

Seismic-Based Volcano Identification and Characterization in HD Oilfield, Tarim Basin*

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Abstract

HD Oilfield is located in the center of Tarim Basin, China. As the target of this study, the Carboniferous Donghe sandstone is characterized by middle porosity, middle permeability, high structure maturity and few interlayers. The practical hydrocarbon development of the recent twenty years shows the spatial heterogeneity of the marine Donghe sandstone. This phenomenon is hardly explained just using interlayers. Aiming at the cause of reservoir heterogeneity, we take a specified study on the seismic processing and interpreting process. In this way, a series of small ancient volcanic zones are discovered for the first time in this oilfield. These volcanic zones are very beneficial for secondary development. Our study also brings a new solution for the further study on the non-penetrated zone within the reservoirs.

In order to characterize the main target stratum, the processing technique that both enhances the vertical resolution and relatively preserves the information of the reservoir is applied. The relative amplitude preservation processing technique mainly includes earth absorption compensation, and two-step deconvolution based on shot-receiver gathers. The major processing steps have been monitored using the geophysical and geological QC method during data processing. Based on the high precision processing results, seismic attributes such as variance, curvature, ant colony and edge detection cubes are extracted. In addition, integrating them with 3D visualization techniques, comprehensive study on the volcano distribution was conducted.

Through integrated analysis of seismic attributes, geological data and drilling results, we conclude that hundreds of volcanoes are widely developed in this zone and mainly distributed from south to north with a belt shape. There are two major volcano development zones in the Donghe sandstone, namely the east zone and west hydrocarbon-bearing zone, respectively. Volcanic conduit diameter in the east zone ranges from 600 meters to 1000 meters, while the diameter in the west zone is smaller and ranges from 10 meters to 80 meters. As seepage flow barriers, these volcanoes locally control the spatial distributions of reservoirs.

Introduction

In recent years, the study of volcanic rock has attracted much attention as a focused in petroleum exploration and development. A number of oil and gas fields associated with volcanic rock with high commercial potential have been reported all around the world, including Japan (e.g. Mitsuhashi et al., 1999), Argentina (e.g. Sruoga et al., 2004) and Russia (Levin, 1995). Recently, industrial volcanic gas reservoirs have been discovered in China, such as the Liaohe Basin (e.g. Wang et al., 1997), Songliao Basin (SB) (e.g. Zhang, et al., 2009). Volcanic gas reservoirs have been played an important role in oil and gas production in China, especially in eastern basins. In the SB, approximate 60%~70% of total deeply buried gas is preserved in volcanic and volcanic clastic rocks (Jin, 2008).

Extensive studies have been performed on the volcanic prediction, formation law and architecture. However, the spatial heterogeneity of clastic reservoir caused by volcanic rocks is not studied enough. Taken HD oilfield as an example, the effects of volcanic rock on the reservoir structure and heterogeneity of reservoirs are carried out. This study provides a better understanding for the petroleum geology, and reduces the risks on hydrocarbon exploitation in this basin.

Background of the Oilfield

HD oilfield is located in the center of Tarim Basin, China (Figure 1). The depth of the target reservoir is greater than 5000 meters. The porosity varies from 12.6% to 24.6%. The permeability is from 8×10^{-3} to $800 \times 10^{-3} \mu\text{m}^2$. The target reservoir is characterized by middle porosity, middle permeability, high structure maturity and few interlayers. Seismic exploration of this area began in 1980s and the 3D data covered the whole area until 2000. However, these data with low-fold and narrow azimuth could not meet the demand of the development of the oilfield. In order to solve the problem, full-azimuth 3D seismic data was acquired in 2012

Seismic Processing

Based on the concept of relative spatial resolution in seismic exploration, the processing procedure that both enhances the vertical resolution and relatively preserves the information of the reservoir as well as the techniques for attenuating the near-surface effects are critical to get a high-precision seismic imaging result. More importantly, a scientific and efficient QC flow is a guarantee of success. The relative amplitude preservation processing techniques mainly include earth absorption compensation in time-frequency domain, two-step deconvolution based on shot-receiver gathers, static correction, etc. The major processing steps have been monitored using the geophysical and geological QC methods during data processing.

Vertical resolution of seismic data can hardly meet the requirement of geological interpretation due to near surface variation, earth absorption, and high-frequency noises. During data processing, it is important to improve the resolution of seismic image while removing the spatial variation caused by non-reservoir factors and preserving the relative spatial information of the reservoir at the same time. The compensation of spherical divergence and absorption in time and frequency domain (Ling et al., 2005) is a powerful technique for resolution improvement and non-reservoir spatial variation (e.g., source energy variation) removal. Figure 2 gives the comparison of shot gathers before and after time-

frequency absorption compensation. Noises have been attenuated and the resolution of signals has been improved greatly. Then, two-step statistical deconvolution (shot and receiver gather) and residual static correction were implemented.

The main geophysical monitoring methods include source energy, source wavelet and high-frequency noise monitoring in 3D volume, and quantitatively analysis of data quality (Gao et al., 2009). [Figure 3](#) shows autocorrelation analysis in the control line, it is evident that the wavelet variation due to shooting, receiving and near-surface changes is eliminated, thus the data resolution is improved. [Figure 4](#) shows the 3D source wavelet QC that compares the spatial variation of wavelets between before and after processing. Obviously, the spatial variation of wavelet is reduced greatly after processing.

The practical hydrocarbon development of the recent twenty years shows the spatial heterogeneity of the marine Donghe sandstone. This phenomenon cannot be explained just using interlayers. Aiming at the cause of reservoir heterogeneity, VTI velocity analysis is firstly implemented. [Figure 5](#) gives the comparison of the conventional and VTI NMO velocity analysis: CMP gathers exhibit more flattened, especially at far offsets, so the interval velocity based on VTI NMO seems more reasonable ([Figure 5c and 5d](#)). Furthermore, the depth mapping of Donghe sandstone using the VTI interval velocities performs better than using conventional interval velocity.

Interpretations

The multi-seismic attributes such as variance, curvature, ant colony and edge detection cubes are also used to characterize the volcanic geometry, distribution and reservoir properties. Structural modelling using seismic and variance data provides an efficient tool to characterize the distributions of the volcanic zones and fault systems.

The evolution of the volcano. In order to study the evolution of the volcano, variance slices of Donghe Sandstone (TC) and the top of volcanic rocks (TP_top) were extracted in the time domain ([Figure 6](#)). In the TC strata slices of the variance data, there are two ring incoherence zones (location of red circle) which indicates the position of the volcanic conduit. While in the TP_top strata slices of the variance data, there are two ring incoherence zones corresponding to the TC's which indicates the position of the volcanic crater.

The distribution of the volcano. For characterizing the distribution of the volcano, variance slices of the volcanic rocks (TP_bot) and the Donghe Sandstone (TC) were extracted in the time domain ([Figure 7](#)). Through integrated analysis of seismic attributes, geological data and drilling results, we conclude that hundreds of volcanoes are widely developed in this zone and mainly distribute from south to north with a belt shape ([Figure 7a](#)). There are two major volcano development zones in the Donghe sandstone, namely the east zone and west hydrocarbon bearing zone ([Figure 7b](#)), respectively. Volcanic conduit diameter in the east zone ranges from 600 meters to 1000 meters (location of red circle), while the diameter in the west zone is smaller and ranges from 10 meters to 80 meters (location of yellow circle).

The type of volcano eruption in HD oilfield. The volcanic geometry can be characterized by the 3D visualization ([Figure 8](#)). The figure shows the variance attribute (slice) of TC and seismic data (section). In the figure, volcanic eruption can be distinguished into two forms: fissure eruption ([Figure 8a](#)) and central vent eruption ([Figure 8b](#)). The former refers to the eruption along Donghe sandstone fault zone while the latter appears as volcanic conduit.

The effect of the distribution of volcanic rocks to reservoir lateral heterogeneity. Well (a) and well (b) are two production wells, Well (a) is high yield well while well (b) is high water-cut well; there is little difference between the two wells from the seismic section (Figure 9c) and well logging interpretation (Figure 9d). However, from the distribution of volcanic rock, the two wells are in different volcanic facies belt (Figure 9a, Figure 9b). Volcanic rock remolded the lithology of reservoir and form a series of low permeability zone, which is the same as the distribution of volcano, and it caused the heterogeneity of reservoir in this area.

Conclusions

After interpretation of the processed full-azimuth seismic data, the following conclusions are obtained:

1. In order to meet the demand of the development of the oilfield, full-azimuth and high-fold 3D seismic data is required.
2. The velocity of volcanic rocks and surrounding rocks varies enormously, so the change of volcanic rocks thickness will influence the accuracy of the depth map of Donghe sandstone. Through VTI velocity calibration, the depth prognosis error can be reduced.
3. In HD oilfield, volcanic eruption can be distinguished into two forms: fissure eruption and central vent eruption. The former refers to the eruption along Donghe sandstone fault zone while the latter appears as volcanic conduit.
4. The large area distribution of volcano can cause the spatial heterogeneity of the marine Donghe sandstone. Fine characterization of volcanic rocks is benefit to the reservoir prediction.

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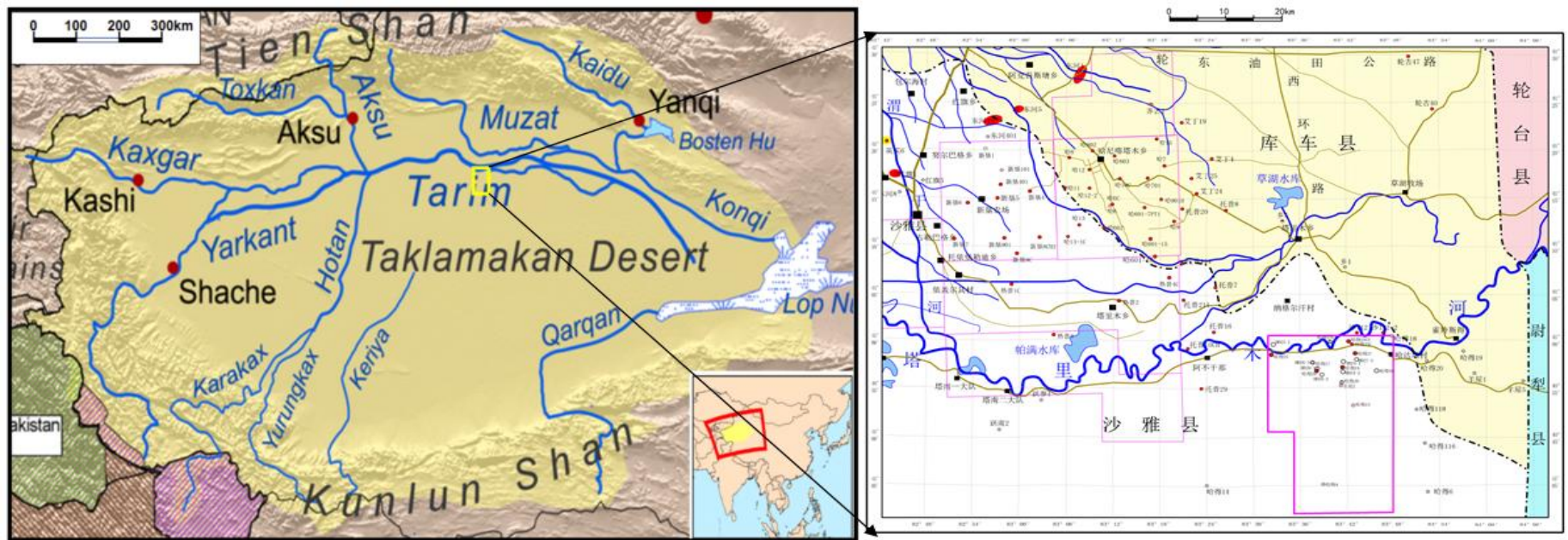
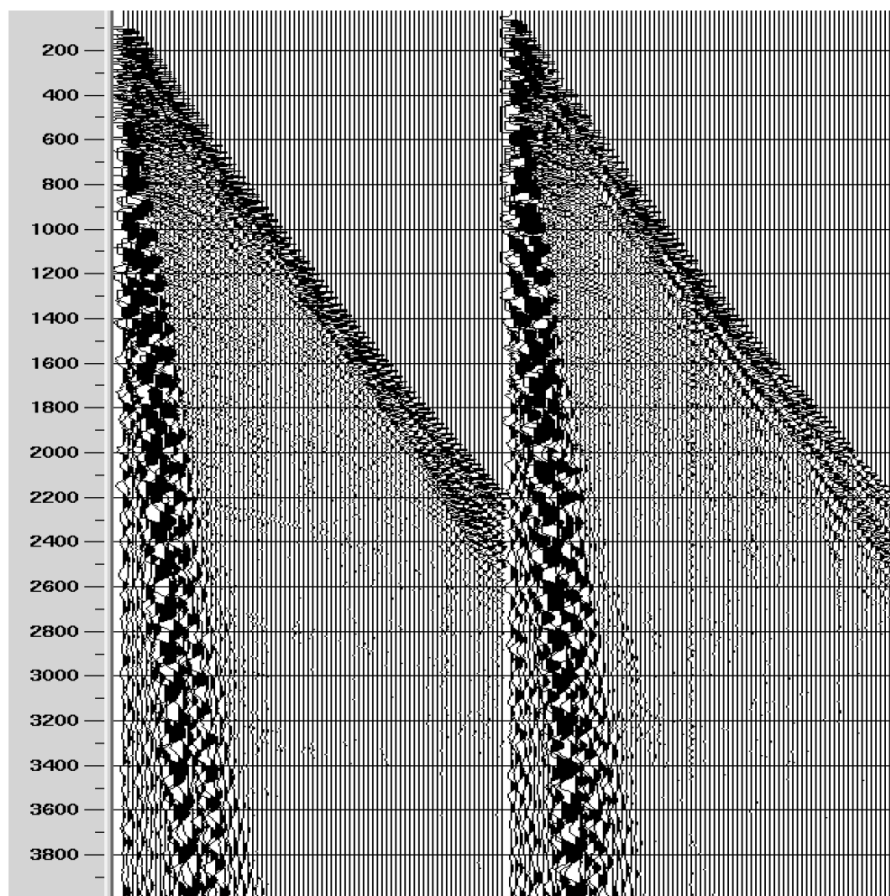
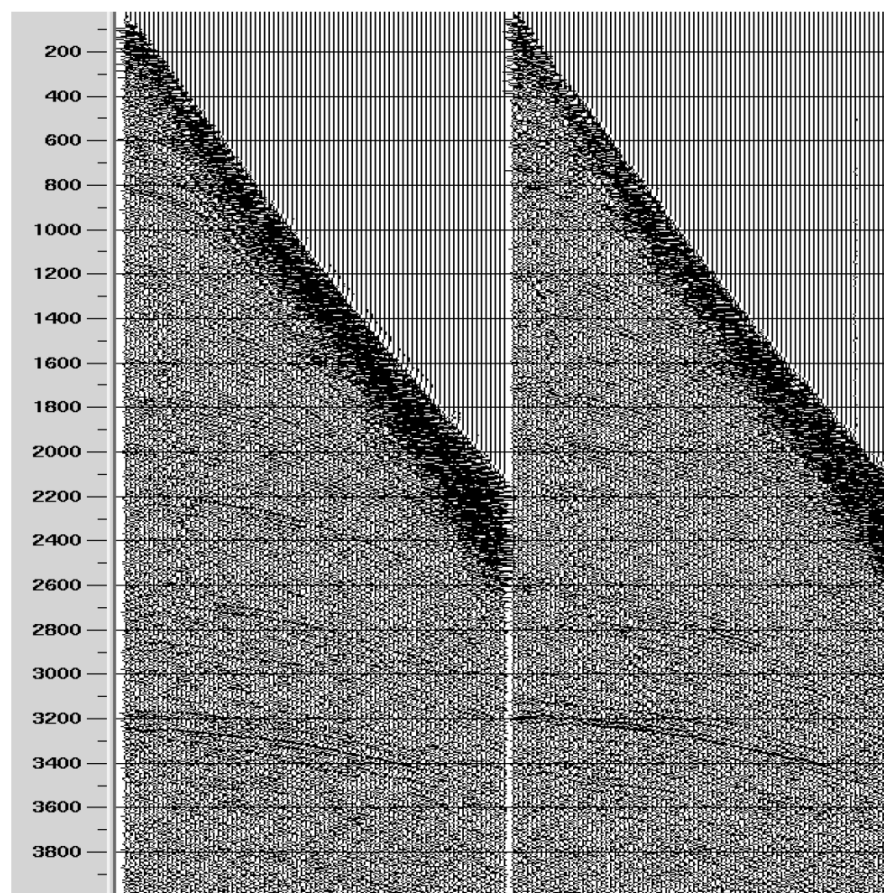


Figure 1. Location map of HD oilfield in China. The red box is the location of Tarim Basin in China, the yellow box is the location of HD oilfield and the pink box is the 3D seismic survey area.



(a)



(b)

Figure 2. a) Raw shots, b) shot gathers after time-frequency absorption compensation.

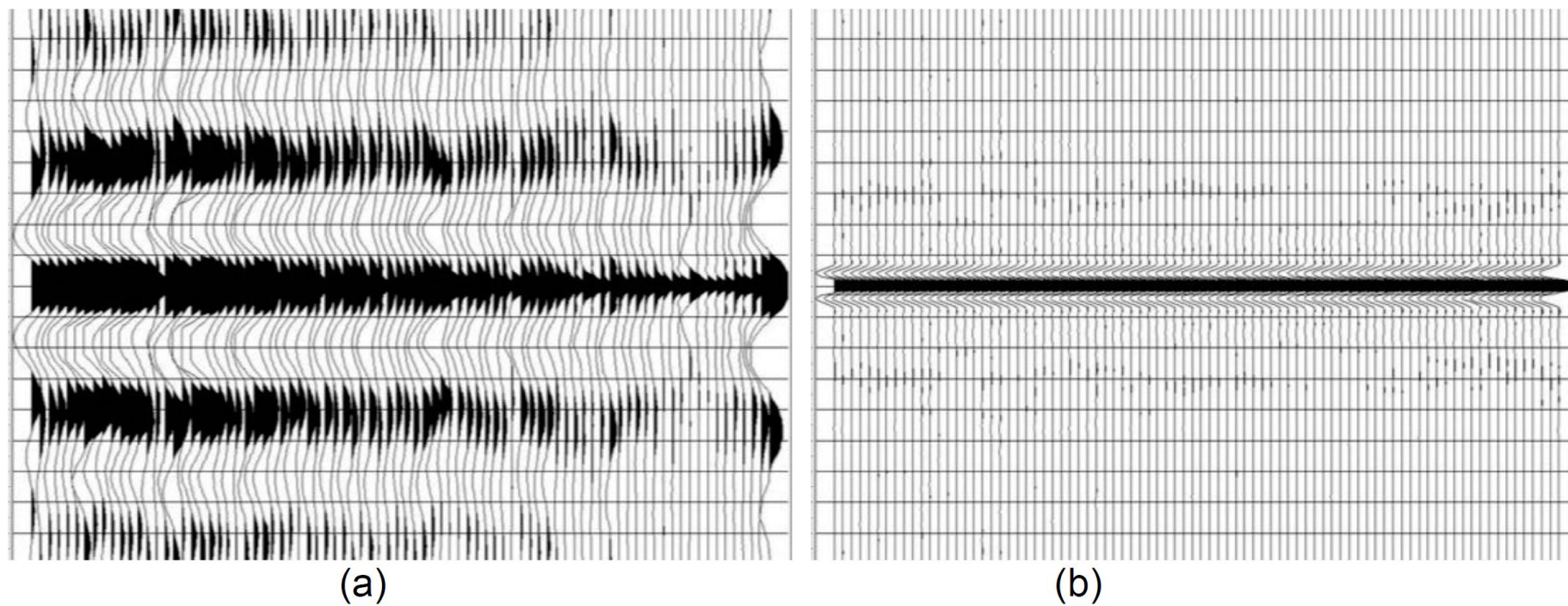
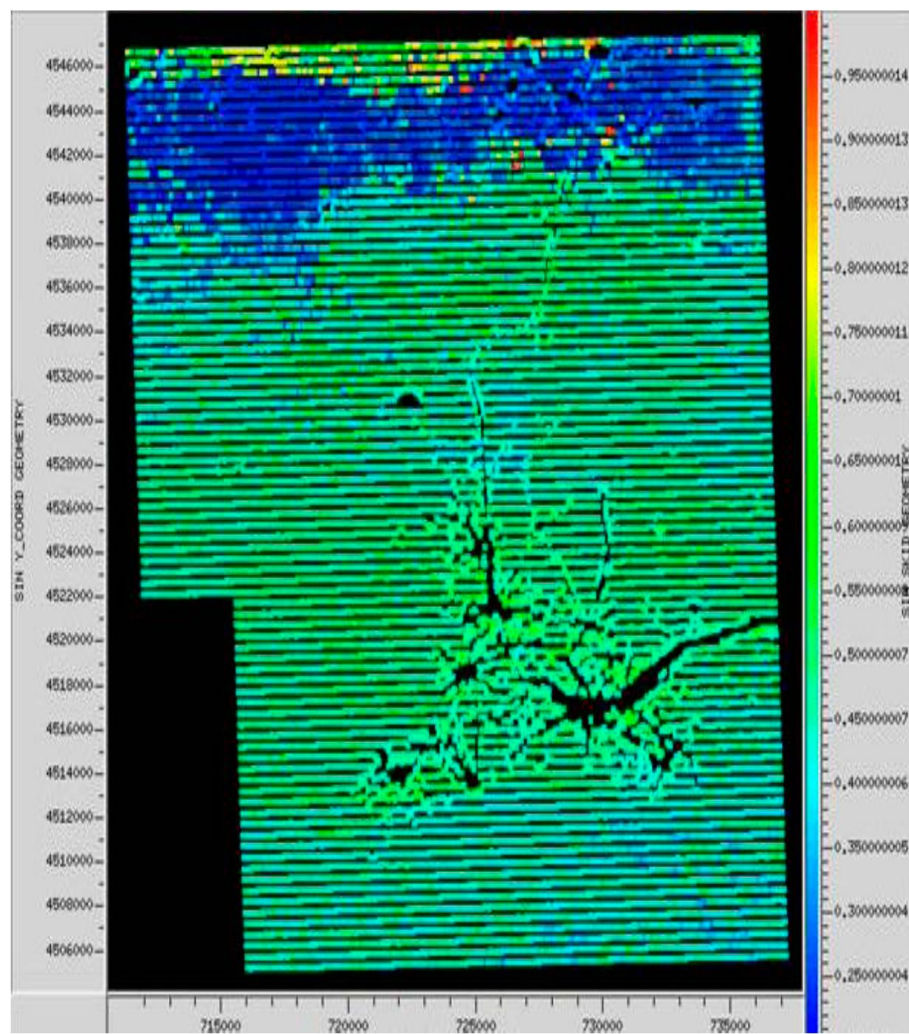
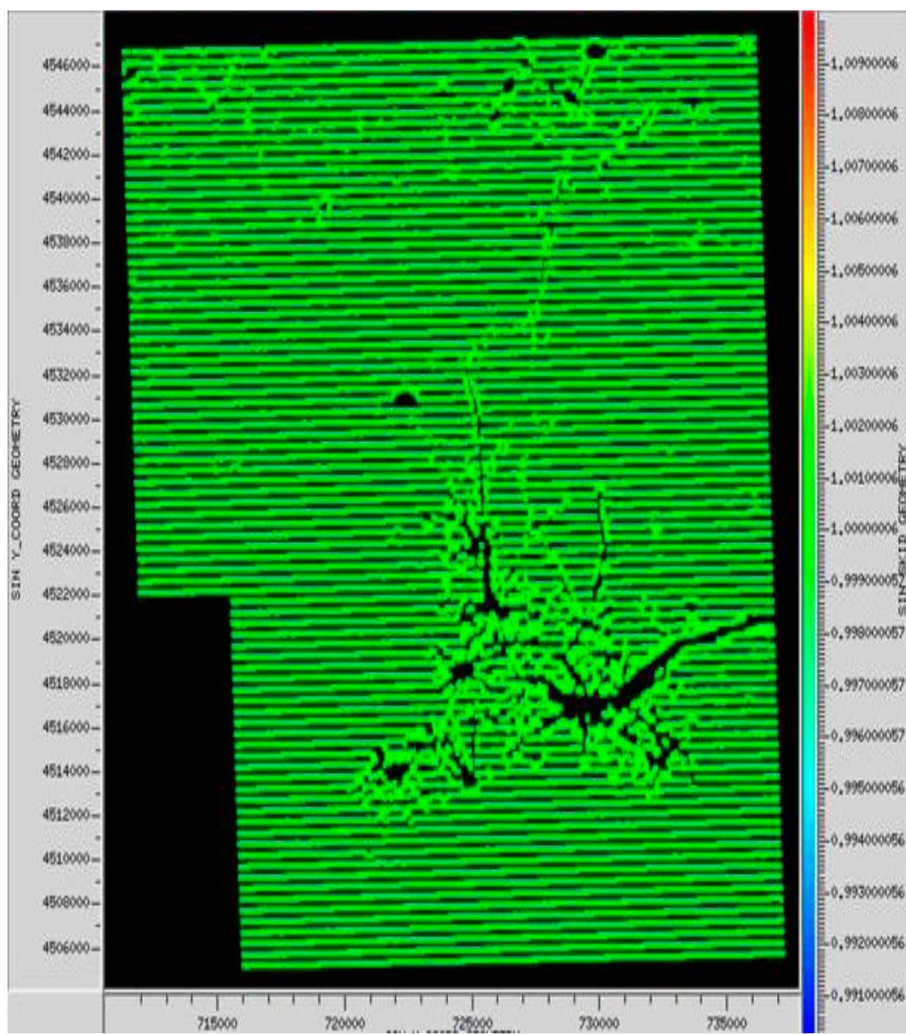


Figure 3. Statistical autocorrelation on the control line: a) raw data and b) final result.



(a)



(b)

Figure 4. 3D wavelet QC: a) raw data and b) final result.

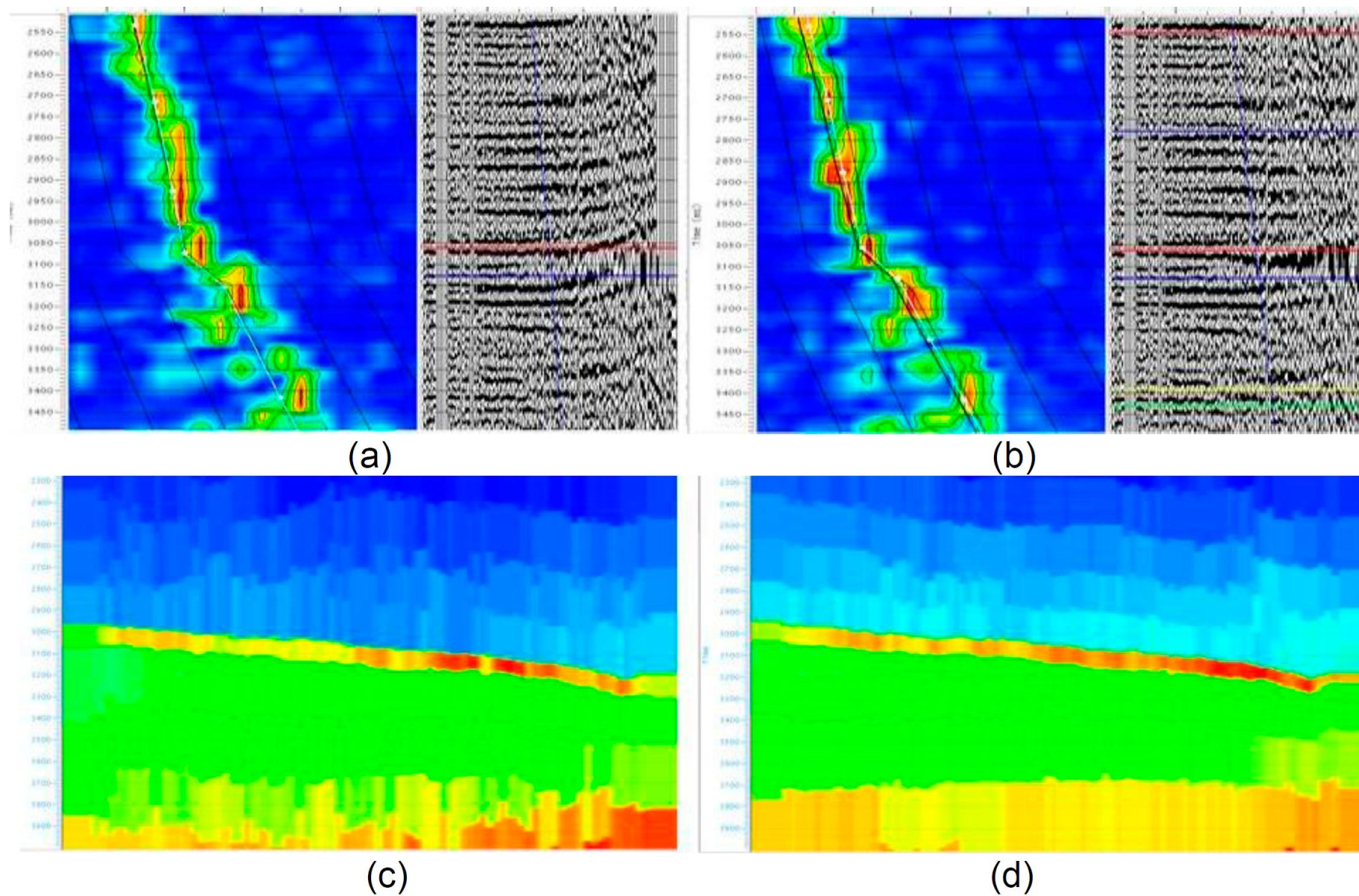


Figure 5. Velocity analysis: a) conventional NMO; b) VTI NMO; c) interval velocity based on conventional NMO; d) interval velocity based on VTI NMO.

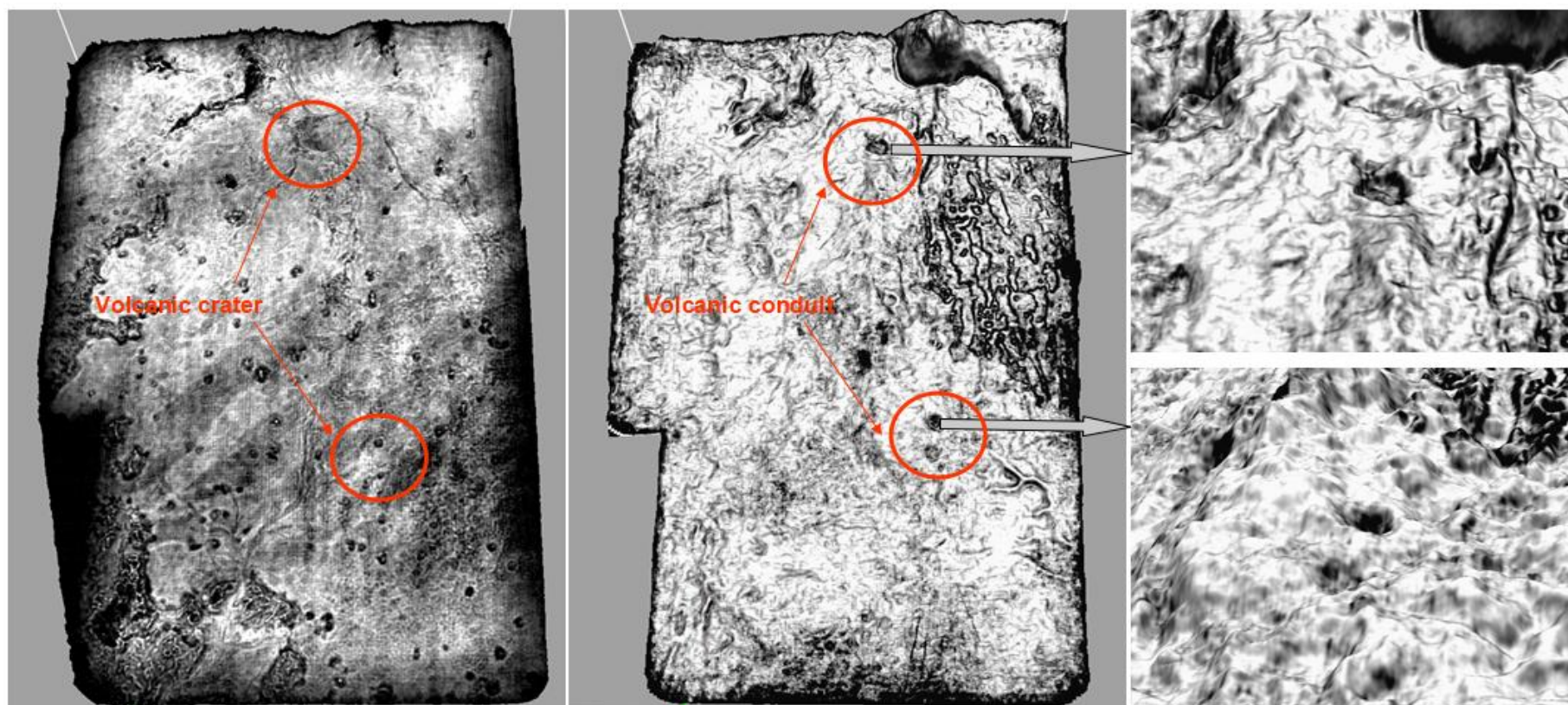


Figure 6. The spatial evolution of the volcano from the Donghe Sandstone to the top of volcanic rocks. a) The variance slice of TP_top; b) The variance slice of TC; c) The Enlarged display of the variance slice of TC.

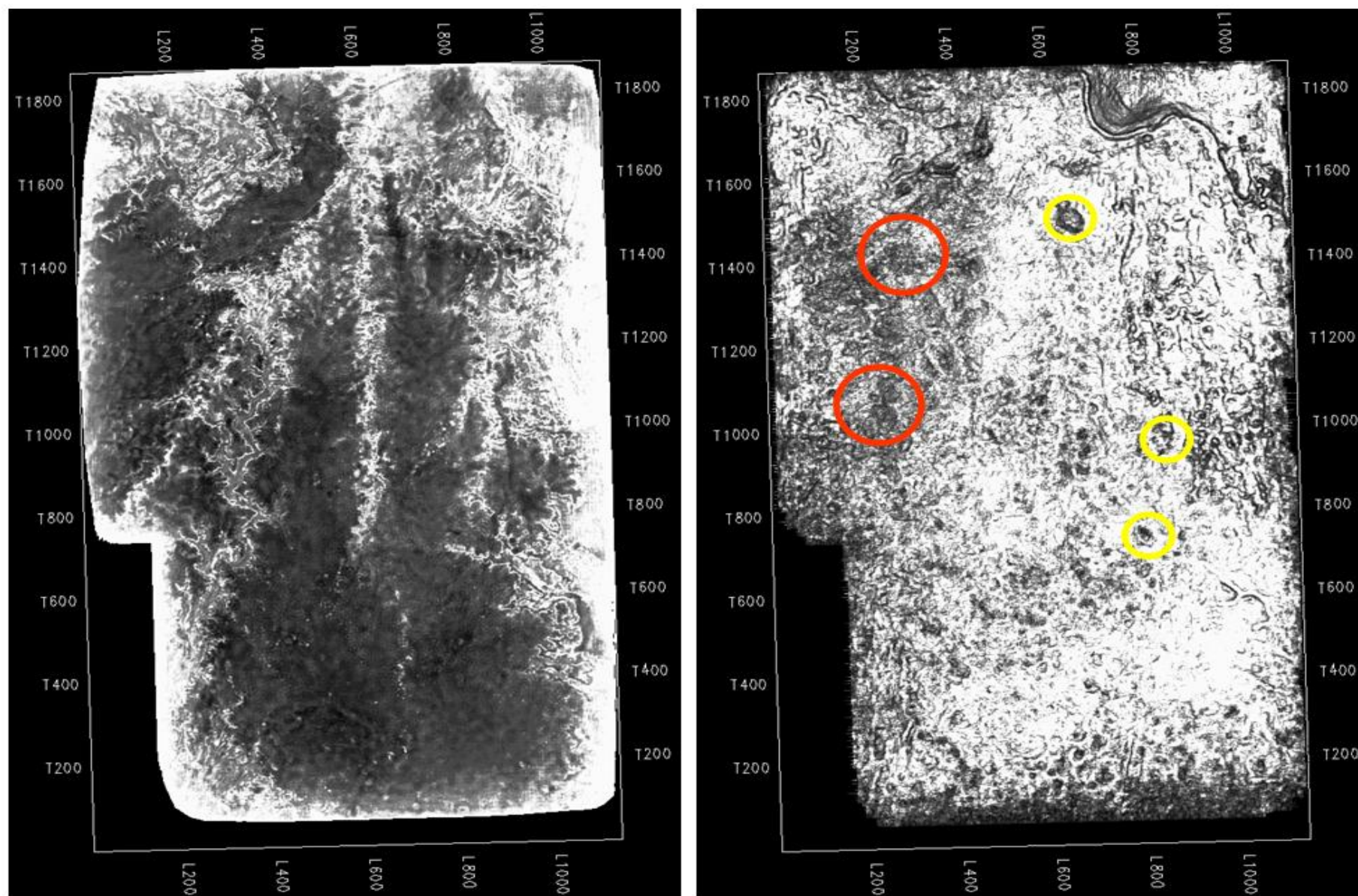


Figure 7. a) The variance slice of TP_bot; b) The variance slice of TC.

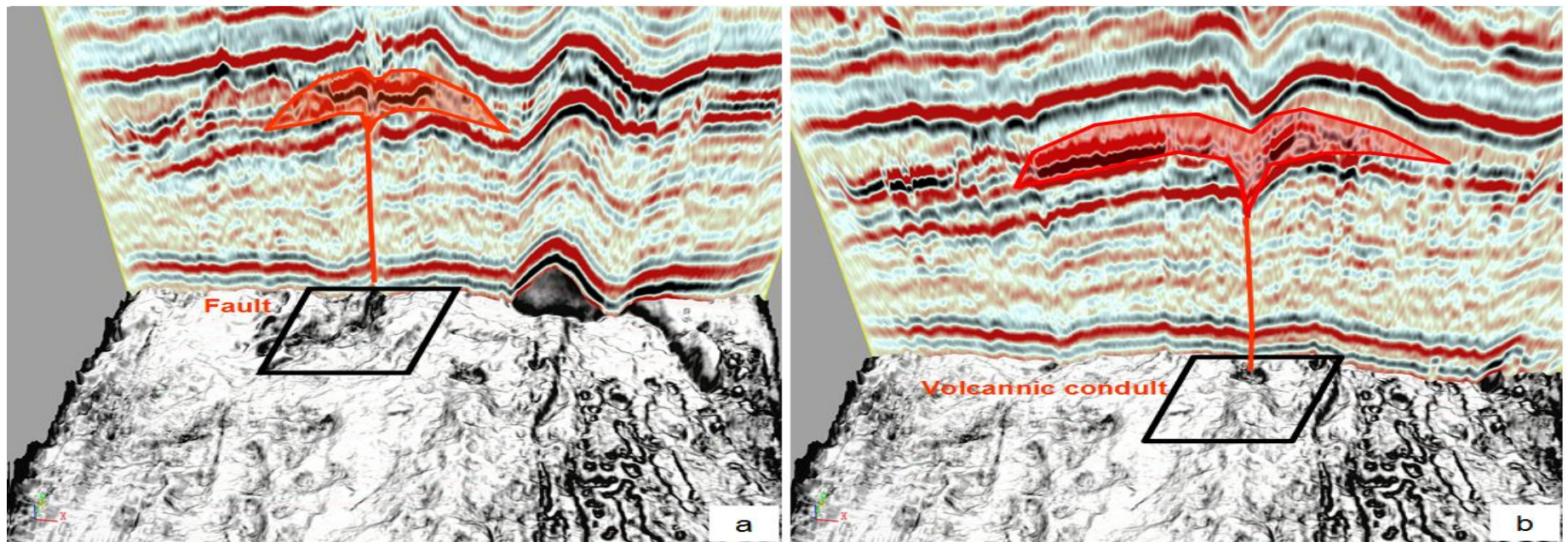


Figure 8. The interpretation of volcanic rocks using strata slices of variance and seismic data. a) Fissure eruption; b) Central vent eruption.

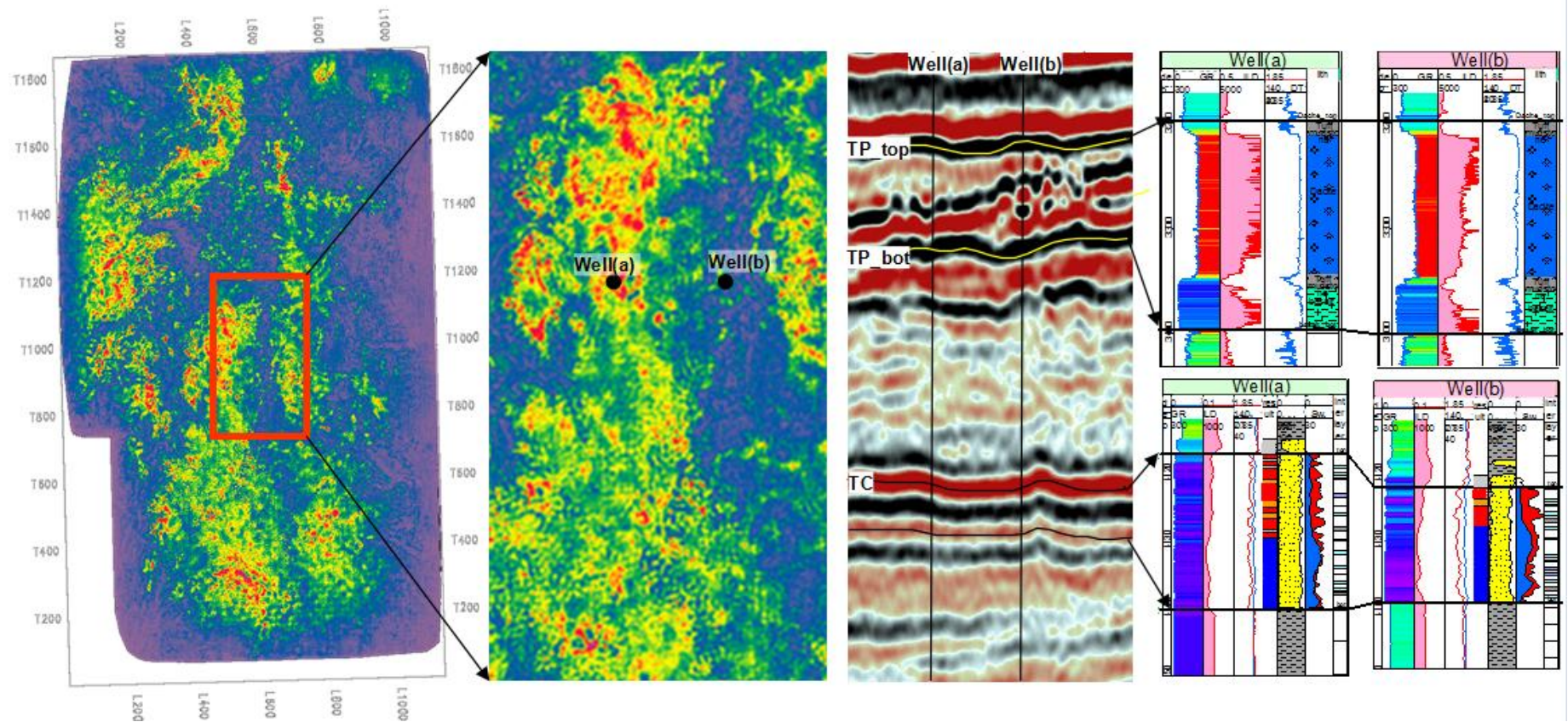


Figure 9. The effect of the distribution of volcanic rocks to reservoir lateral heterogeneity: a) The amplitude slice of TP_bot; b) The Enlarged display of the amplitude slice of TP_bot; c) the seismic section crossing well(a) and well(b); d) Well logging interpretation.