colored by wells.

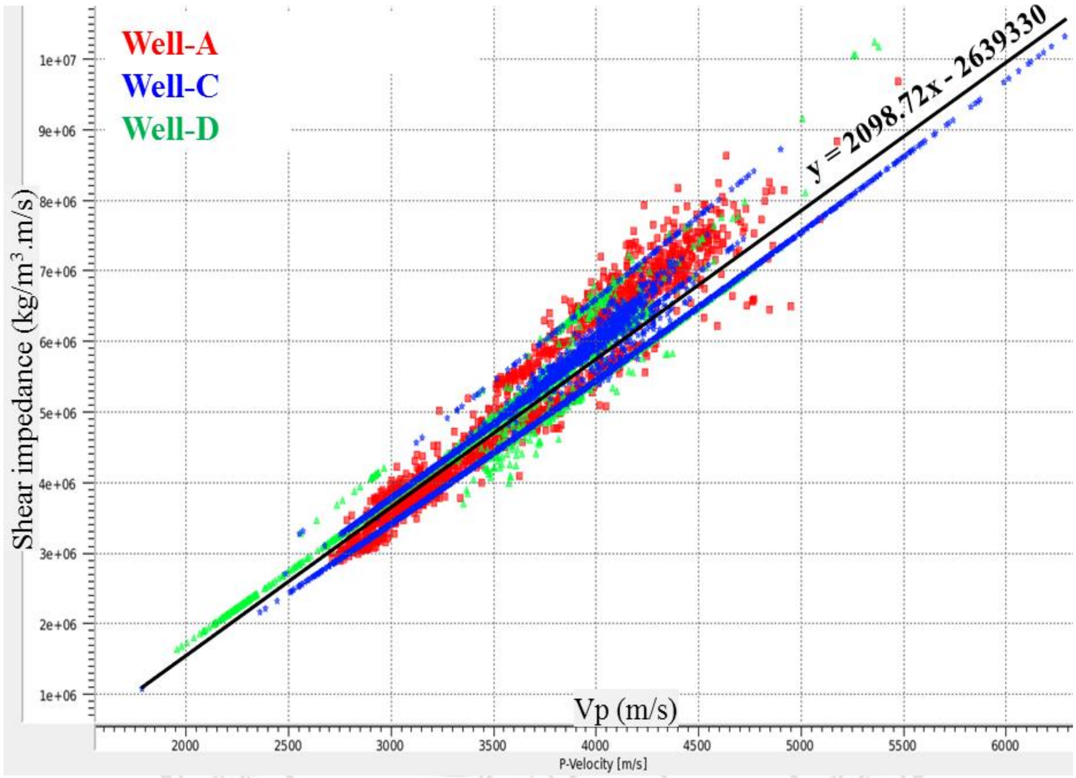
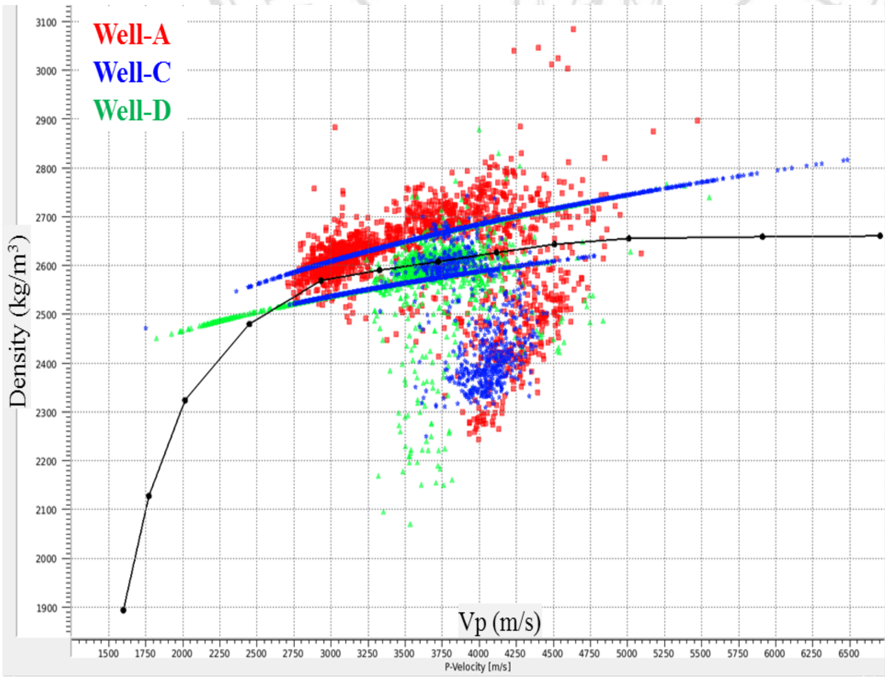


Figure 5-5 Vp and SI relations using well data colored by wells.



Vp (m/s)	Density (kg/m³)
1599.41	1894.06
1771.32	2127.8
2014.86	2323.72
2449.4	2480.12
2933.19	2569.23
3327.68	2590.43
3722.17	2607.78
4116.66	2626.36
4507.52	2643.39
5008.92	2655.42
5911.43	2658.86
6704.12	2660.58

Figure 5-6 Vp and density relations using well data colored by wells. The table was shown the data points which used to construct the relationships of Vp and density.

Figure 5-7 illustrates that this initial ULFM did not provide an optimized calibration along wells. To achieve reliable models, residual logs of elastic properties were calculated using 0-2 Hz filtered well log data that were subtracted from the extracted ultra-low frequency models as follows;

$$\mathrm{AI_{residual}} = \mathrm{AI_{well}} - \mathrm{AI_{ULF}} \quad (5\text{-}2),$$

$$\mathrm{SI_{residual}} = \mathrm{SI_{well}} - \mathrm{SI_{ULF}} \quad (5\text{-}3),$$

$$\mathrm{RHO_{residual}} = \mathrm{RHO_{well}} - \mathrm{RHO_{ULF}} \quad (5\text{-}4),$$

where $\mathrm{AI_{residual}}, \mathrm{SI_{residual}}$ and $\mathrm{RHO_{residual}}$ are residual logs of elastic properties, $\mathrm{AI_{well}}, \mathrm{SI_{well}}$ and $\mathrm{RHO_{well}}$ are filtered properties from well log data and $\mathrm{AI_{ULF}}, \mathrm{SI_{ULF}}$ and $\mathrm{RHO_{ULF}}$ are ultra-low frequency models of elastic properties. The results of the calculation of these residuals are shown in Figure 5-8. Then, residual logs were interpolated between wells using a constructed stratigraphic framework (see also Section 5.2), as shown in Figure 5-9.

The final ULFMs were created by addition of the interpolated residual properties with the initial ULFMs for each property. The final ULFMs showed reasonable alignment with the filtered well log data (0 to 2 Hz) (Figure 5-10), and would be used to derive the final LFMs that will be further discussed in Section 5.4.

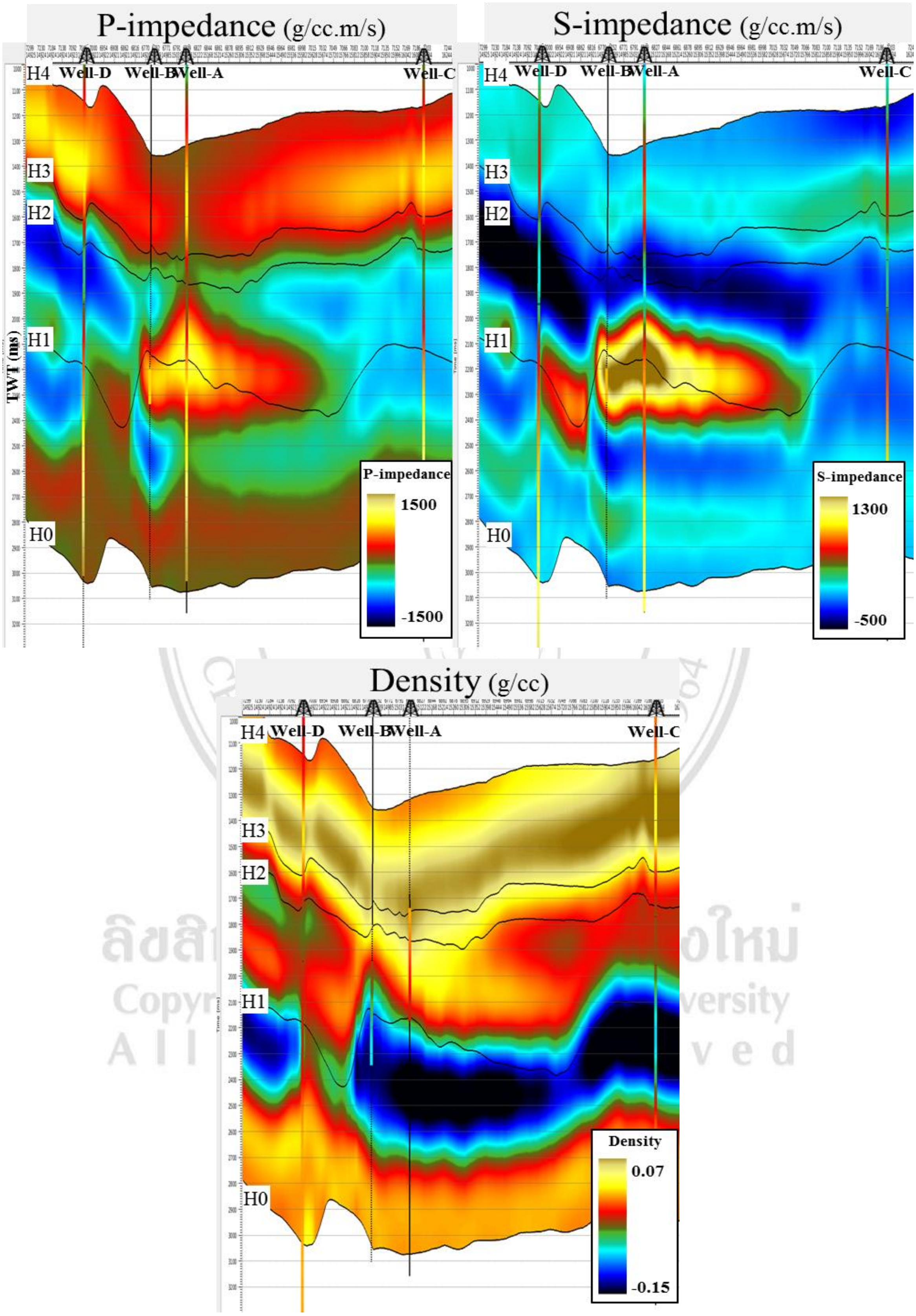


Figure 5-7 Initial ultra-low frequency models transformed using relationships at wells.

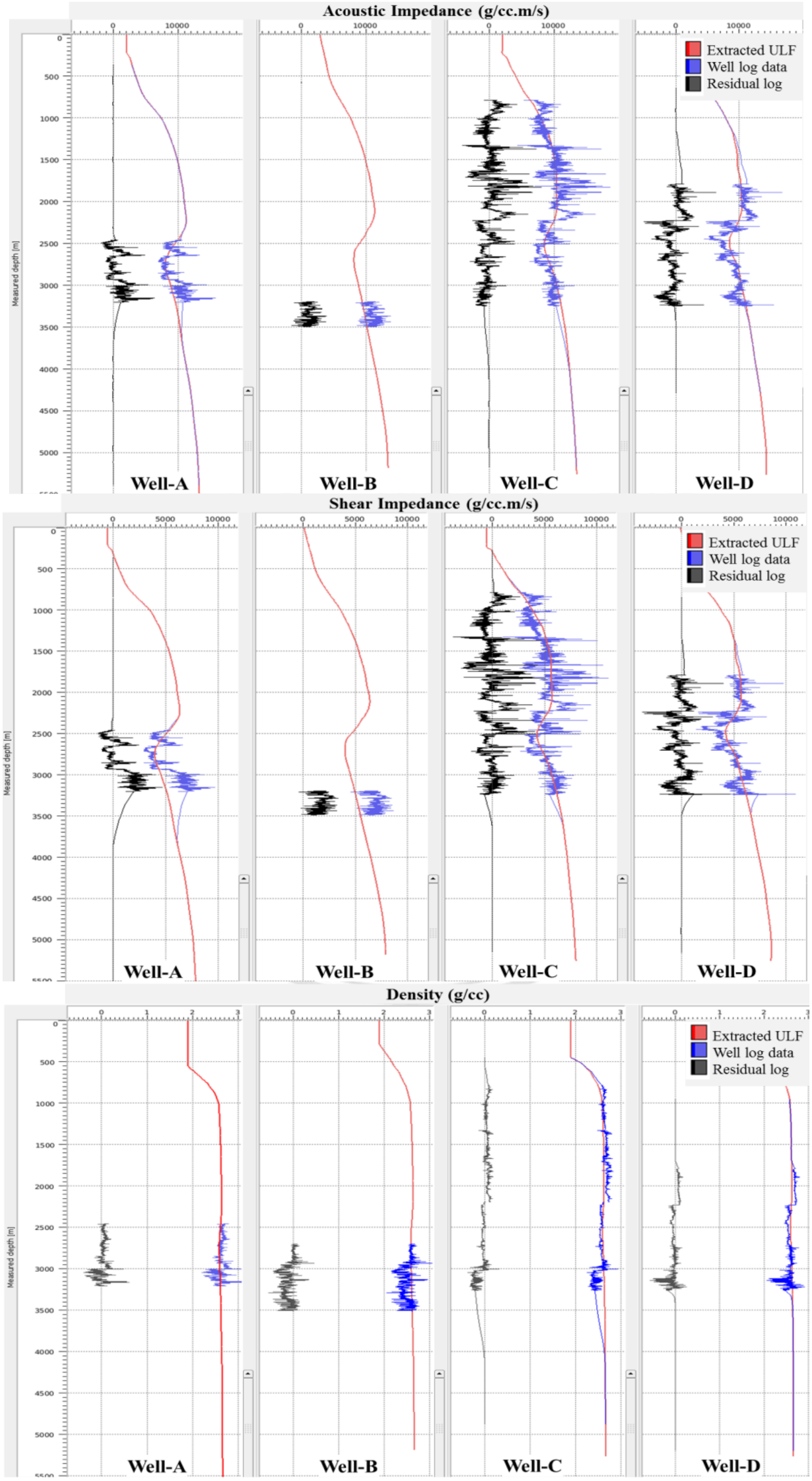


Figure 5-8 Residual log of all properties and theirs inputs.

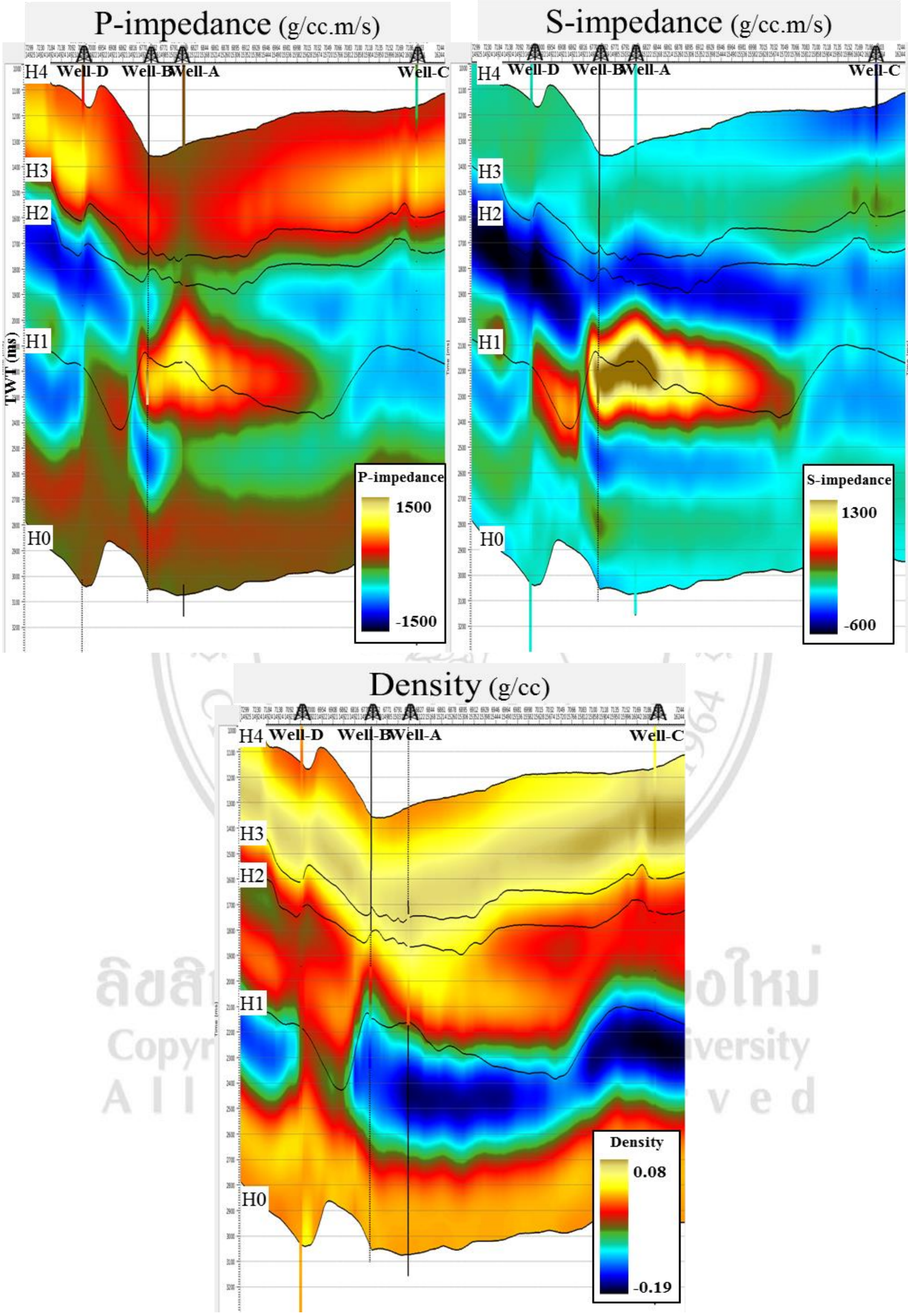


Figure 5-9 Interpolated residual logs of each property.

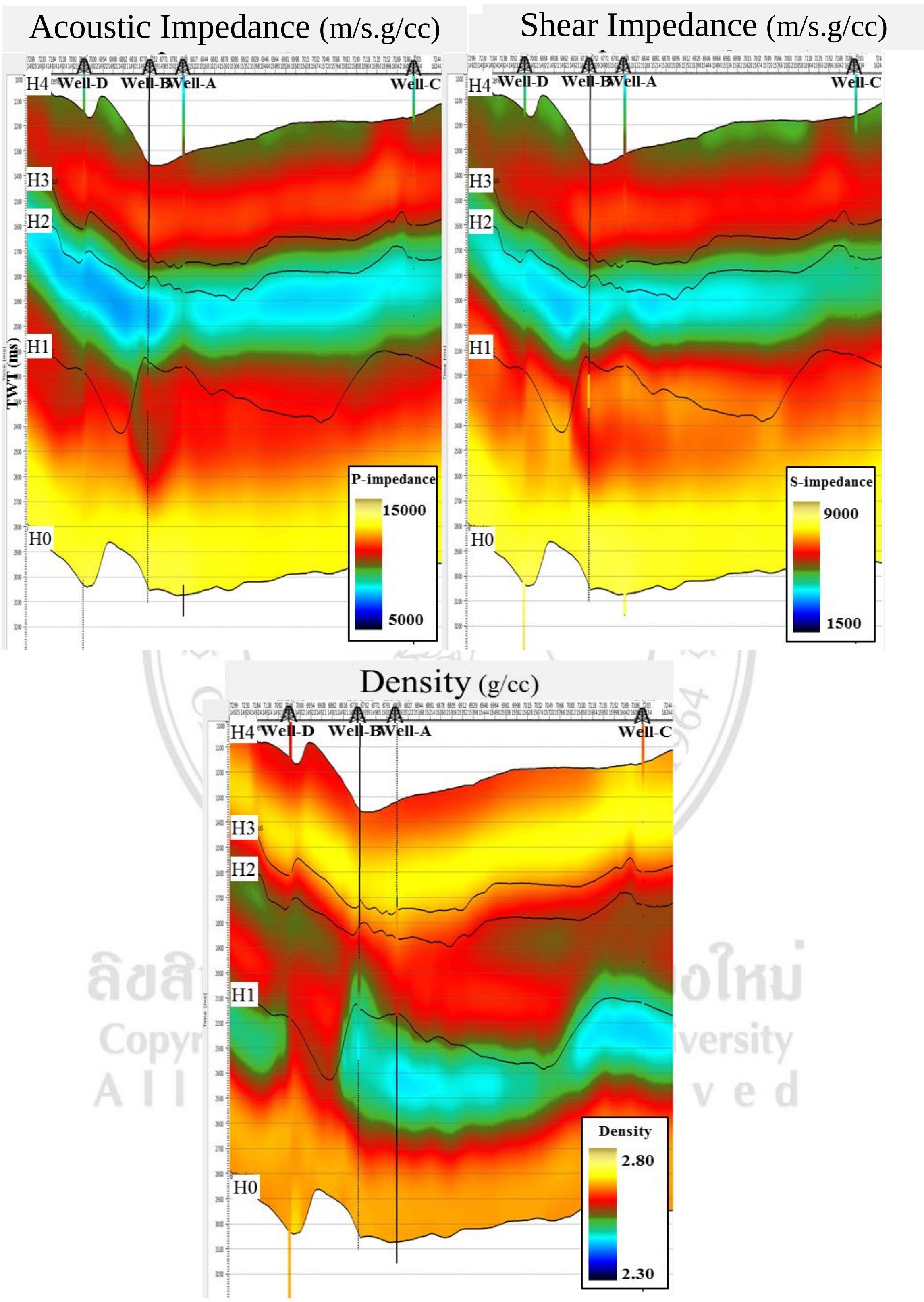


Figure 5-10 Final ultra-low frequency models which were contained 0-2 Hz of frequency range.

5.2 Low Frequency Models (using well log data)

A stratigraphic framework model was constructed using four layers that were based on five interpreted horizons and their respective depositional environment, as shown in Table 5-1. The result of the framework model building is shown in Figure 5-11, illustrated by an arbitrary line passing through all input well locations.

Table 5-1 Details of the stratigraphic layer type that were accounted for in the framework model building process.

Layer	Primary interface	Stratigraphy
3	H4	Proportional to top and base
2	H3	Proportional to top and base
1	H2	Proportional to top and base
0	H1	Truncation
	H0	Proportional to top and base

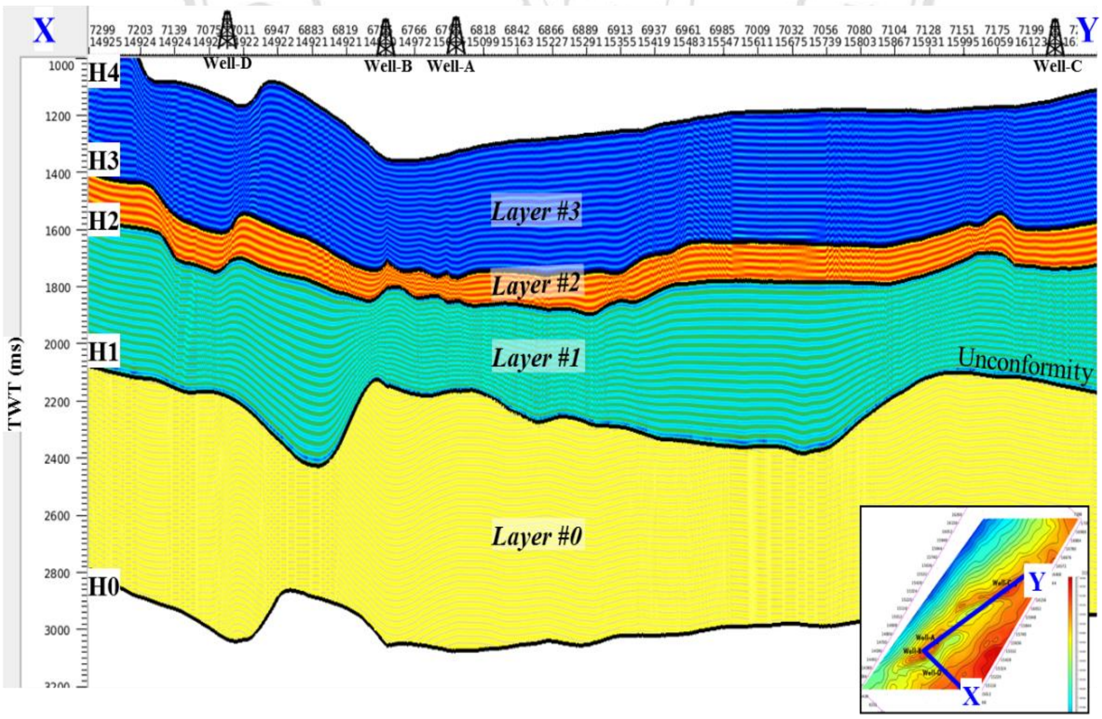


Figure 5-11 Stratigraphic framework model used to constrain well log data interpolation during construction of LFM.

As well log data were sparsely distributed throughout the area, a combination of interpolation and extrapolation were used to populate elastic properties throughout the model. The stratigraphic framework model was used to constrain this process. Further geostatistical parameter tests were conducted to ensure that the weighted interpolation methods, such as "Locally Weighted" and "Global Kriging" provided optimal results. As shown in Figure 5-12, both areal weight methods were carried out, providing good match with the filtered well log data due to all interpolation weights decrease with distance from the well, and are exactly zero at the other well positions.

The global kriging method was based on a geostatistical simple kriging technique by using all the wells to set up the matrix and inverting it only once; the resulting inverted matrix is used over and over again at all unknown locations. This method was resulted in smooth and slightly reduced weighting factors away from well control, when compared to results derived using locally weighted. It was therefore decided that global kriging would be used in this project.

Based on testing it was decided that a variogram range of 10 km away from well control would be used when building low frequency models for AI, SI and density (Figure 5-13).

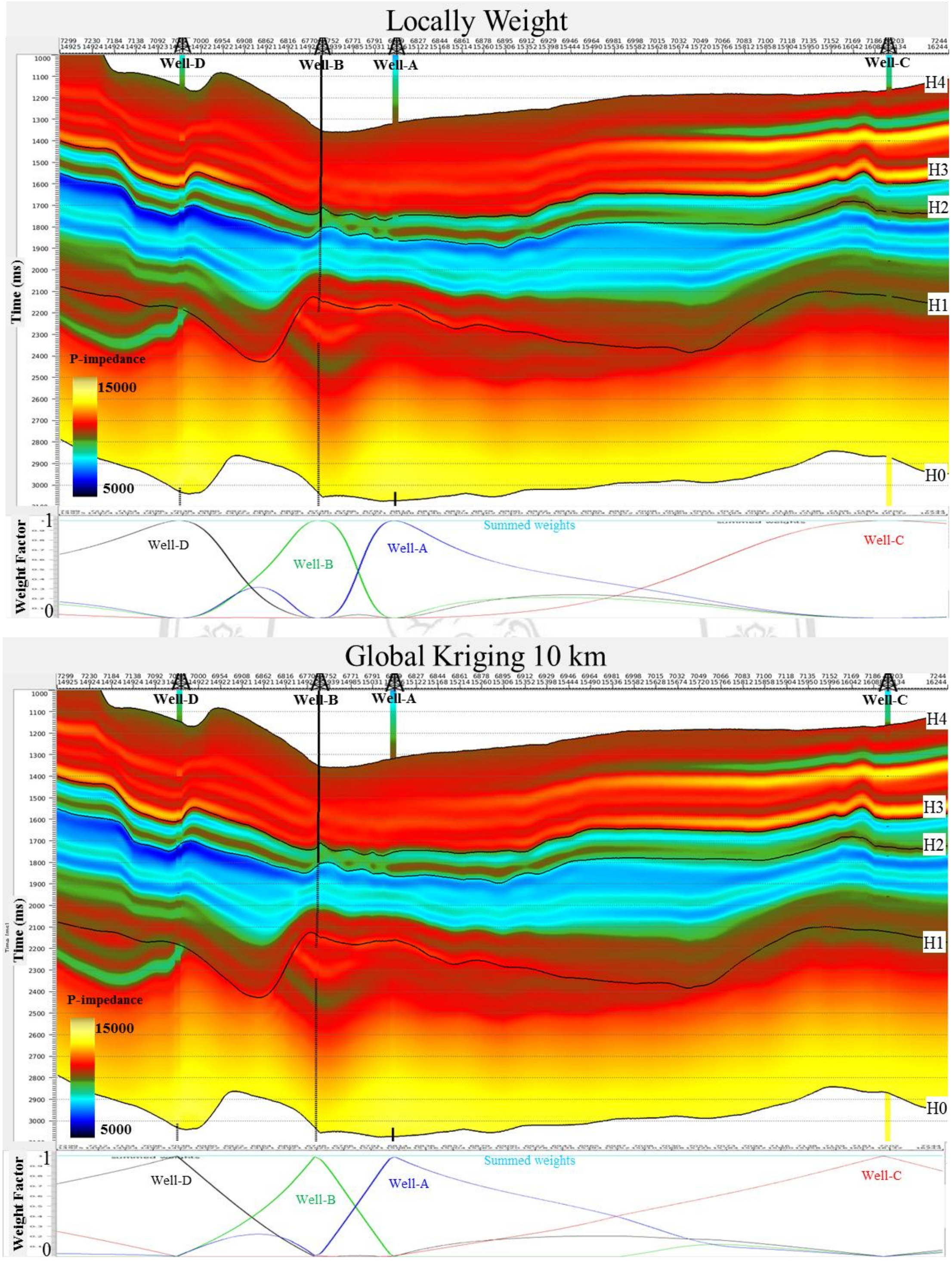


Figure 5-12 Various areal weighting interpolation methods were tested to verify the influence when introducing well log data to the low-frequency model building. Based on these tests, global kriging with 10 km variogram range was selected in this project.

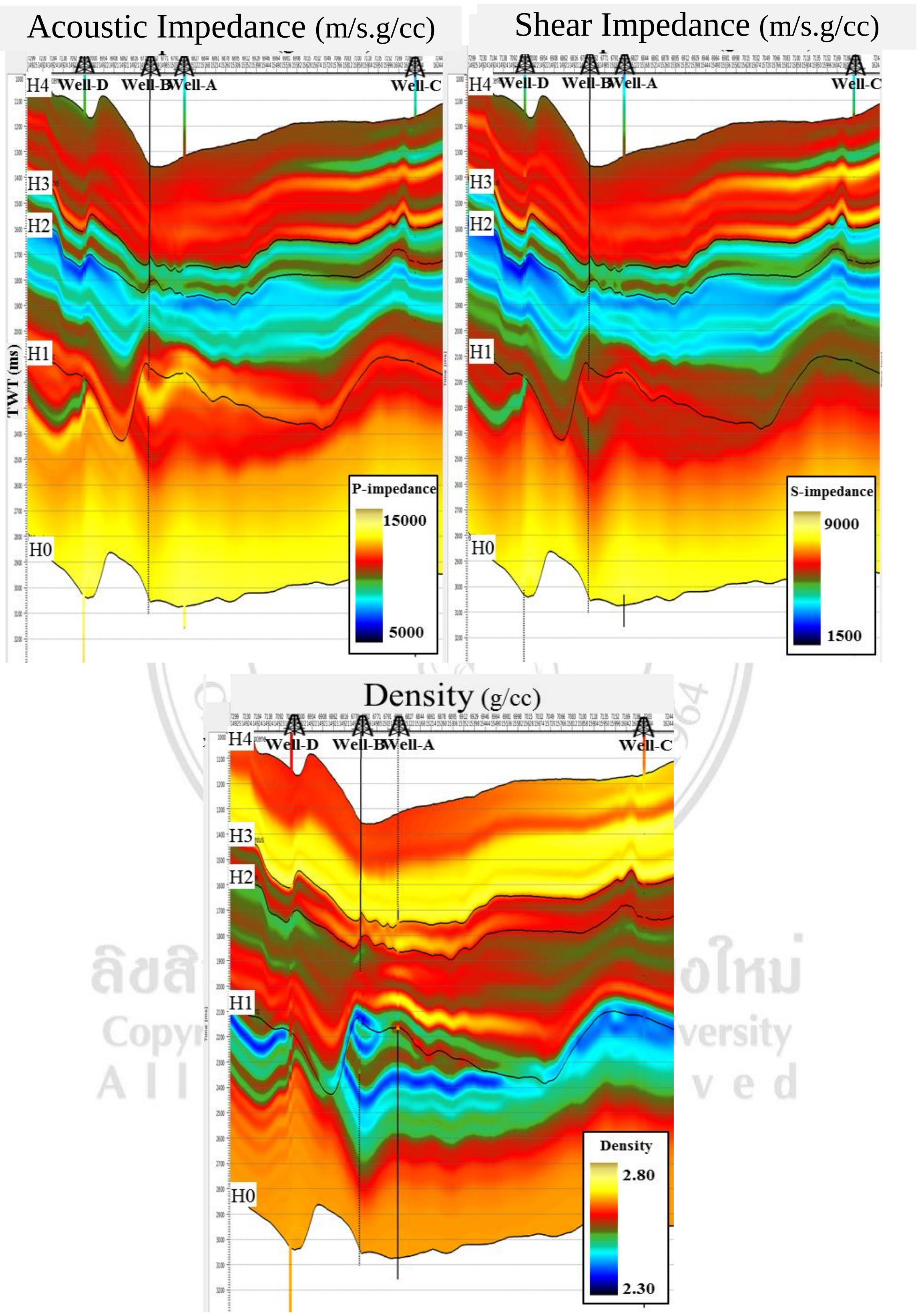


Figure 5-13 Final low frequency models using well data i.e. acoustic impedance, shear impedance and density. The frequency content of these models was 2-10 Hz.

5.3 Final Low Frequency Models

The calibrated ultra-low frequency models (ULFM) and the initial low frequency models (initial LFM) using well log data only were constructed using the approach explained in Sections 5.2 and 5.3, respectively. The final low frequency models were produced by merging these models for AI, SI and density. The ULFMs were limited to frequencies of 0-2 Hz, while the initial LFM included a frequency range of 2-60 Hz, as illustrated in Figure 5-14. However, the final LFM for all properties used in the seismic simultaneous inversion process (CHAPTER 6) were filtered to only contain data within the frequency range of 0-10 Hz (Figure 5-15).

Frequency analysis of the input seismic data was carried out over an arbitrary line as shown in Figure 5-16, using a high-cut filter with 2 Hz overlap to extract the low-end seismic frequency content. The tests applied high-cut filters to the mid angle stack data from 5 to 11 Hz with an increment of 1 Hz. At 10 Hz, the main reflectors could be observed in the seismic data, and this was chosen as the high frequency range of the LFM spectrum.

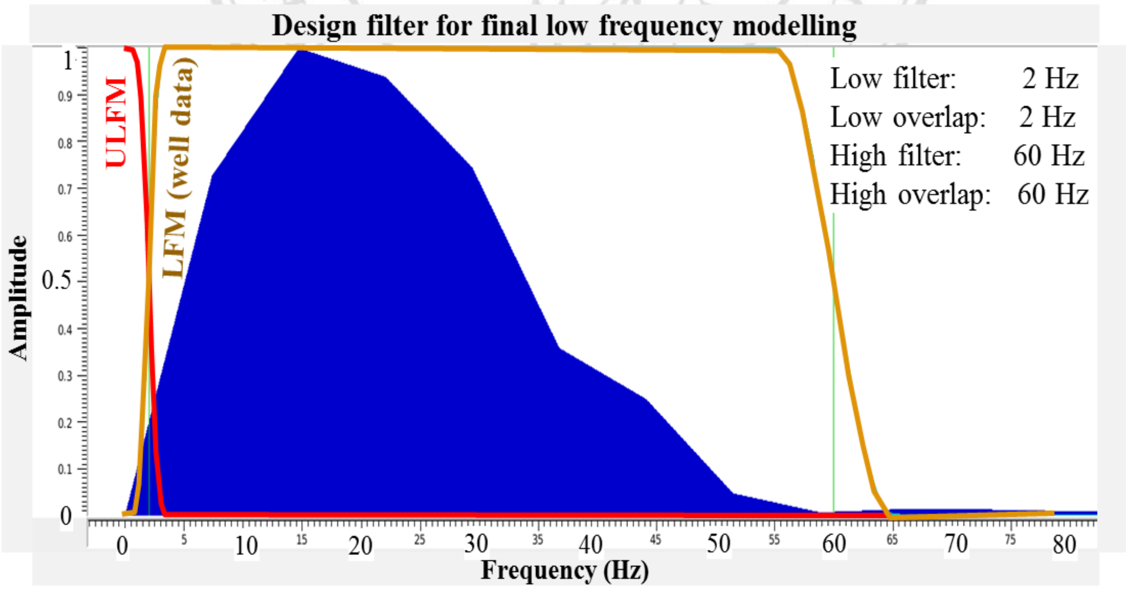


Figure 5-14 Design filter using final low frequency model

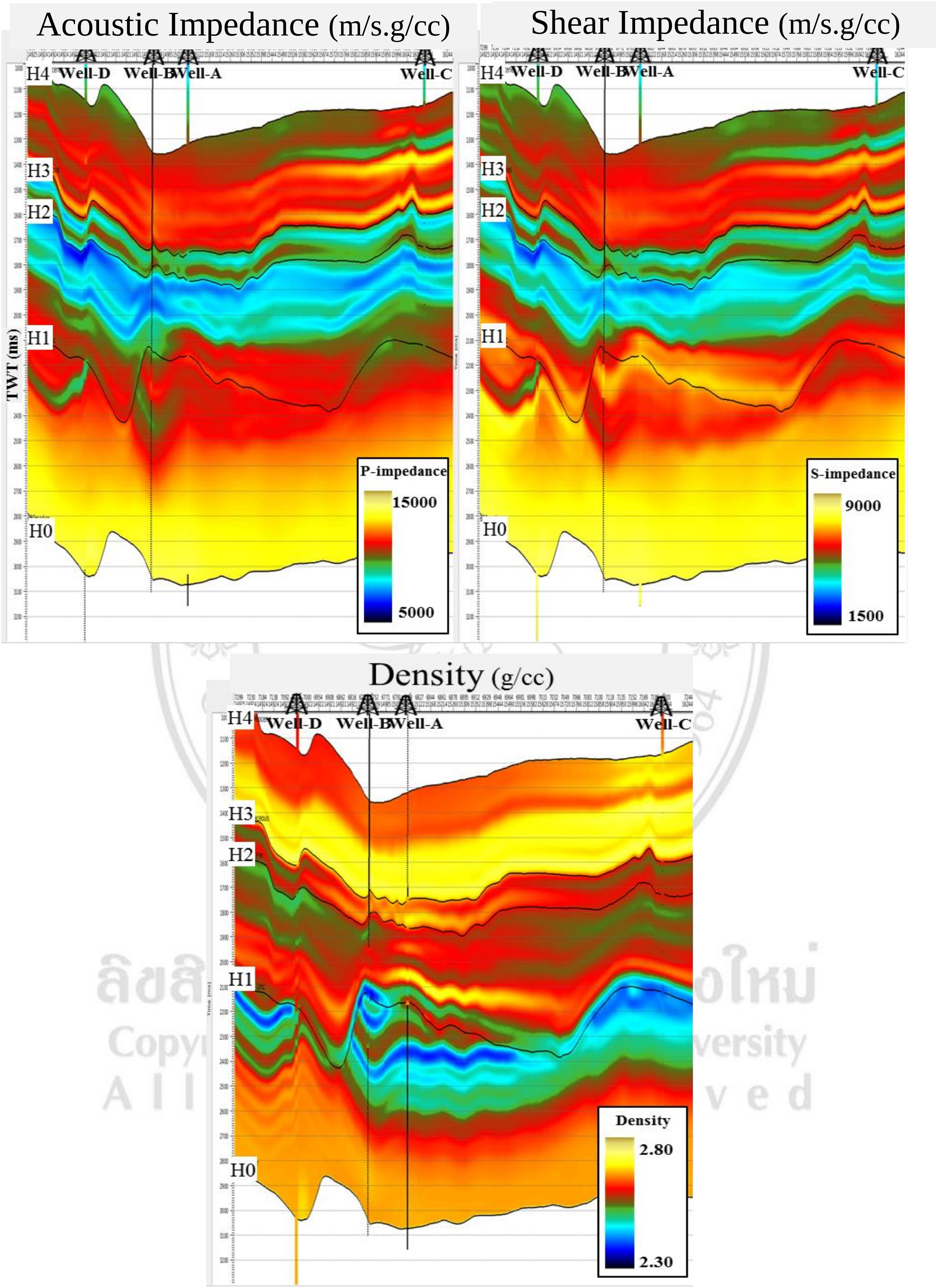


Figure 5-15 Final low frequency models were generated using calibrated ultra-low frequency models merged with low frequency model from well data.

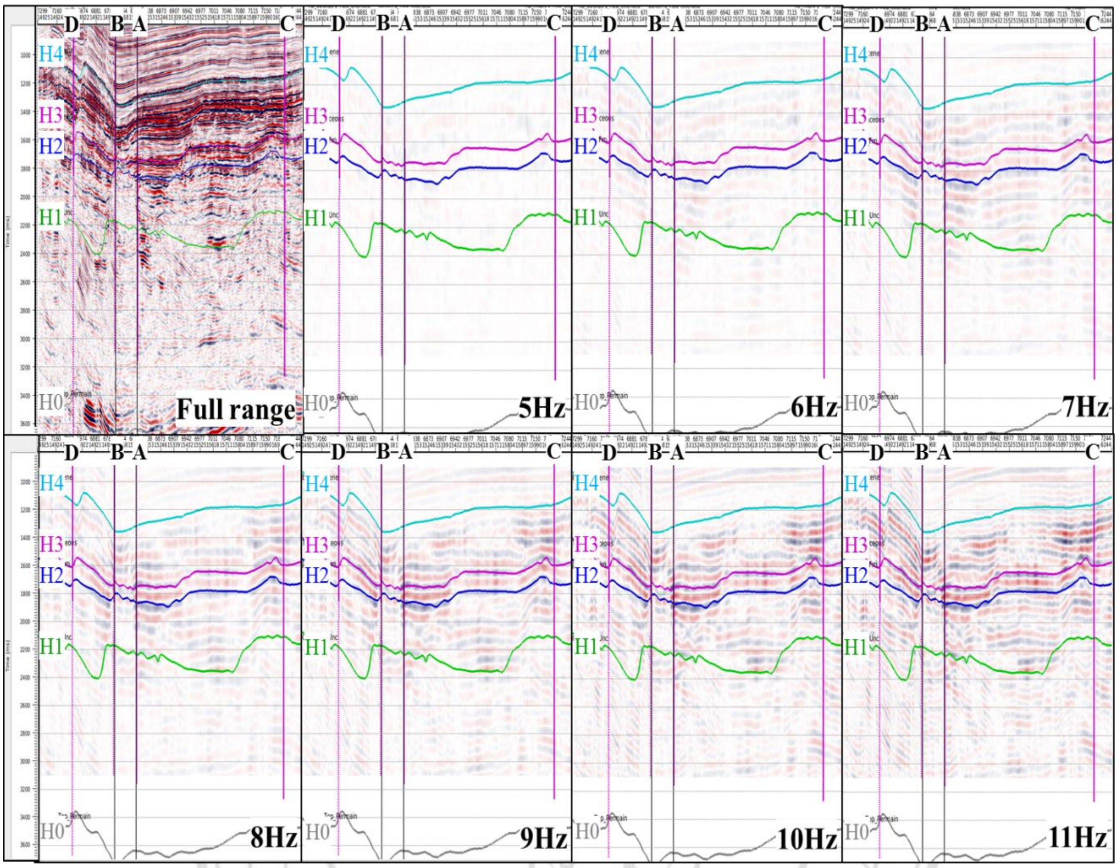


Figure 5-16 Frequency analysis was performed on mid angle seismic to find the low-end of seismic frequency.