[GC]Finding a Better Path to Impedance Inversion*

Amit Kumar Ray[1], Ritesh Kumar Sharma[1], and Satinder Chopra[1]

Search and Discovery Article #41722 (2015)
Posted November 2, 2015

*Adapted from the Geophysical Corner column, prepared by the authors, in AAPG Explorer, September, 2015. Editor of Geophysical Corner is Satinder Chopra (schopra@arcis.com). Managing Editor of AAPG Explorer is Vern Stefanic. AAPG © 2015

[1]Arcis Seismic Solutions, TGS, Calgary, Canada (schopra@arcis.com)

General Statement

A recent series of Geophysical Corner articles focused on impedance inversion of seismic data, and how it allows the estimation of elastic properties for reservoir characterization:

Impedance Inversion Transforms Aid Interpretation, Search & Discovery Article #41622,
Prestack Impedance Inversion Aids Interpretation Search & Discovery Article #41664,
Joint Impedance Inversion Transforms Aid Interpretation, Search & Discovery Article #41667

For making qualitative predictions about the reservoir, a simple transformation of the seismic amplitudes into impedance values is good enough. Such an impedance section will show relative impedance changes, which may not match the impedance log data in terms of absolute values.

As discussed earlier, the low-frequency band (less than 10 Hz) of the frequency spectrum is missing in the seismic data – and consequently, the transformed impedance data also have this frequency band missing. This low-frequency band can be extracted from the impedance well log curves and added to the transformed impedance data, when their values – now called absolute values – match the values seen on the impedance log curves. The low-frequency band we refer to here is first constructed in the form of a model, which may be 2-D or 3-D, depending on whether the data being inverted is 2-D or 3-D.

The low-frequency model is constructed such that the different subsurface interval impedance values are constrained by the horizons interpreted on the seismic data. This leads to more meaningful inverted impedance data. As we begin to use such inverted data, we realize we are in for surprises:

- For a 2-D seismic profile passing through some wells, when the low-frequency trend extracted from a single well is used in the impedance inversion, the impedance section may or may not match the impedance logs at the other well locations.

- Similarly, if a single-well low-frequency trend is used for inverting a 3-D seismic volume, we often run into a similar problem.

Another way to generate a low-frequency model is to make use of a few wells for generating the low-frequency model for inclusion in the impedance inversion. Such a technique linearly interpolates the impedance data between the wells using weights calculated on the basis of inverse distance, and similarly extrapolates away from the well control.

When quality checks are performed on the generated low-frequency models using this technique, they often are found to exhibit artifacts in the form of artificial tongues with anomalous impedance values, appearing more like bull's eyes. Such patterns are not geological and do not generate meaningful impedance sections or volumes.

Method with Examples

Here we discuss a new workflow for building a low-frequency model for impedance inversion that uses both the well log data as well as seismic data. Suitable attributes derived from seismic data, as well as the data from different wells, are used to estimate a linear regression relationship. This relationship is then used to predict the low-frequency component for use in impedance inversion. The steps followed in the workflow are described below and are applied to a dataset from northeast British Columbia in Canada.

First we generate a low-frequency impedance model using a single well. This model represents the overall compaction trend within the 3-D volume.

Next, we carry out model-based impedance inversion on the 3-D seismic volume. As mentioned above, the log correlation at other wells may not be satisfactory, which is found to be true in this case study.

Before we go further it is important to understand the idea behind the use of multi-attribute regression. In this case, the objective of multi-attribute analysis is to find a relationship between the well log data and seismic data at the well locations. Once this relationship is obtained it will be used to predict a volume of the log property at each trace location of the seismic data.

A simple way of doing this is to crossplot the two in the broad zone of interest, where a cluster of points is usually seen. A best-fit or regression line is then drawn through the cluster of points, which represents the relationship between the two variables crossplotted. In such cases in general, however, a large scatter of the points is noticed on the crossplots, which prevents us from using a single seismic attribute for predicting the target log property.

For improving upon the scatter of points on the crossplot, we try bringing in more attributes in our analysis and executing the multi-attribute regression analysis. In this analysis, the target log is modeled as a linear combination of several input attributes at each sample point. This modeling yields a series of linear equations, which are solved for obtaining a linear weighted-sum of the input seismic attributes in such a way that the error between the predicted and the target log is minimized in a least squares sense.

We began with the multi-attribute analysis for first determining the low-frequency impedance curves at well locations from seismic attributes, comparing them with the real log data and then using the determined multi-attribute transforms to generate such curves at all the traces in the seismic volume. Different seismic attributes such as relative acoustic impedance from colored inversion, instantaneous attributes and different filtered versions of seismic data were used for the purpose.

Figure 1 shows the outcome of this analysis, which is a match between the predicted low-frequency impedance curve (red) and the actual low-frequency curve (black) for different wells. For each of the wells, a poor correlation is seen between the two types of curves over the target window that includes the broad zone of interest indicated with the yellow bars.

Disappointed with the poor correlation, we repeat the previous step by bringing in the low-frequency model derived using a single well in step 1 as another attribute, along with the other seismic attributes. In Figure 2, we show the match between the predicted impedance log using this workflow and the actual filtered impedance log curves. Notice now there is a very good correlation between the two sets of curves at each well location.

Encouraged with this result, we go through another process called cross-validation, wherein we exclude one well from the analysis in the previous step and then use the process to predict it. This analysis is repeated as many times as there are wells on the 3-D volume. Once this is done, the cross-validation prediction error is calculated at each of the well locations, which in this case was found to be very low. This step is used to gain confidence in the applicability of the present approach.

The multi-attribute regression analysis is now run for the full volume, and the low-frequency model is computed. The output volume was examined for its quality and a horizon slice from this volume is shown in Figure 3. We observe there is a gradual transition of low frequency impedance from one well to another as we expect. In contrast to this we show an equivalent horizon slice from the low-frequency impedance volume generated using the inverse-distance interpolation method. Notice the pronounced low-frequency impedance anomalies appear as bull’s eyes at wells W5 and W6, which will surely result in artifacts when used in impedance inversion.

Conclusions

The proposed workflow for generating a low-frequency impedance model is superior to the existing methods of low-frequency impedance generation. The quality of the low-frequency impedance model used in the inversion has a pronounced effect on the final impedance result, and thus a superior low-frequency impedance model when used in the inversion process yields a more accurate impedance inversion output.

Our work on other such exercises corroborate this conclusion. We recommend this workflow for carrying out estimation of elastic parameters for quantitative interpretation of seismic data – especially when there is lateral variation of the impedance from well-to-well through the 3-D volume.

Acknowledgment

We thank Arcis Seismic Solutions, TGS, for allowing us to present this work.

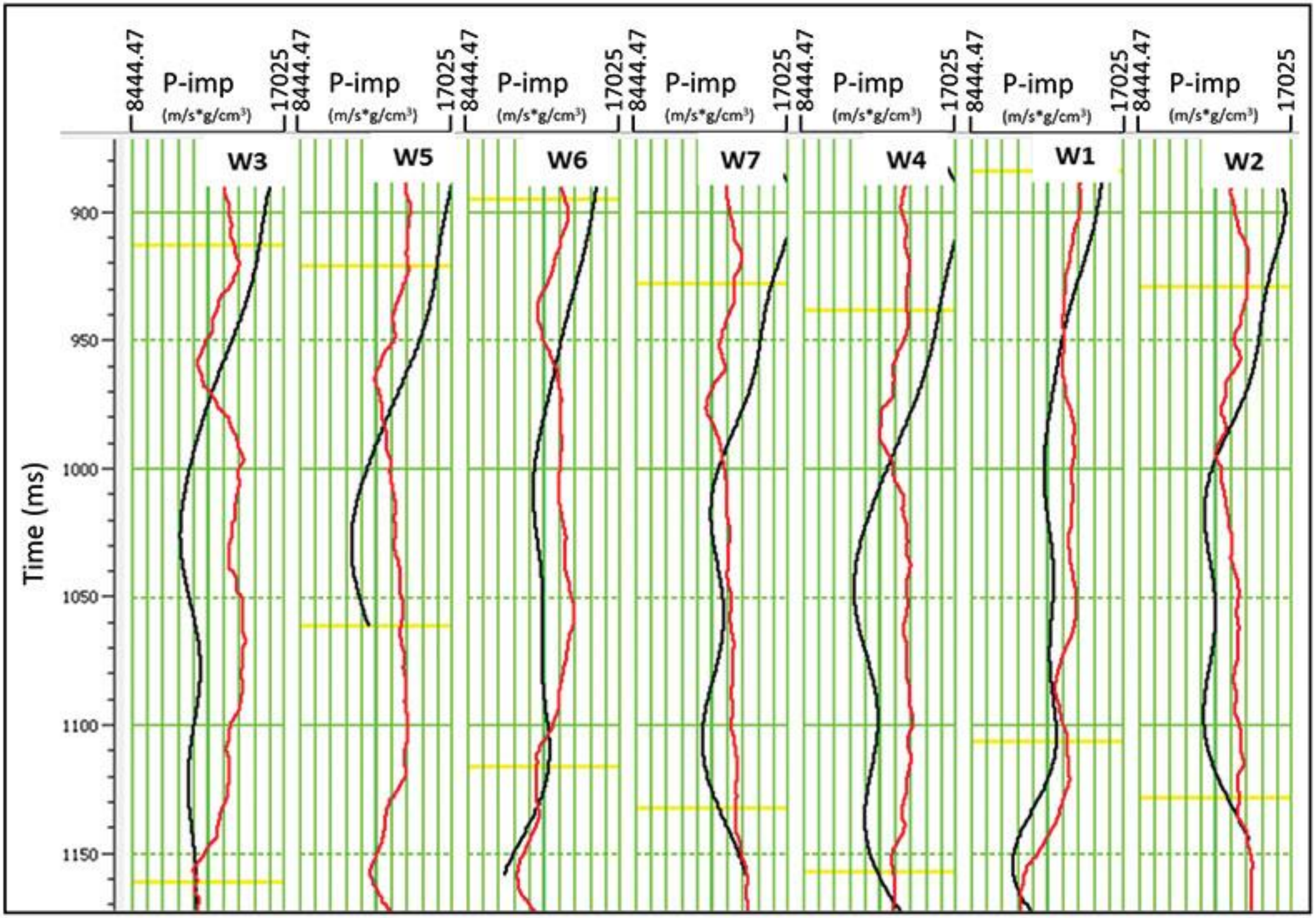

Figure 1. Match between the modeled impedance log and actual filtered impedance log curves using multi-attribute regression with use of seismic data and the derived seismic attributes. Black curves represent the filtered impedance logs and red curves represent the modeled impedance curves. Analysis window is marked with yellow bars. A poor correlation coefficient of 0.4 is observed.

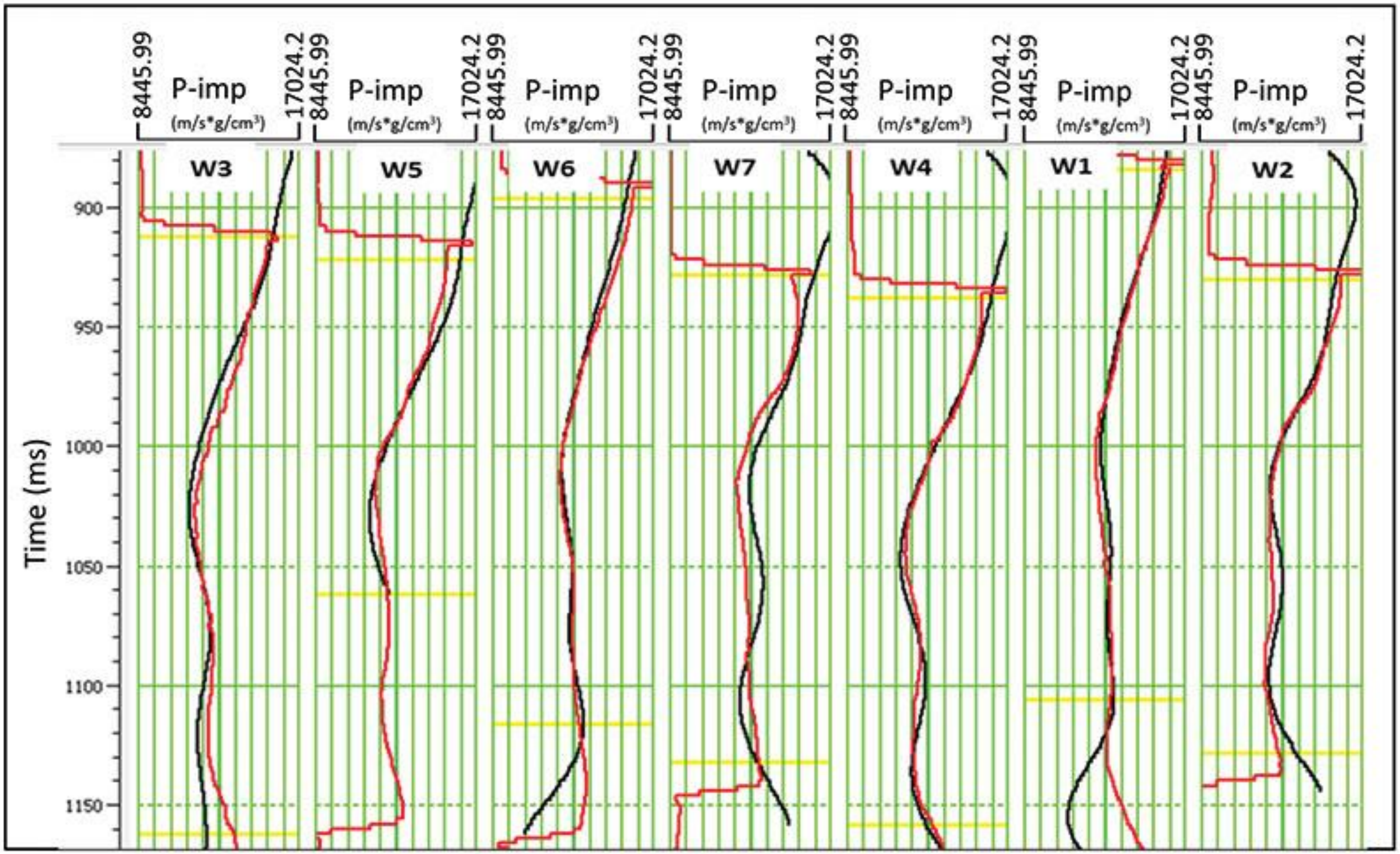

Figure 2. Match between the modeled impedance log and actual filtered impedance log curves using multi-attribute regression analysis, including single well low-frequency model as one of the inputs. Black curves represent the filtered impedance logs and red curves represent the modeled impedance curves. Analysis window is marked with yellow bars. Correlation coefficient improves significantly to 0.96.

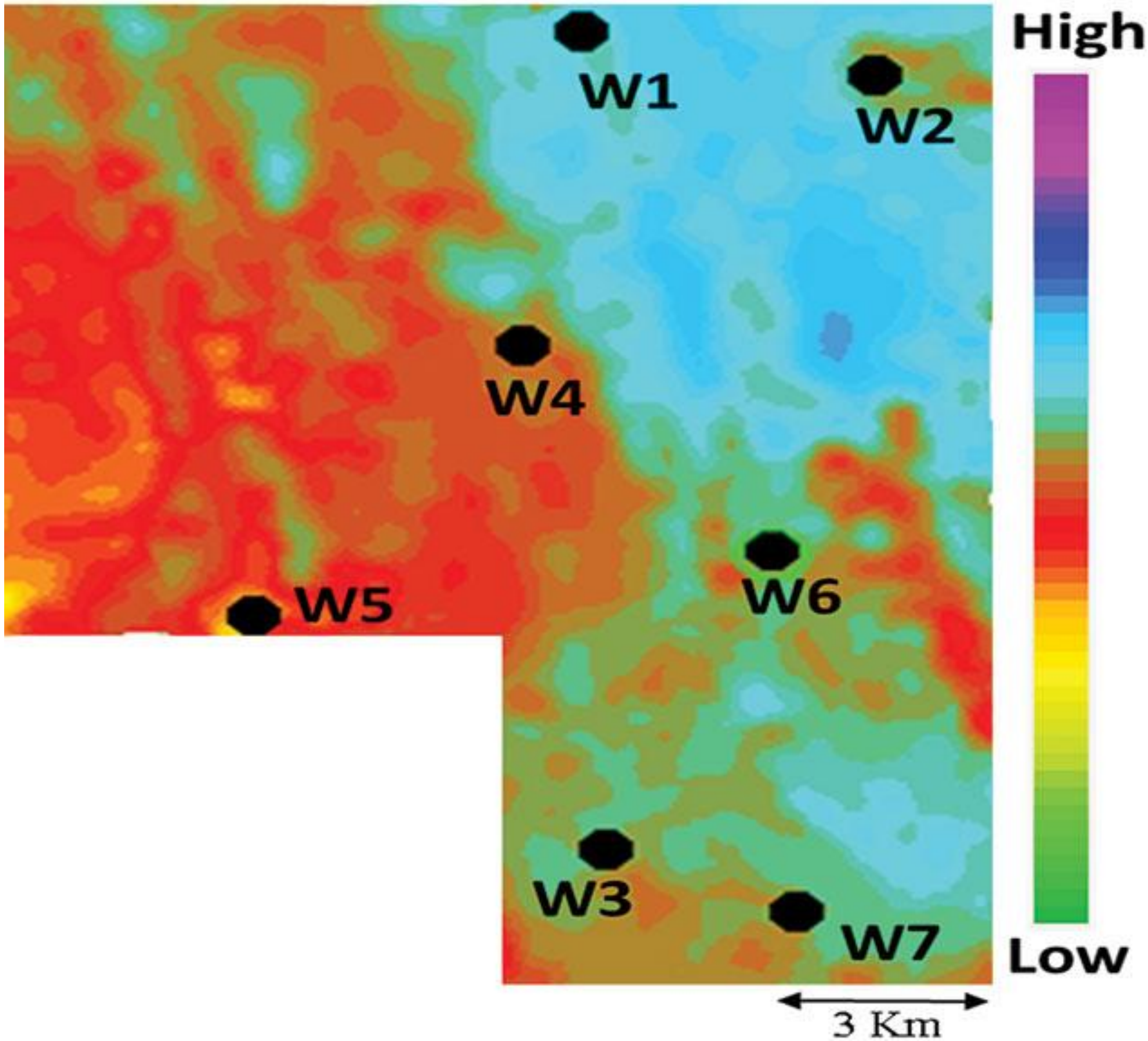

Figure 3. (left) Horizon slice in the zone of interest for the low-frequency model generated using multi-attribute regression method.

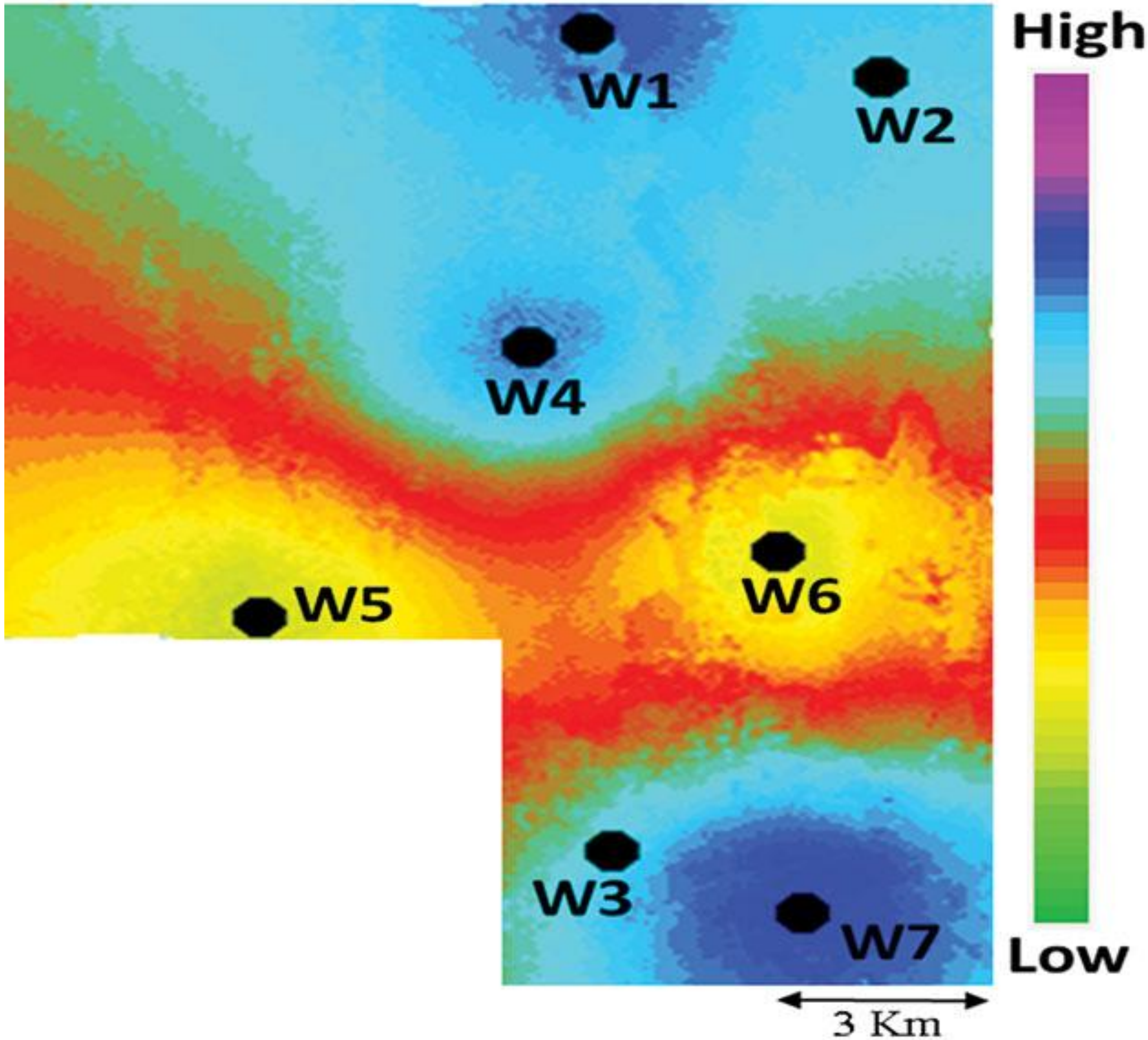

Figure 4 (right) Horizon slice in the zone of interest for the low-frequency model generated using inverse distance interpolation method. Notice the bull's eyes on the display, which would show artifacts on impedance inversion output.