Heavy Oil Reservoir Characterization by Time-lapse Seismic and Rock Physics in a Cold Production Reservoir*

Naimeh Riazi[1], Laurence Lines[2], and Brian Russell[3]

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[1]CHORUS, Department of Geoscience, University of Calgary, AB, Canada (nriazi@ucalgary.ca)
[2]CHORUS, Department of Geoscience, University of Calgary, AB, Canada
[3]CGG, Calgary, AB, Canada

Abstract

Time-lapse (4D) seismic technology is a well-known and effective technique for reservoir monitoring. In this approach, 3D seismic acquisition is performed several times during the production period of a reservoir to monitor changes in the elastic properties of the subsurface. The interpreted changes are then attributed to changes in the reservoir, such as saturation and pressure, due to production effects. The acquisition and processing techniques used, along with the calibration processes, should be implemented carefully on the seismic baseline and monitor surveys to optimize and improve the repeatability of non-reservoir effects and consequently enhance the production-related anomalies in the reservoir. Time-lapse seismic inversion can also be applied to derive acoustic and shear impedance volumes. These volumes can be used to extract useful attributes to investigate elastic attribute changes in the heavy oil. Rock physics is a link between the well log and seismic data that can help in the interpretation of the results and also aid in performing pre-stack time-lapse inversion. In this study, all of the above techniques are used in a heavy oil field which is produced by cold heavy oil production with the Sands (CHOPS) method.

Introduction

The time-lapse seismic reservoir monitoring technique has advanced rapidly over the past two decades. It consists of performing a 3D seismic imaging operation several times during the production period of an oil or gas field to formulate an accurate model of reservoir performance over time (Anderson et al, 1997). Time-lapse seismic monitoring can enhance the recovery efficiency of old fields by providing valuable information on field performance. The opportunity provided by time-lapse data is the ability to image the fluid flow in the volumetric region of the reservoir (Lumley, 2001, Lines et al, 1989). Assuming that the geological effects on the petrophysical properties of the reservoir over the production time are negligible, the change in seismic response can be related to production-related effects such as changes in pressure, saturation, and temperature of the reservoir.

Rock physics theory is the link between the seismic data and the reservoir processes. In many Enhanced Oil Recovery (EOR) methods for heavy oils, the seismic wave velocity and density of the reservoir is altered and this provides the opportunity to monitor the reservoir parameter changes by measuring the changes in these elastic parameters.

The change of seismic velocity also changes the acoustic and shear impedance of the reservoir, since acoustic impedance is the product of density and P-wave velocity and shear impedance is the product of density and S-wave velocity. Thus, by performing inversion on the seismic volumes acquired during the production process, the changes in impedance can be extracted and calibrated to changes in the reservoir parameters. In this study, two inversion methods, post- and pre-stack inversion, are used to extract the acoustic and shear impedance volumes from the baseline and monitor surveys for a CHOPS heavy oilfield. Cold heavy oil production with Sand (CHOPS) is one of non-thermal recovery methods which is used in Canadian heavy oilfields, especially in Alberta and Saskatchewan. In this method, progressive cavity pumps cut the unconsolidated sands.

Methodology

Due to many non-production effect on the time and amplitude changes of the repeated seismic surveys, such as different near-surface weathering effects, different instrumentation, different seismic geometry, etc. it is necessary to process and calibrate the seismic volumes to optimize the repeatability of time-lapse seismic data. Different calibration tools were applied in this case study. The complete seismic calibration process that was done in the studied area is shown in Figure 1. Figure 2 illustrates the result of the seismic calibration and compares it with the data before calibration.

Before starting the seismic inversion, rock-physics analysis was performed in this case study. For modeling how the P-wave velocity changes with the saturation variation, the Gassmann fluid substitution model (Gassmann, 1951) was used. The bulk modulus of saturated rock (K_{sat}) can be estimated by Equation 1, which is referred to as the Gassmann equation.

Equation 1

$$K_{sat} = K_{dry} + \frac{\left(1 - \frac{K_{dry}}{K_m}\right)^2}{\frac{\emptyset}{K_{fl}} + \frac{1-\emptyset}{K_m} - \frac{K_{dry}}{{K_m}^2}}$$

where ø is the porosity, K_m is the bulk modulus of the mineral. Here, K_{fl} is the fluid modulus and is given by the weighted harmonic average of the bulk moduli of the individual phases:

Equation 2

$$\frac{1}{K_{fl}} = \frac{S_w}{K_w} + \frac{S_o}{K_o} + \frac{S_g}{K_g}$$

where S_w, S_o, and S_g are the water, oil, and gas saturations respectively, and K_w, K_o, and K_g are the water, oil, and gas moduli respectively. The bulk moduli of the various phase were obtained by using the equations of Batzle and Wang (1992), which are dependent on hydrocarbon temperature, API and GOR.

Figure 3 shows the effect of production when gas comes out of solution just by 10%, where the red curve indicates the initial state and the blue curve the final state. The decrease of P-wave velocity is quite large.

Time-lapse Seismic Inversion

Model-based post-stack and pre-stack inversion was performed in this case study. As shown in Figure 3 the seismic P-wave velocity decreases during reservoir production because of pressure and saturation changes. This also means that the acoustic impedance will decrease. Figure 4 shows the difference between the inverted acoustic impedance between the base and monitor surveys. The maximum change of acoustic impedance is 7%, comparable to the change of the velocity modeled in Figure 4. Pre-stack time-lapse inversion provides more information about the reservoir changes because shear impedance volumes can be produced by pre-stack seismic inversion in addition to acoustic impedance volumes. It is clear from the Figure 5b that the shear impedance also reveals the change in the reservoirs zone. For comparison, the P-impedance change is shown in Figure 5a. Note that only one anomalous zone in shown on the S-impedance inversion, compared to two anomalous zones on the P-impedance. This is due to matrix changes and high viscosity, a high change of shear impedance can be seen very well in the production zone.

Time-lapse Seismic Attributes

Discriminating the changes in the reservoir zone is the main goal of reservoir characterization. As just discussed, pre-stack inversion provides us the opportunity to build different seismic attributes. We can extract different time-lapse seismic attributes by using combinations of post- and pre-stack time-lapse seismic inversion results such as Lamé parameters Vp/Vs ratio and Poisson’s ratio. All of these inversion attributes can help us to estimate the reservoir changes such as porosity. Figure 6 illustrates the average porosity estimation by using a multi-attribute technique in the reservoir zone. The reservoir zone can be seen to have very high porosity values.

Conclusions

Post- and pre-stack time-lapse seismic inversion is a useful technique for discriminating the reservoir zone from non-reservoir zone and also describing fluid changes. Rock physics models help us to link the well-log and seismic data and also provide the basis for inversion analysis.

We can also perform fluid substitution modeling using the Gassmann Equation. We also showed that by deriving the acoustic and shear impedance volumes from post- and pre-stack time-lapse inversion, we could predict fluid changes in the reservoir as well as deriving porosity estimates in a CHOPS heavy oilfield.

Acknowledgements

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References Cited

Anderson, R.N., A. Boulanger, W. He, L. Xu, B. Meadow, and R. Neal, 1997, What is 4D reservoir Monitoring?: World Oil, v. 218/3.

Batzle, M., and Z. Wang, 1992, Seismic properties of pore fluids: Geophysics, v. 57/11, p. 1396–1408.

Gassmann, F., 1951, Uber die elastizitat poroser medien: Vier. Der Natur. Gesellschaft, v. 96, p. 1–23.

Lines, L.R, R. Jackson, and J.D. Covey, 1989, Seismic velocity models for heat zones in Athabasca tar sands: 59th Annual International Meeting, SEG, Expanded Abstracts, p. 751-754.

Lumley, D.E., 2001, Time-lapse seismic reservoir monitoring: Geophysics, v. 66/1, p. 50–53.

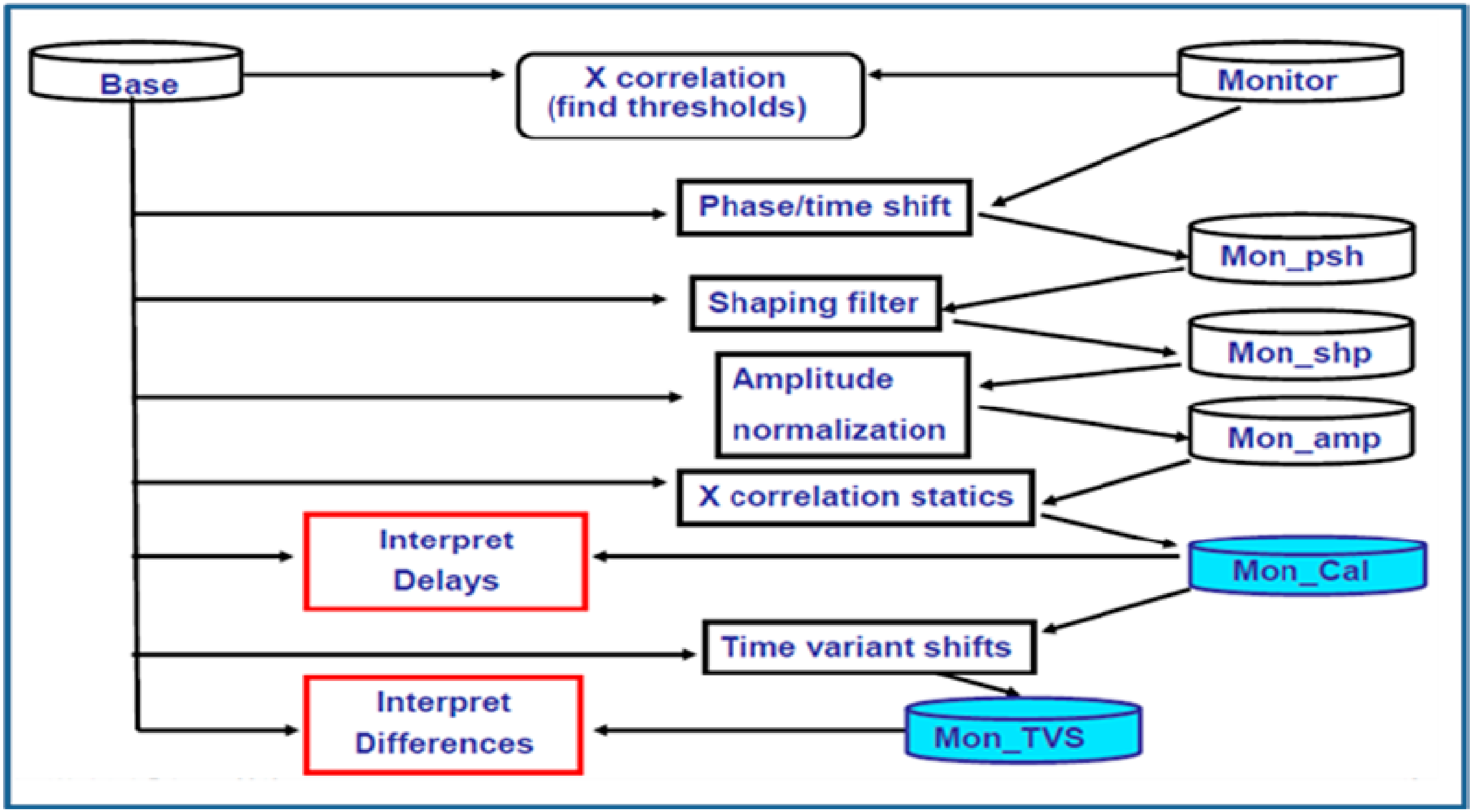

Figure 1. The time-lapse seismic calibration process (HR unpublished course noted for PRO4D).

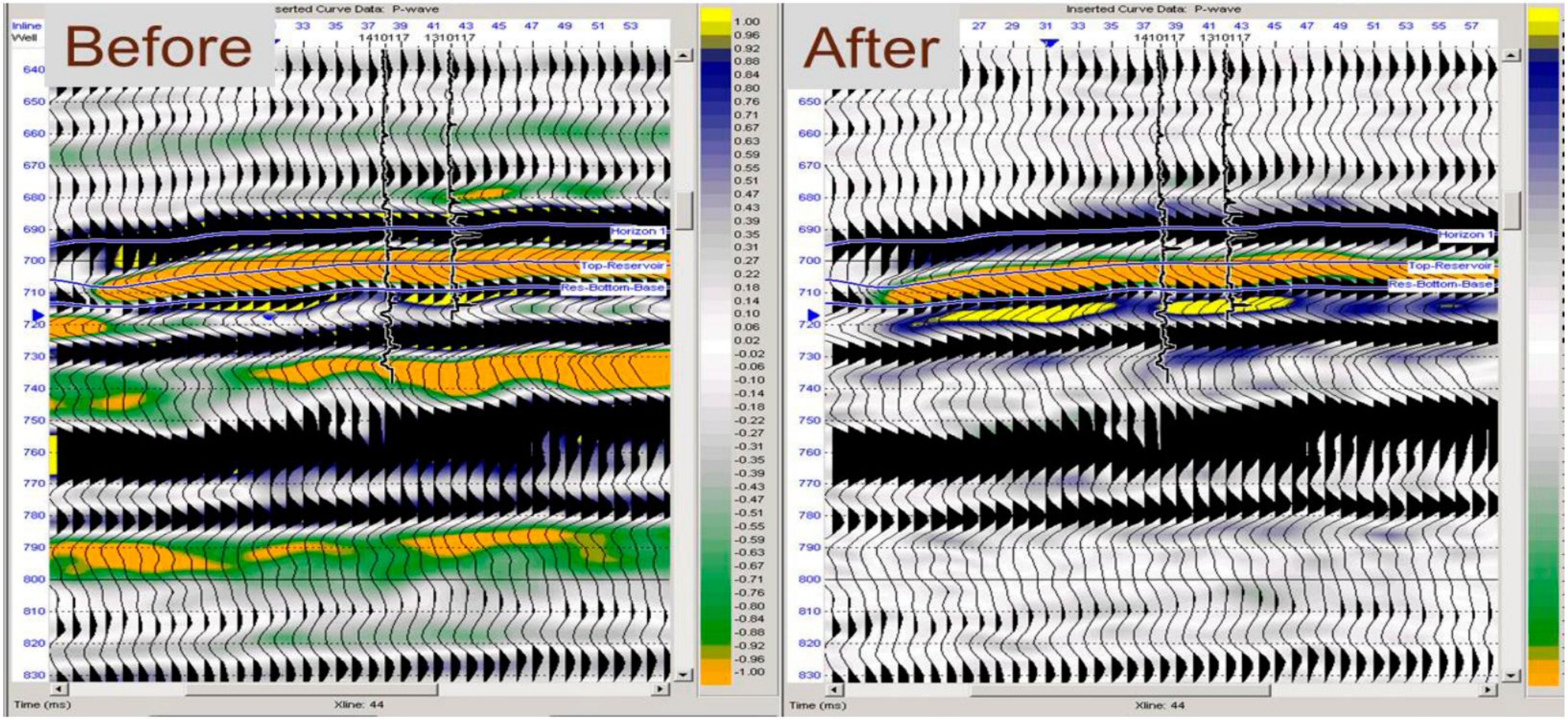

Figure 2. Left (before) and Right (after) calibration of time-lapse seismic data.

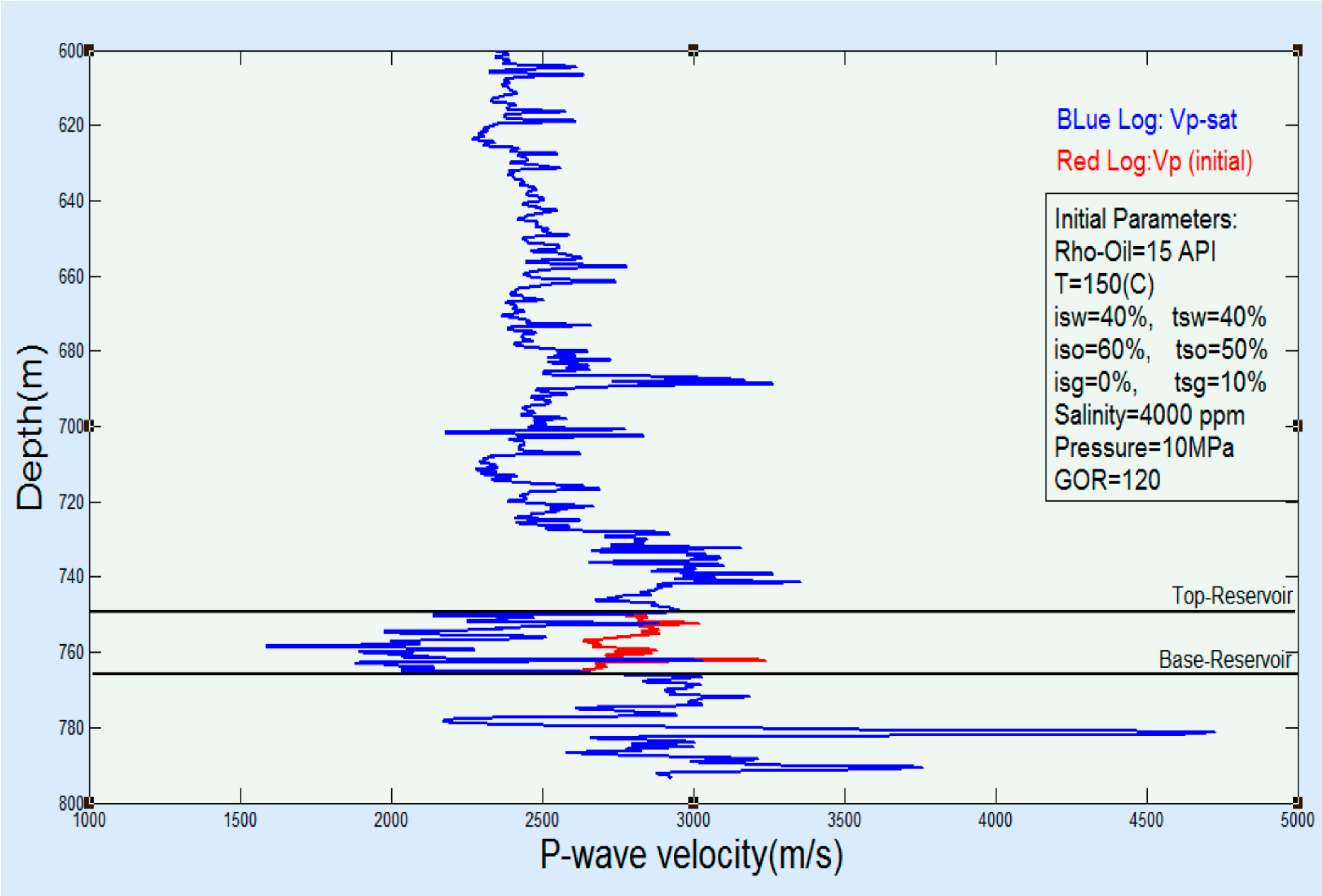

Figure 3. Fluid substitution modeling in one of the wells in the studied area.

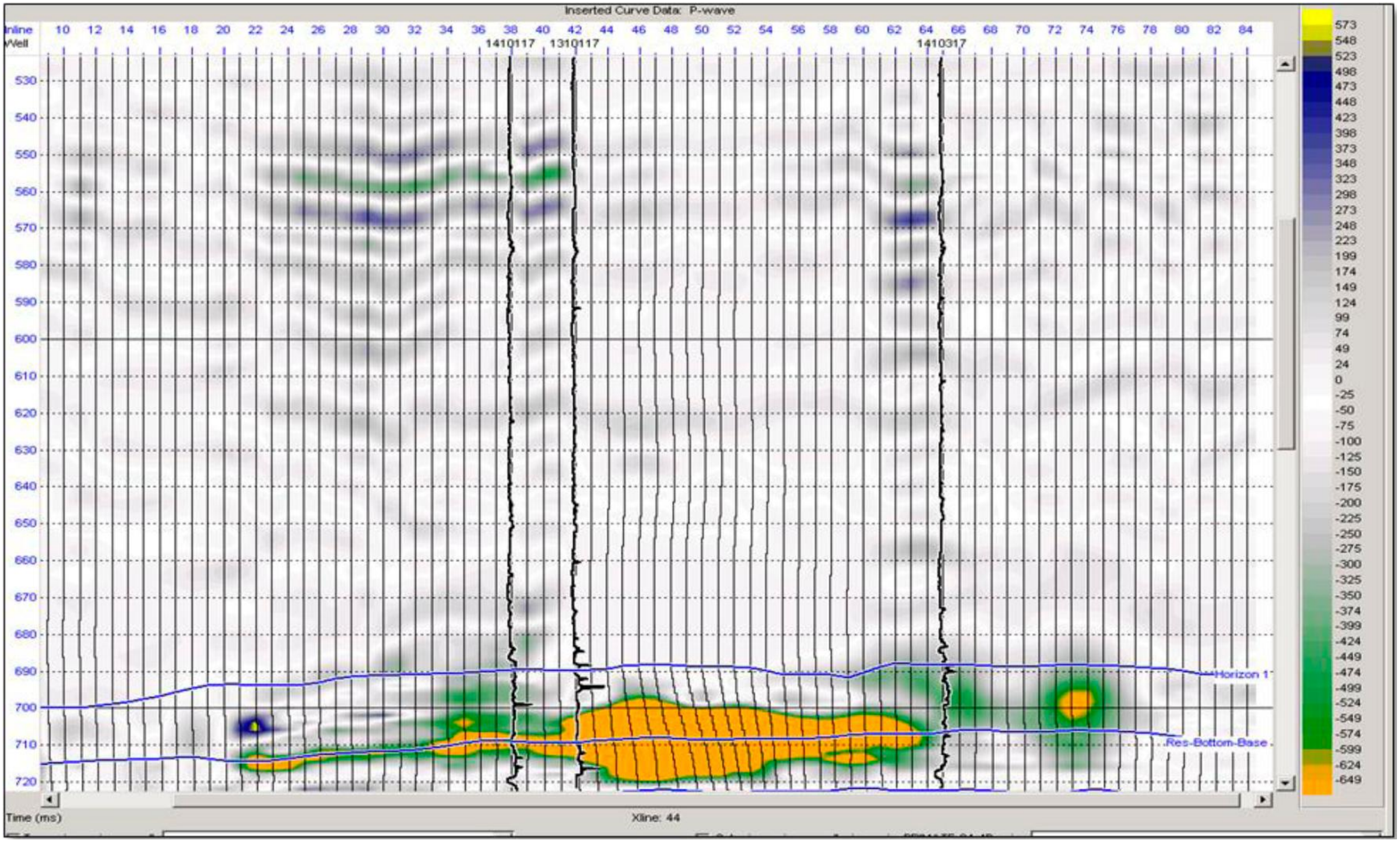

Figure 4. Acoustic impedance section from time-lapse post-stack inversion.

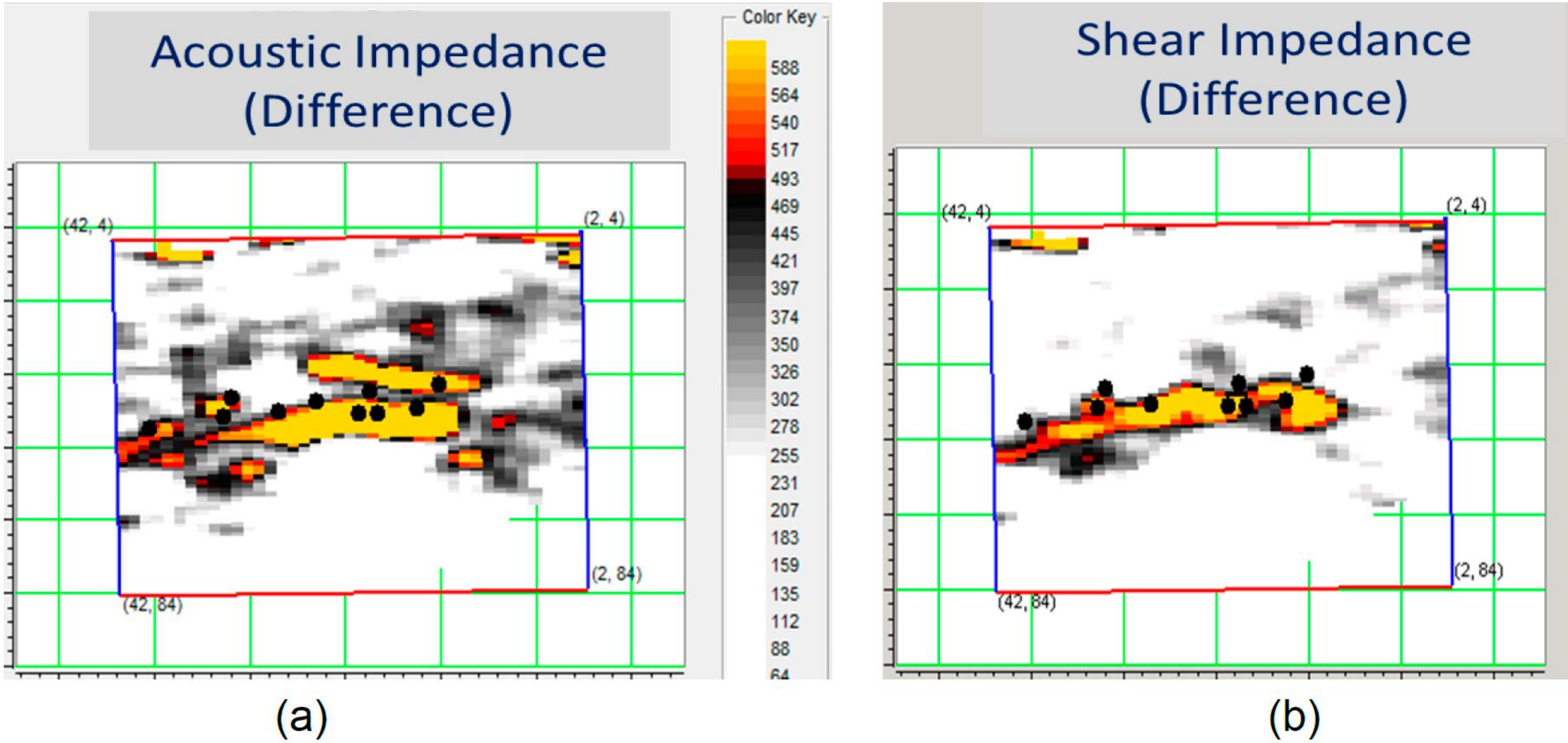

Figure 5. The average difference map of (a) acoustic and (b) shear impedance in the reservoir zone.

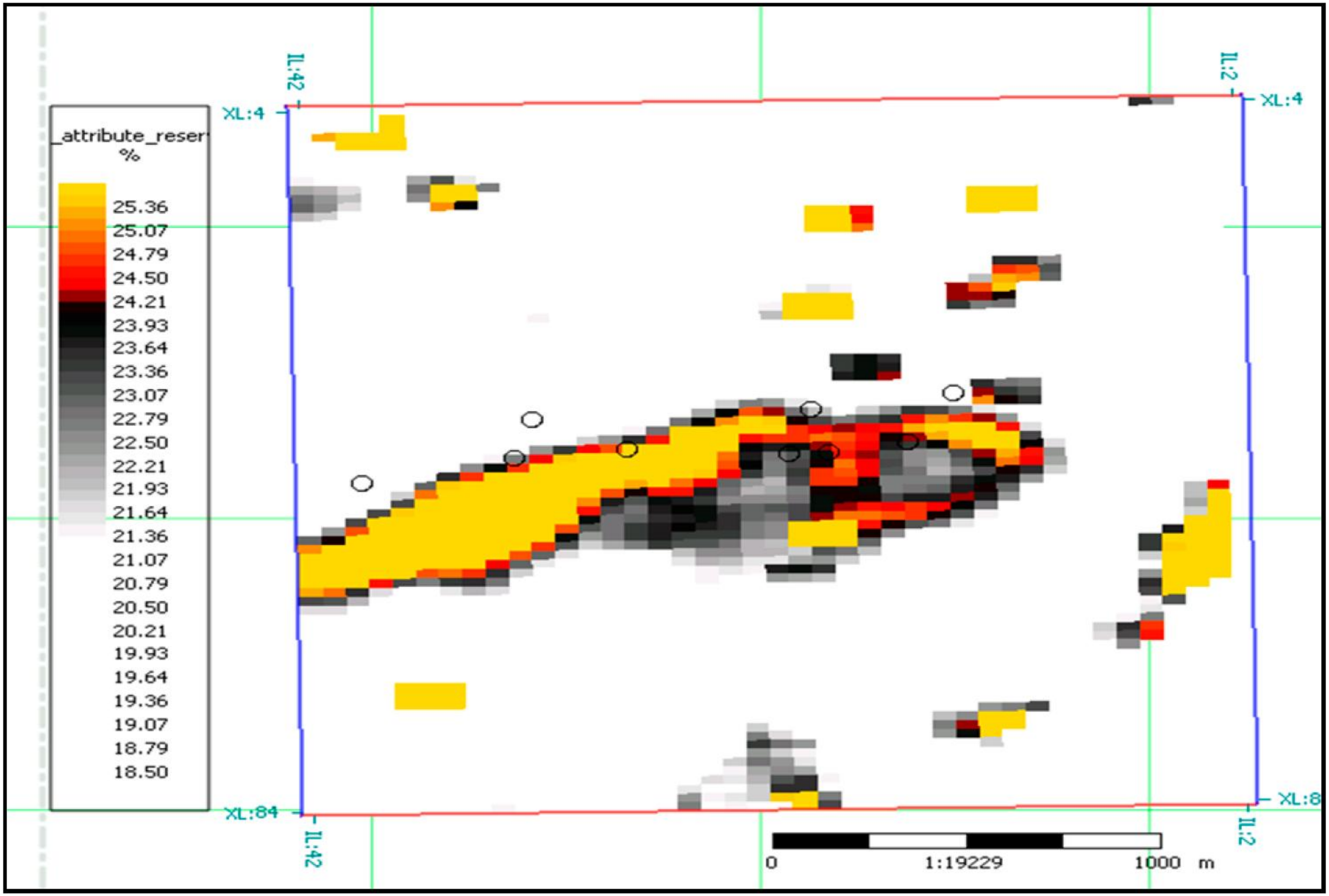

Figure 6. Average porosity Estimation map using multi-attribute in reservoir zone.