A Study of Volcanic Rocks Identification by Seismic Methods in Subei Basin, Jiangsu Province, China*

Guoping Zuo[1] and Guozhang Fan[1]

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[1]Ocean Research Department, Petrochina Hangzhou Research Institute of Geology, Hangzhou, China (zuogp_hz@petrochina.com.cn)

Abstract

In recent years, volcanic rocks exploration has enjoyed growing popularity globally and scores remarkable achievements. The reserves and output of volcanic rocks are increasing yearly.
The volcanic rocks, however, are difficult to identify, which is mainly attributed to their complex structural features and drastic lateral variations.

The aim of the study in Subei Basin (Jiangsu Province, China) is to identify volcanic rocks accurately and efficiently. According to the positions where the volcanic rocks were formed, three kinds of volcanic rocks are available in the area under study: volcanic crater rock, volcanic conduit rock and volcanic intrusion rock. Different kinds of volcanic rocks show various seismic reflection characteristics and attributive characteristics. According to those features and well-logging information, five methods can be used to identify volcanic rocks: seismic profile, amplitude time slice, coherence time slice, seismic amplitude attribute and seismic inversion. Volcanic crater rock can be identified through seismic profile, amplitude time slice, coherence time slice and seismic amplitude attribute. This kind of volcanic rock is characterized by down cut and high amplitude and the image on its amplitude time slice, coherence time slice and seismic amplitude attribute diagrams is ellipsoidal. Volcanic conduit rock also can be identified through its seismic profile, amplitude time slice, coherence time slice and seismic amplitude attribute. It has cylindrical irregular reflection and ellipsoidal images on its amplitude time slice, coherence time slice and seismic amplitude attribute diagrams. The difference between volcanic crater rock and volcanic conduit rock is that the latter has lower amplitude and lower coherence value than the former. Volcanic intrusion rock can be identified through seismic profile, seismic amplitude attribute and seismic inversion. It is featured by continuous high seismic reflection and high acoustic impedance.

Thanks to this study, many volcanic rocks have been identified accurately and quickly. Some of them have been proved by wells. Therefore, it can be concluded that those methods have achieved remarkable effectiveness in identifying volcanic rocks in the area under study.

Introduction

Australia has the largest volcanic rock gas reserves in the world (3877×10^8 m^3). Indonesia has the largest volcanic rock oil reserves in the world ($16{,}400\times10^4$ t); besides these two countries, many other countries also have large amounts of oil and gas reserves. The country with the largest oil production from volcanic rocks is Cuba, which produces 3425 t/d. Many other countries also have considerable oil production (Zou et al., 2008).

The reservoir volcanic rocks include rhyolite, andesite, trachyte, basalt and dolerite. The facies of the volcanic rocks can be classified into five categories: volcanic sediment facies, extrusion facies, volcanic conduit facies, lava facies and explosive facies. Various volcanic facies have different seismic reflection features and structural positions (Figure 1).

In volcanic exploration, the first and most important consideration is to identify volcanic rocks. This paper demonstrates some methods which are used to identify volcanic rocks, such as using seismic profiles, time slices, attributes and inversion. Different volcanic rocks can be recognized by different techniques.

Identification Techniques

The survey of this study covers Subei Basin in Jiangsu Province, China. All of the data come from this survey. There are three kinds of volcanic rocks in this area, namely volcanic craters, volcanic conduits and volcanic intrusion rocks. The following part will illustrate the details of volcanic rocks identification techniques, mainly focusing on these three types of volcanic rocks.

Volcanic Craters

There are three methods to identify volcanic craters.

（1）The first is identifying them from vertical seismic profiles. They have obvious high amplitude characteristics and concave shapes (Figure 2). In 3D display, we can see the craters clearly (Figure 3). Through this method, the craters can be identified directly.

（2） The second method is identifying them through time slices. There are two kinds of time slices, amplitude time slices and coherence time slices. The reflections of craters are very different from the surrounding rocks. Seismic coherence is out of the lateral changes in the seismic response caused by variation in structure, stratigraphy, lithology, porosity, and the presence of hydrocarbons. In general, the closer to craters the worse the coherence. This tendency also is found in the inner strata. Thus, the accurate usage of coherence will benefit the volcanic identification (Tang and Bian, 2007; Marfurt et a1., 1998; Marfurt et a1., 1999). They also have distinguished features in time slices.

In Figure 4 we can see some ellipse features in amplitude time slices and coherence time slices, in the green outlines, these features are clear. Thus, browsing through both of these two kinds of time slices from lower to deeper, craters can be identified quickly.

（3） The third method is identifying them through attribute. Due to its high amplitude, craters can be recognized by an image of maximum amplitude in special time window, which contains craters. In Figure 5, the high amplitude areas, which are displayed as ellipses, indicate craters.

Volcanic Conduits

Volcanic conduits and craters often appear at the same place. Conduits start from the deeper areas and extend toward to upper areas. On the top of the conduits craters usually are formed.

There are three methods to identify volcanic conduits:

（1） The first method is vertical seismic profiles. Volcanic conduits display as a cylinder with disordered reflection characteristics. They are often beside or along faults (Shao et al., 1999). In seismic profiles the sediment layers in volcanic conduits cannot be seen clearly (Figure 6). In 3D display, these features also are evident (Figure 3). Most of these characteristics indicate volcanic conduits.

（2） The second method is time slices. Volcanic conduits often are cylinders. So in amplitude time slices, they display as ellipses; their boundaries are clear (Figure7 A and B). As discussed above, in coherence time slices they also have elliptical shapes. And inside the ellipses there are low coherence values (Figure7 C and D). Using this method, combined with seismic profiles, volcanic conduits can be identified quickly and accurately.

（3） The third method is attribute. Volcanic conduits have disorderly reflection characteristics, so the amplitudes are not regular. According to this, they can be identified through amplitude map. Figure 8 shows two volcanic conduits. In this maximum amplitude map, they have comparatively low amplitudes in volcanic conduit areas compared to those areas around. By this way, volcanic conduits also can be recognised.

Volcanic Intrusion Rocks

There are also three methods to identify volcanic intrusion rocks:

（1） The first method is to identify them from vertical seismic profiles. Volcanic intrusion rocks often appear near volcanic conduits. They have continued seismic reflection characteristics (Shao et al., 1999). In Figure 9, the blue line areas indicate volcanic intrusion rocks. They feature high continued amplitude. Most of them are formed in slop or low-lying areas. Due to all these features, volcanic intrusion rocks can be recognized easily through vertical seismic profiles.

（2） The second method is to identify them by seismic attributes. It is universally acknowledged that volcanic intrusion rocks have obvious high amplitude. So the seismic amplitude attributes which are extracted along layers from seismic data can be used to identify volcanic intrusion rocks. Figure 10 shows three seismic attributes. The red colour indicates high values. Wells proved that most of these red areas have volcanic intrusion rocks, such as the black elliptical areas (Figure 10). They also correspond to seismic profiles. When using this method, the time window is important.

（3） The third method is the inversion method. Before using this method, we need to analyse the physical characteristics of volcanic intrusion rocks from wells. In this study, two wells are used to do such analysis. Both of them have low AC, low GR and high resistance in volcanic rocks (Figure 11). They are extremely different to those of sandstones and mudstones. So, theoretically these rocks can be identified through inversion. The impedance inversion method is adopted in this study, and some wells are used to constrain the process. Figure 12 shows the results of the impedance inversion. The map is a max impedance image which is extracted along the layer with volcanic rocks. The yellow to red areas indicate volcanic intrusion rocks. In inversion profiles, they also have obvious high impedance values. Therefore, the inversion method is efficient to identify volcanic intrusion rocks.

Conclusions

This study demonstrates volcanic identification techniques. There are four methods: seismic profiles, time slices, seismic attributes and impedance inversion. Different kinds of volcanic rocks can be identified by different methods. Through this study, the following three conclusions can be reached:

(1) The characteristics of craters, volcanic conduits and volcanic intrusion rocks in seismic profiles are more definite.

(2) Craters and volcanic conduits can be identified clearly by coherence time slices; also, they can be distinguished through the abnormities of amplitude attributes.

(3) Volcanic intrusion rocks can be identified quickly and accurately by amplitude attributes, energy attributes and the inversion method.

In order to identify volcanic rocks efficiently, it is best to combine several methods.

References

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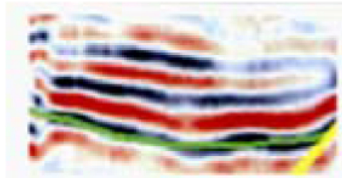
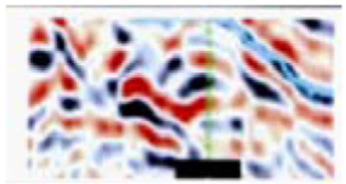
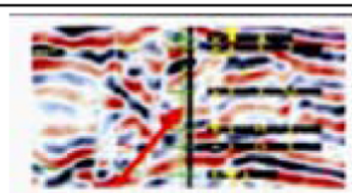
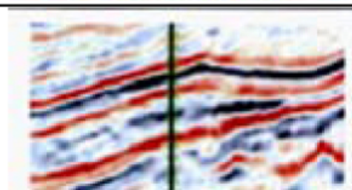
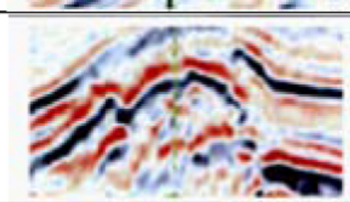
type	seismic reflection profile	frequency	amplitude	reflection feature	volcanic facies	structure position
1		middle-high	high	layer shape	volcanic sediment	low-lying place
2		middle-high	high	disorder	extrusion	near crater
3		low-middle	high	disorder	volcanic conduit	crater
4		middle-high	high	layer or wedge shape	lava	slope or low-lying place
5		low-middle	high	dome-shape	explosive	crater

Figure 1. The classification of volcanic facies.

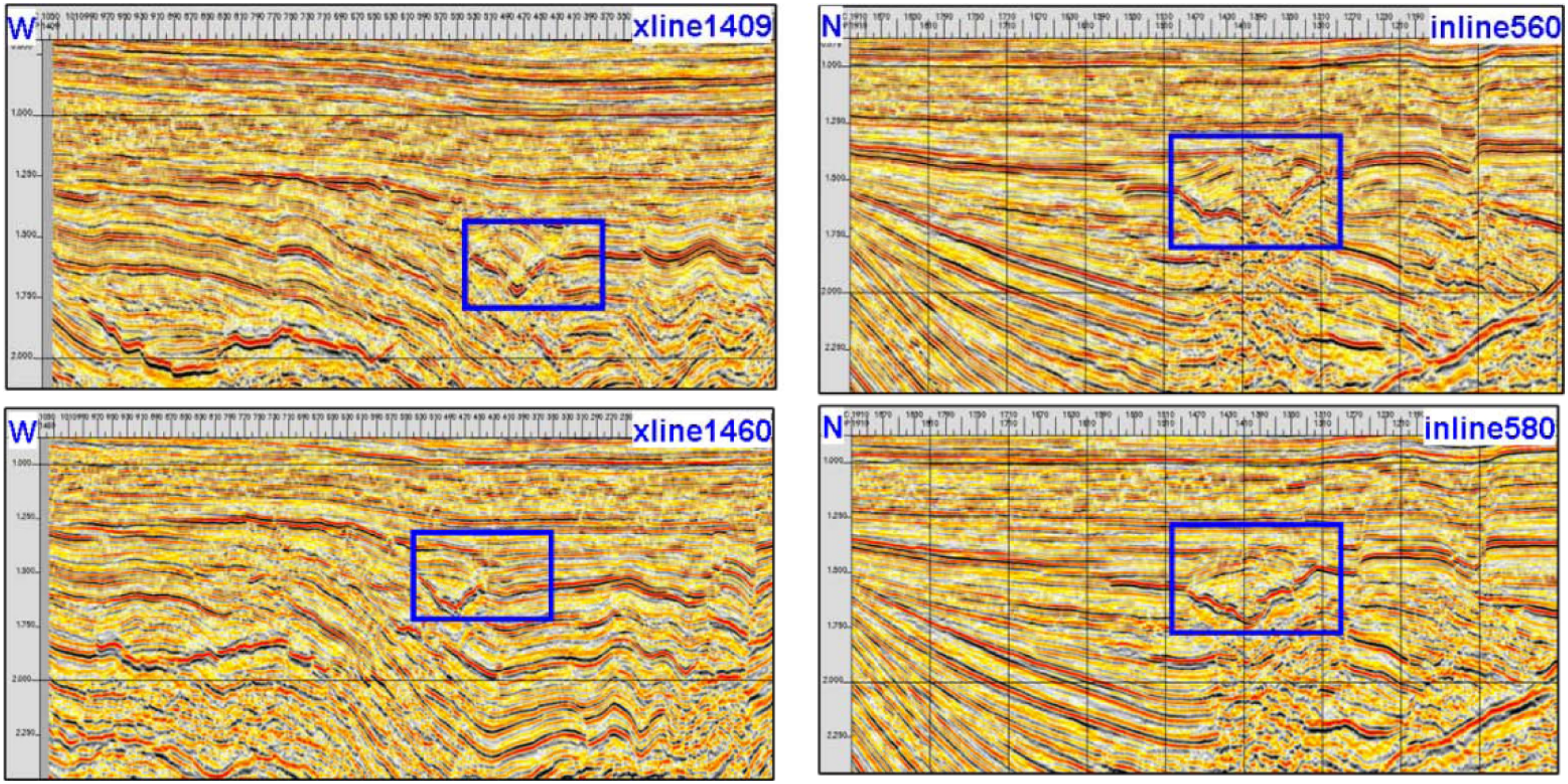


Figure 2. Vertical seismic profiles (the blue boxes indicate volcanic craters).

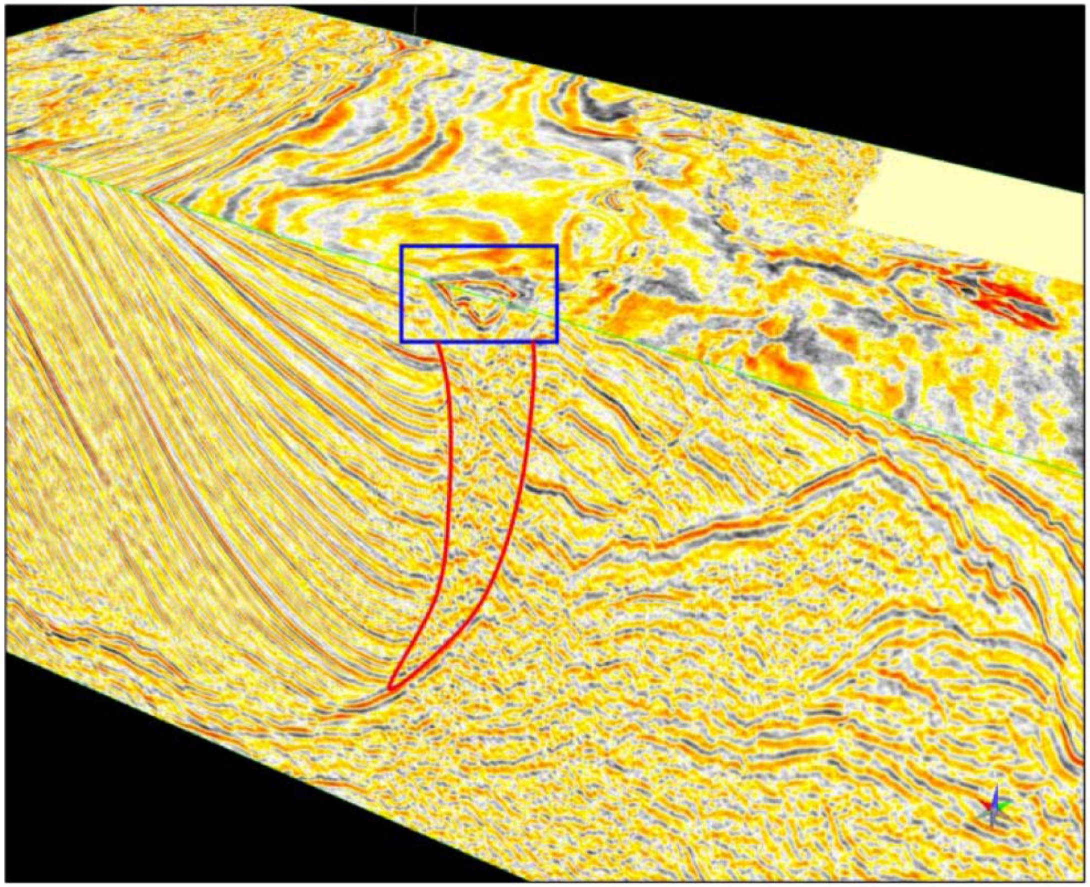


Figure 3. 3D display of seismic data (the blue box indicate volcanic crater, the red line shows volcanic conduit).

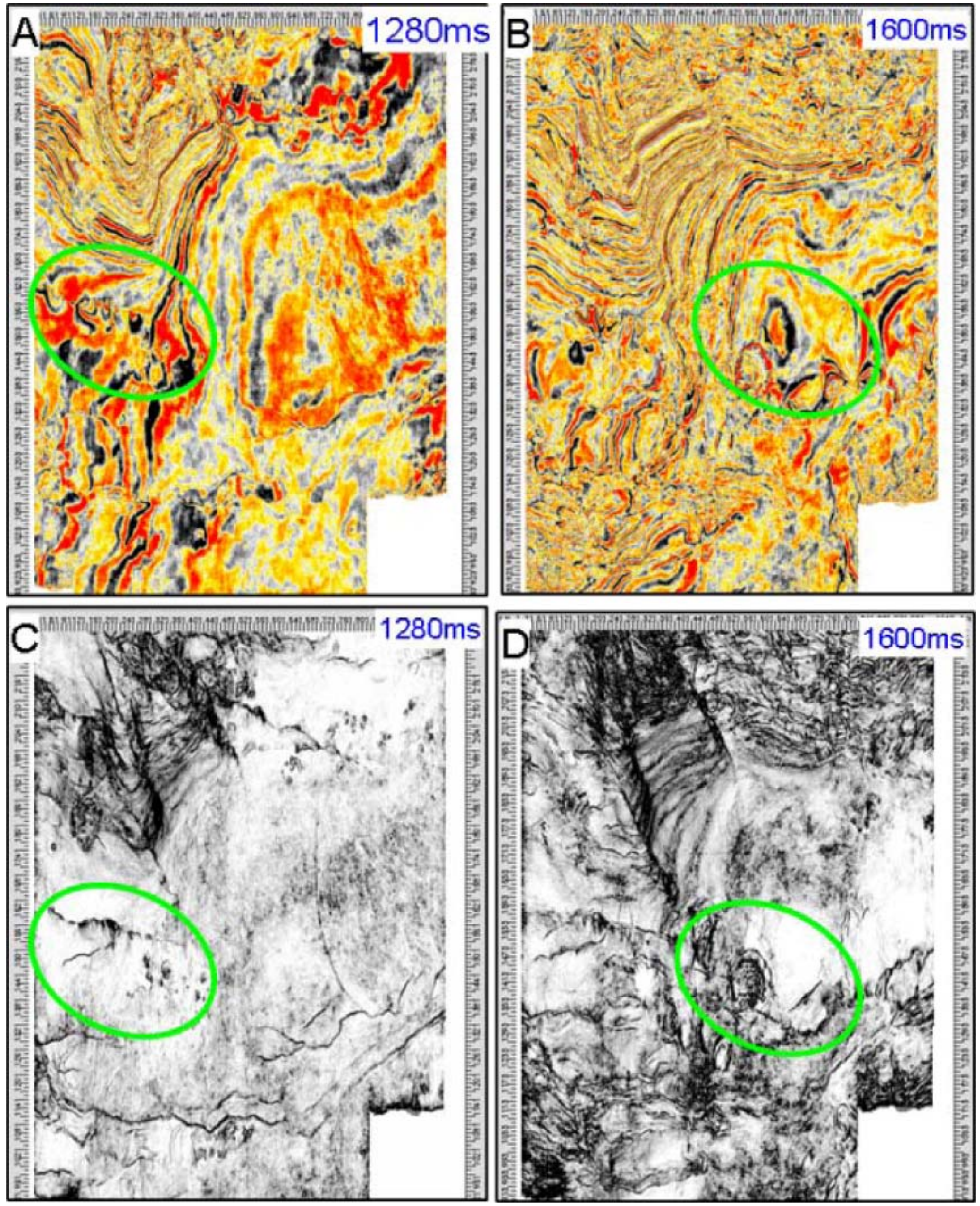


Figure 4. Time slices of seismic data (A and B are amplitude time slices, C and D are coherence time slices, the ellipse features in the green elliptical areas indicate craters).

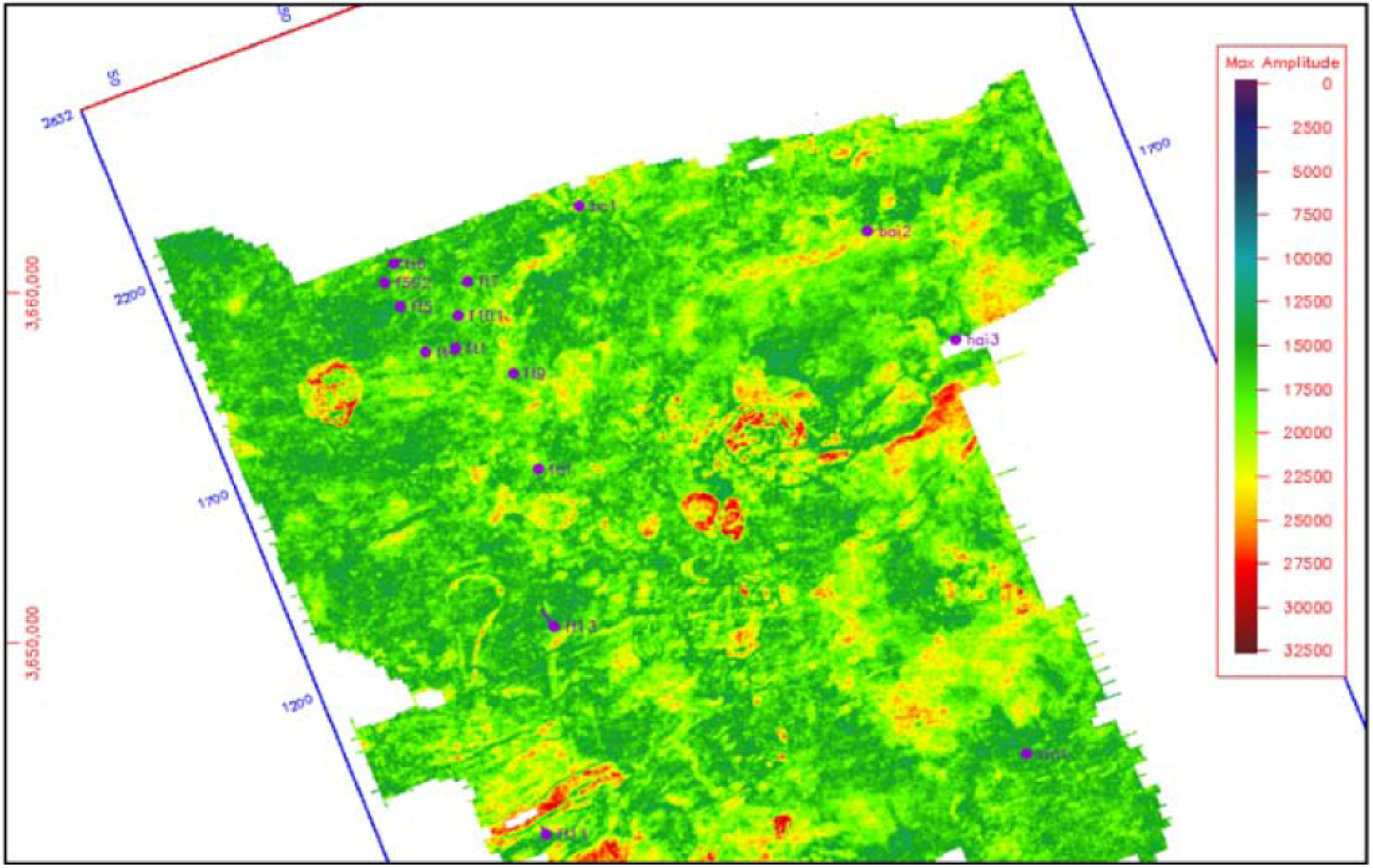


Figure 5. Map of maximum amplitude attribute (high amplitude red areas indicate craters).

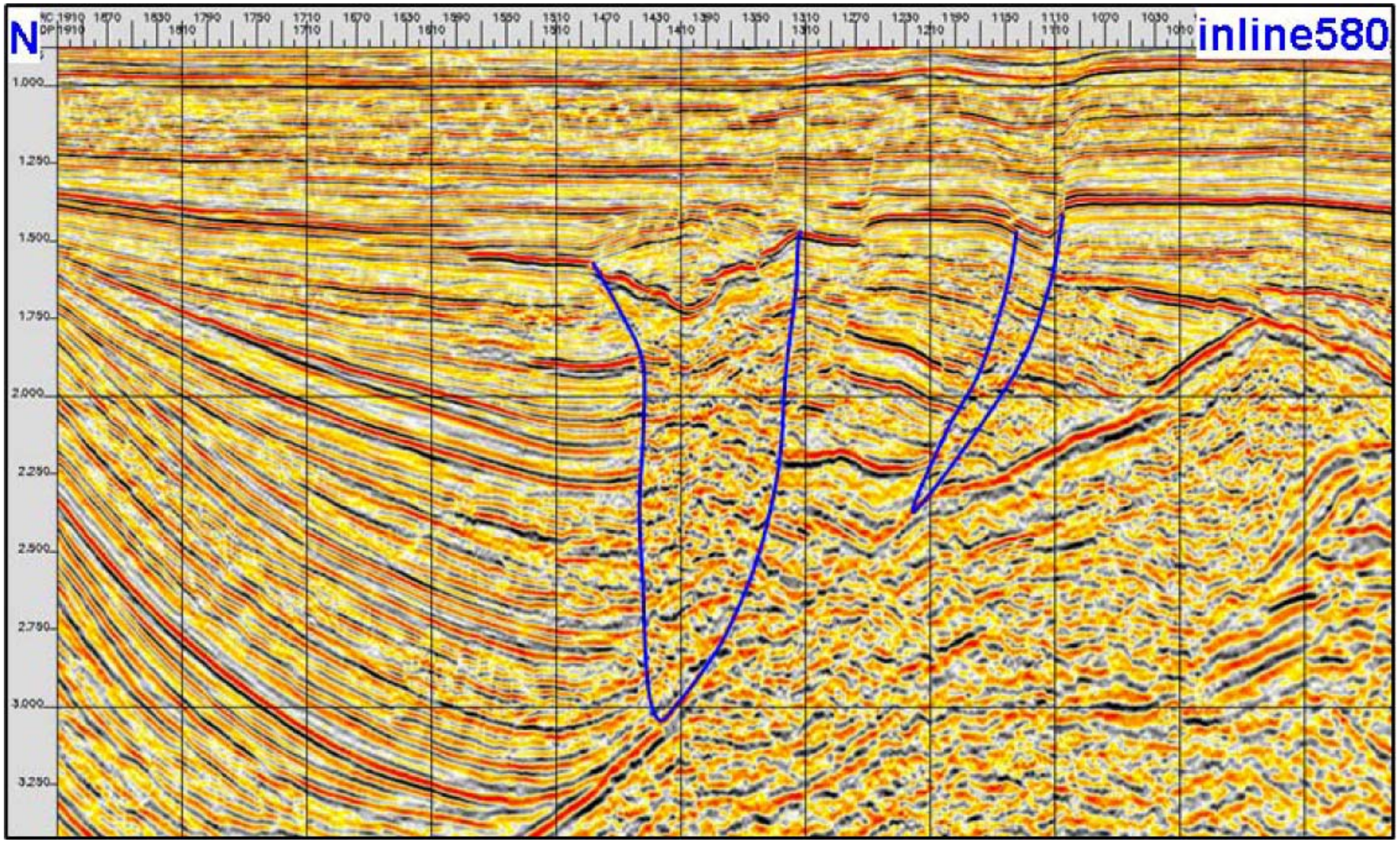


Figure 6. Vertical seismic profile (blue lines indicate volcanic conduits).

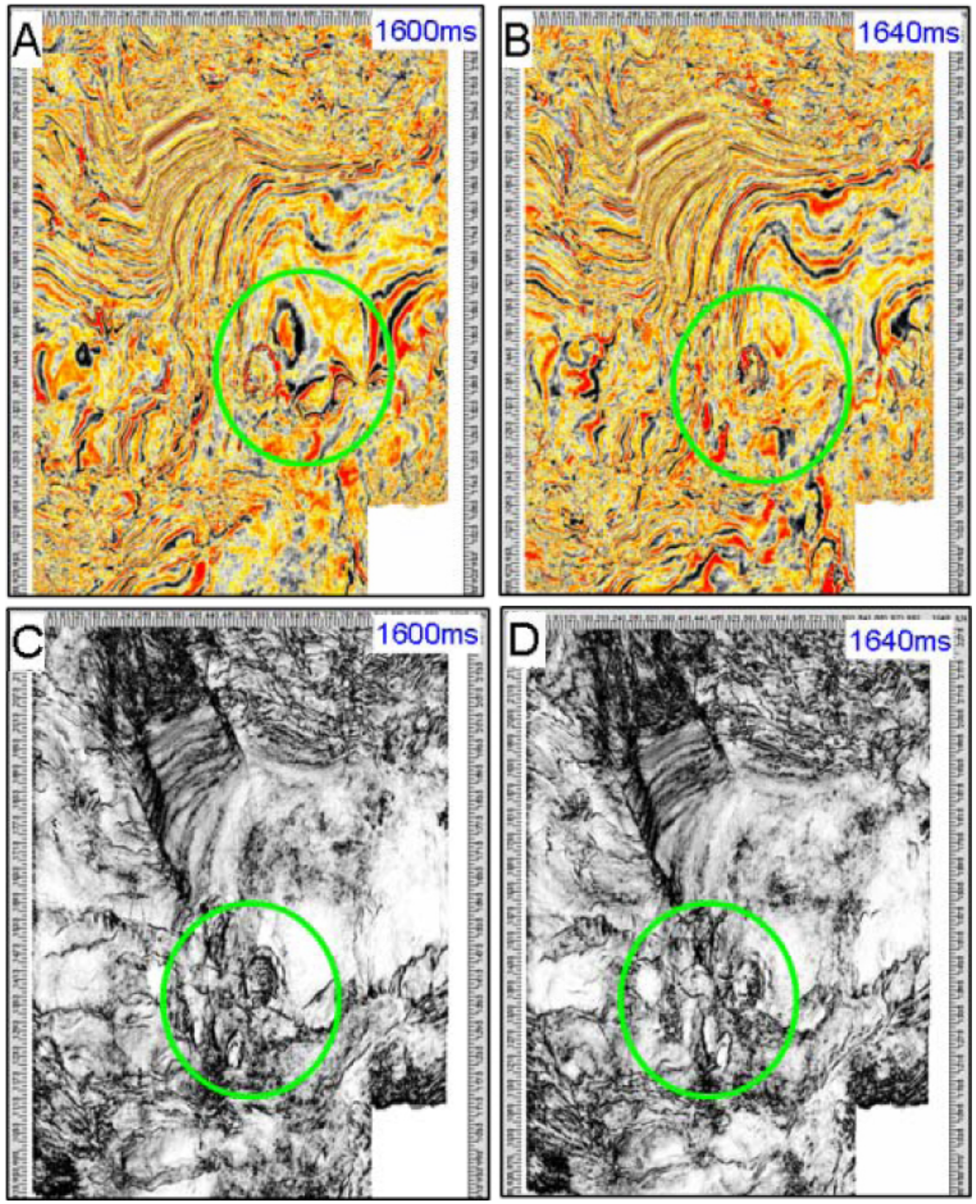


Figure 7. Time slices of seismic data (A and B are amplitude time slices, C and D are coherence time slices, the ellipse features in the green ellipse areas indicate volcanic conduits).

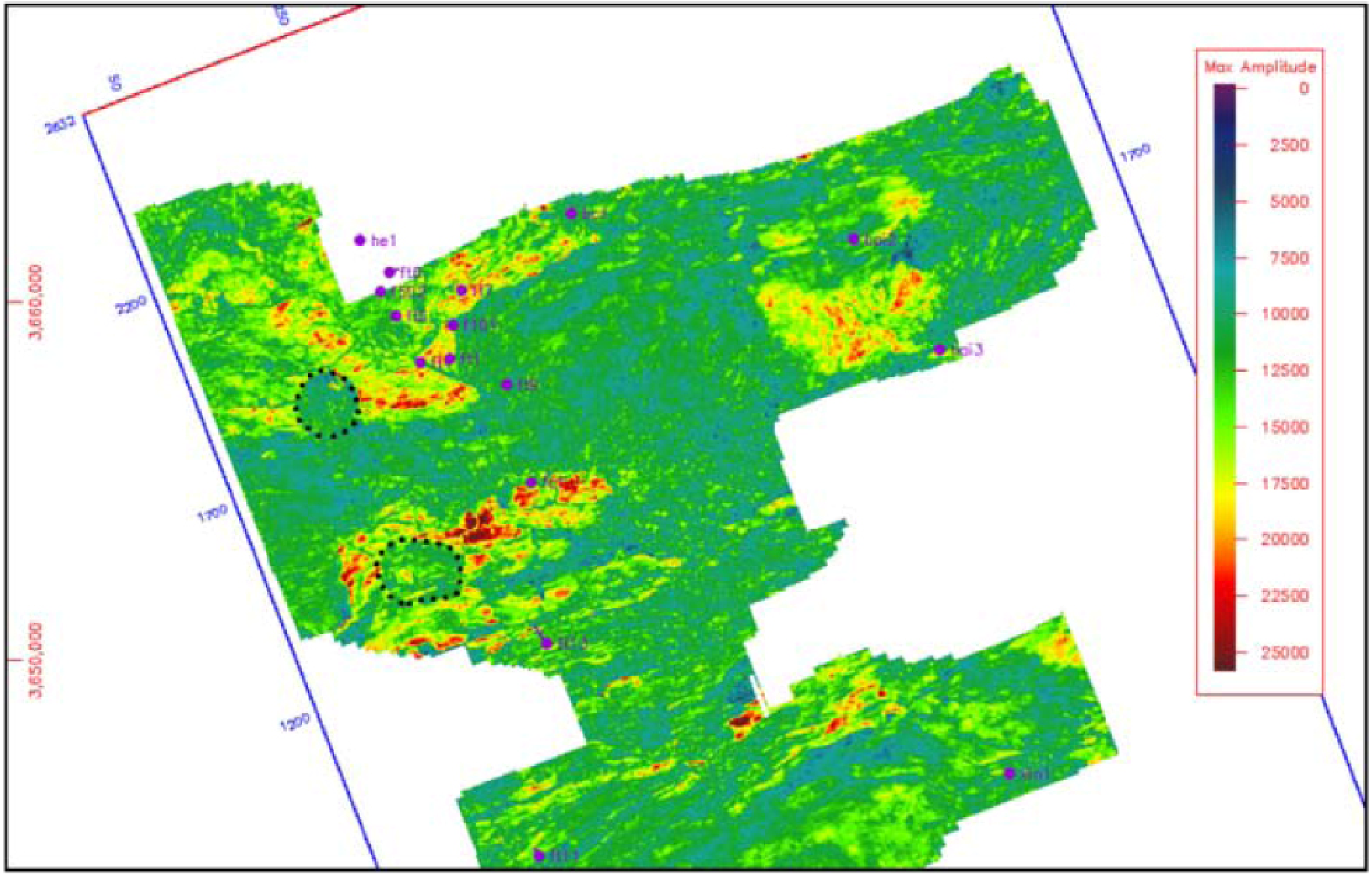


Figure 8. Map of maximum amplitude.

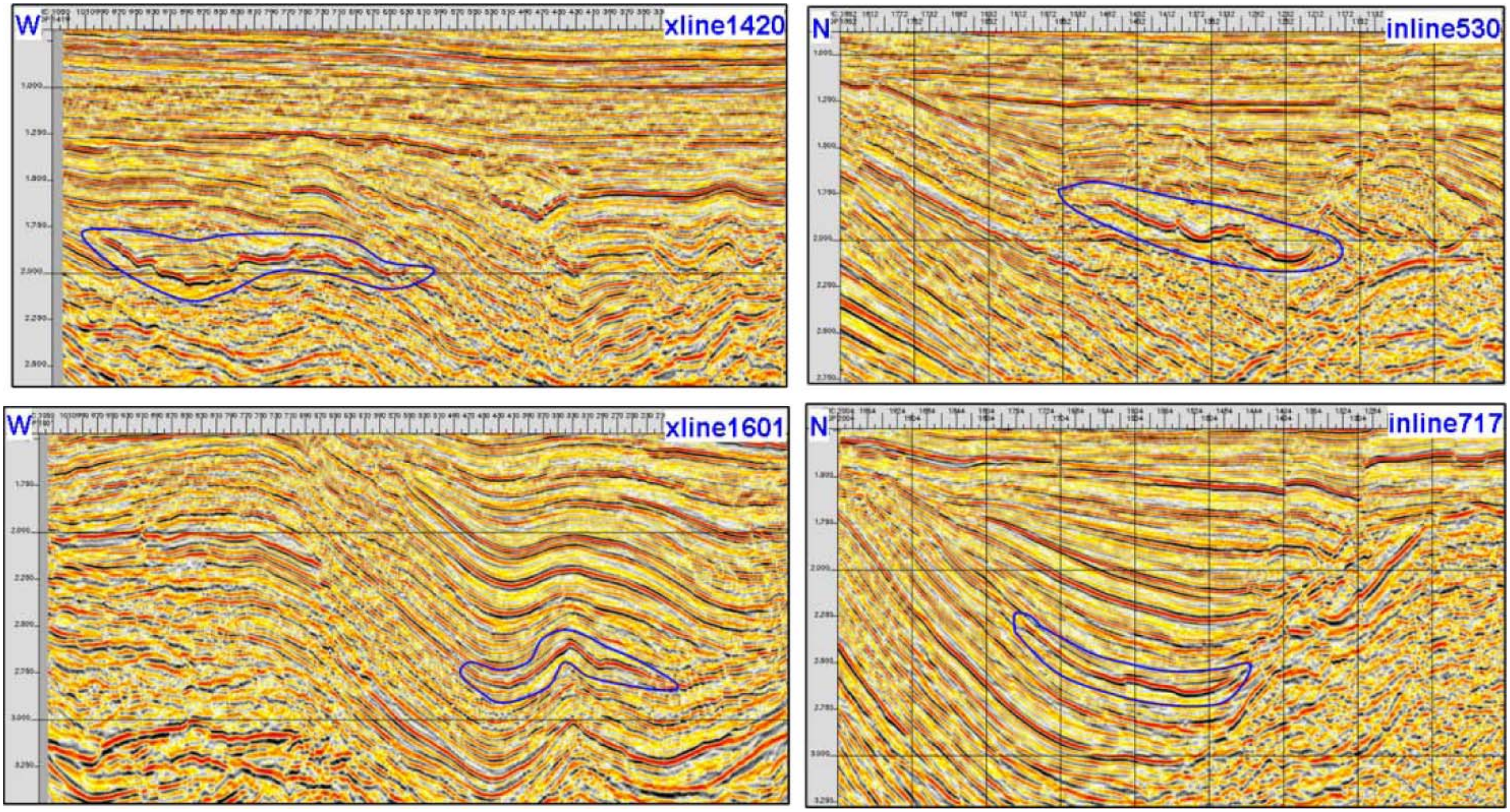


Figure 9. Vertical seismic profiles (blue line areas indicate volcanic intrusion rocks).

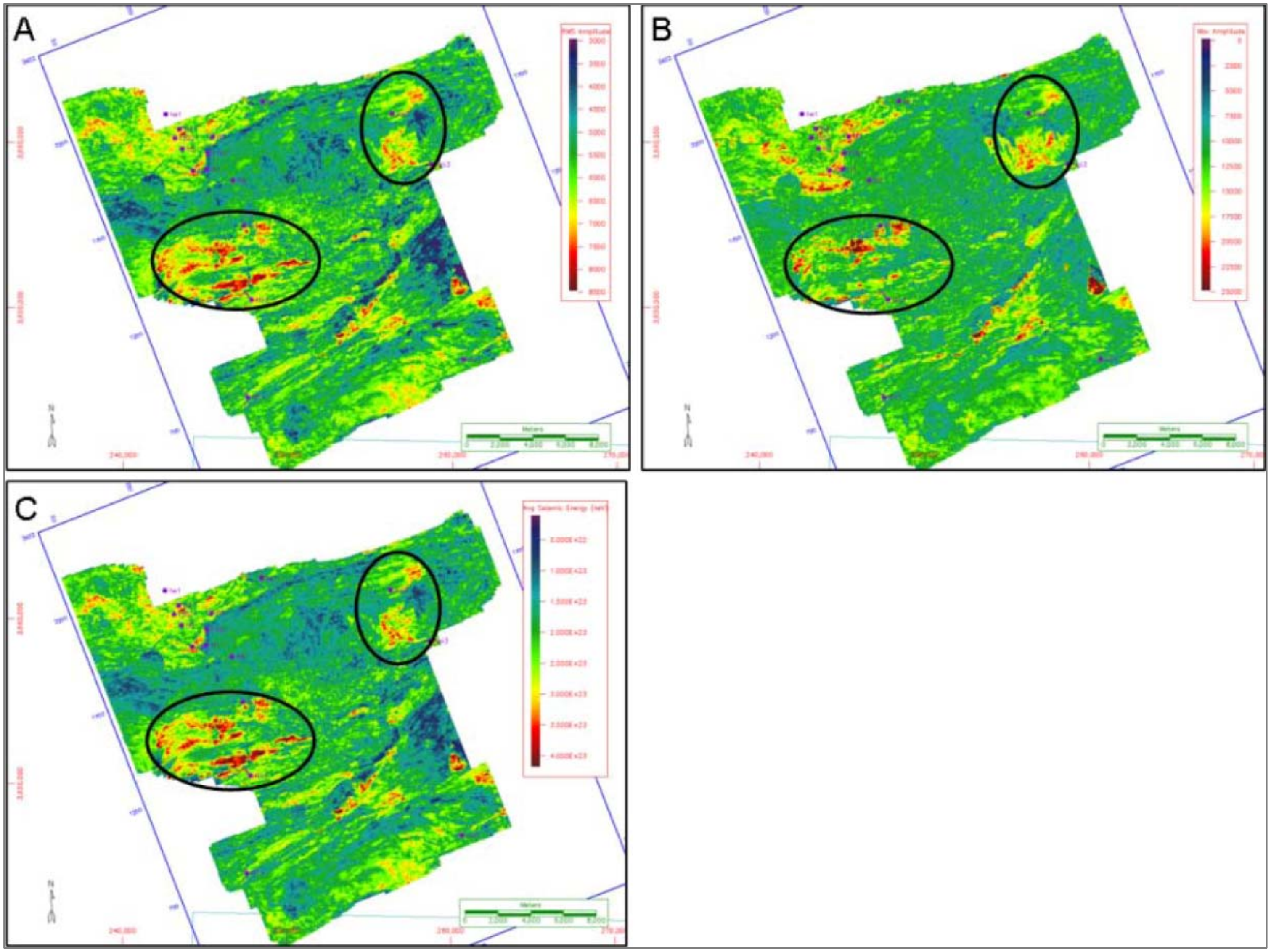


Figure 10. Maps of seismic amplitude attributes (A: map of root mean square amplitude, B: map of maximum amplitude, C: map of average energy).

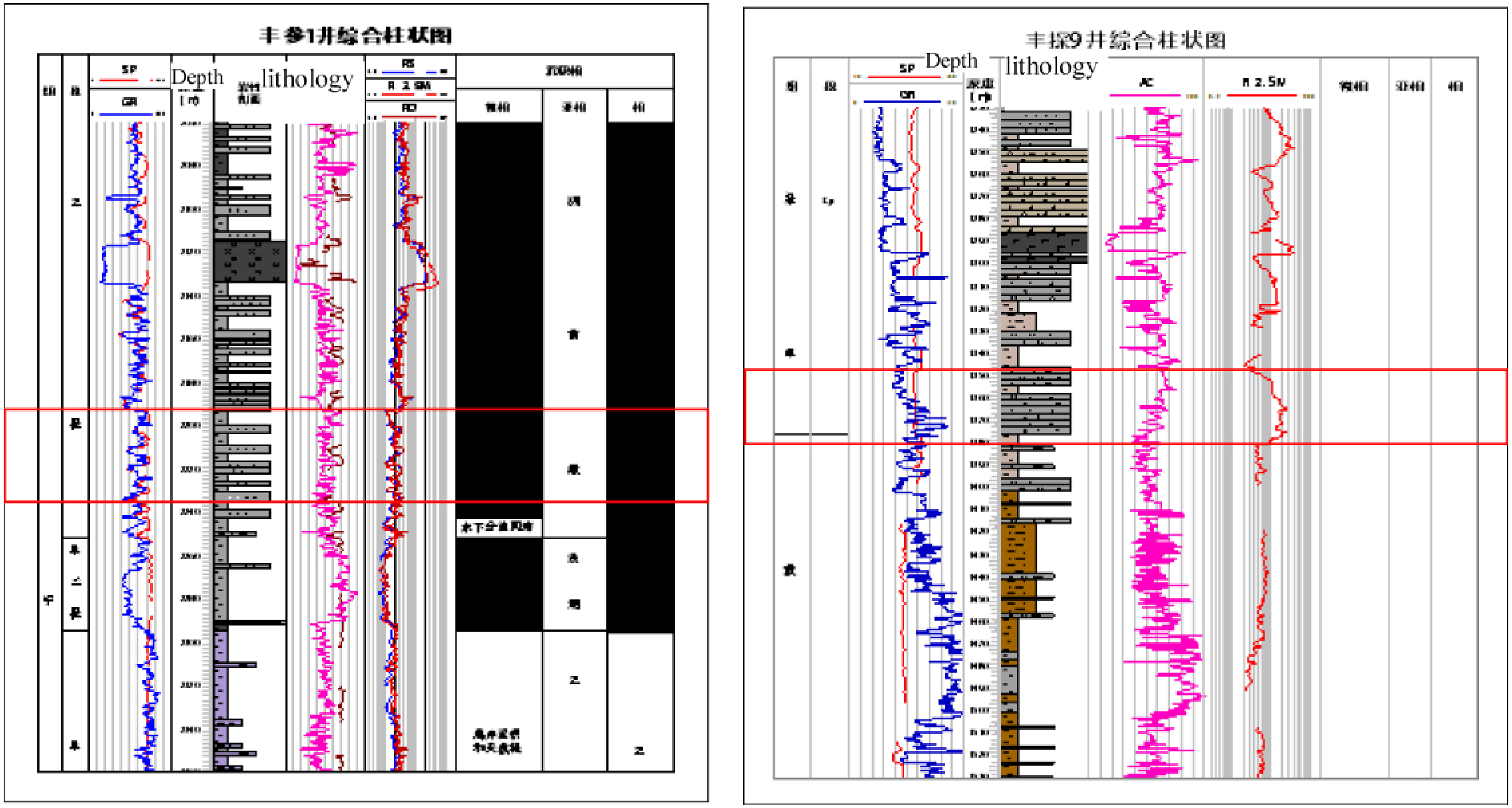


Figure 11. Displays of volcanic rocks' physical characteristics.

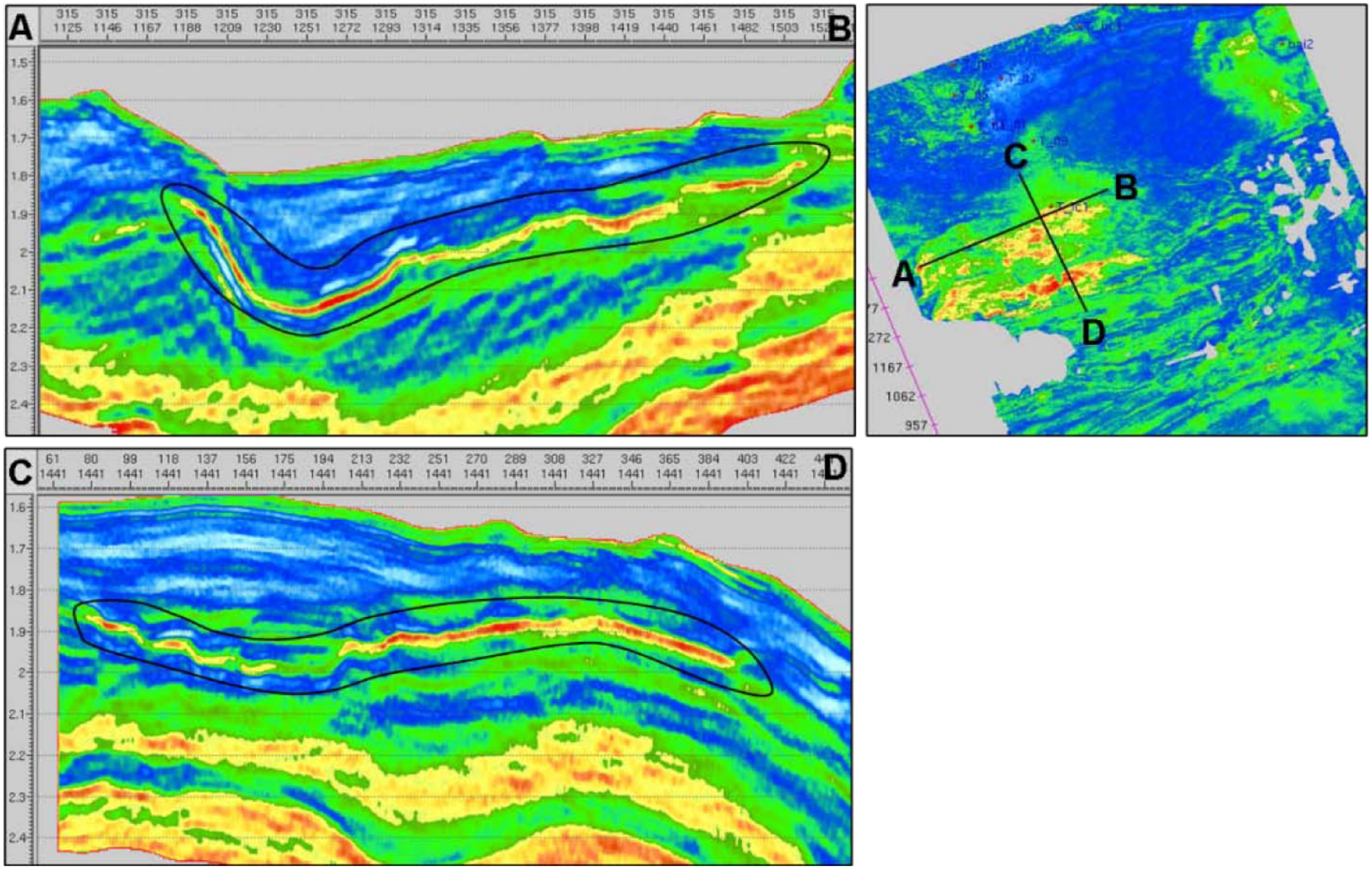


Figure 12. Impedance inversion profiles and map.