The Application of Seismic Attribute Analysis Technique in Coal Field Exploration*

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Abstract

Minor faults, subsidence columns, coal tunnels and gob are very important in coal mining because they can cause flooding accidents, broken coal beds, added fissures, and gas accumulation. All of these factors will increase coal mining risk. In addition, minor faults also affect the design of roadways. In this article, we have achieved satisfactory results in identifying minor faults, subsidence columns, coal tunnel and gob by using the high-precision three-dimensional seismic data and seismic attribute analysis techniques. After verification in the actual coal mine, the match rate of predicted minor faults with a fault throw within 2-3 meters and the actual, is up to 85%. The predicted subsidence columns, coal tunnels and gob are exactly the same as the actual.

Introduction

The coalfield in this study is located in eastern China and the coal seams belong to Permian strata, with the depth ranging from 500 to 1000 meters and the thickness of coal about 2-5 meters. After years of seismic exploration and coal mining, the distribution of geological structure underground and the faults with fault throw greater than 5 meters have been clearly known on the whole, but minor faults with fault throws less than 5 meters remain unknown. The subsidence of columns has also been found in coal mines, which can cause flooding accidents by connecting the coal seam and the water in Ordovician limestone. There are many coal tunnels in the underground that have been drilled before seismic exploration, and in some mines the caving zone and the surface reservoirs are made by the collapse of upper strata after coal mining. These geological phenomena are very important for safe and efficient coal mining, so the focus in this article is the methods to identify those phenomena. The seismic data we used is high-precision three-dimensional seismic data, which is acquired by digital geophone, with a group interval of 5 meters and a sample interval of 1 ms. Here we use the seismic attributes analysis technique to identify minor faults, subsidence columns, gob and coal mine tunnels.

Subsidence Columns

The subsidence column is caused by the collapse of a cave in the Ordovician limestone under the coal seam. The range of influence on upper strata by the collapse is up to several hundred meters. Its diameter ranges from less than ten meters to hundreds of meters, and even a few kilometers. They can destroy the continuity of coal seams, affect the layout of the coal mining face and the stability of surrounding rock; in addition, they can cause accidents by connecting the water in Ordovician limestone. Because the difference in velocity between the inner subsidence column and the surrounding rock can cause an abnormal seismic signal, in the seismic data we often deal with the subsidence column as a fault. Usually it is easy to identify the big subsidence columns in the seismic profile, but the smaller ones, the diameter of which are less than 20 meters, are not easy to find. However, we can identify the small ones by application of the seismic attributes technique. For example, in the P3X3 seismic survey we can clearly see that there are three groups of faults in the seismic profile between the trace Nos. 600 and 800, shown in Figure 1. In fact, drilling has confirmed that the faults shown in the seismic profile are subsidence columns.

From the curvature and variance attribute along horizon in Figure 2, we can find that there are four subsidence columns with a similar round shape. We measured the diameters of subsidence columns from the seismic profile, and the diameters of columns No. 1, 2, 3, and 4 are respectively 140 m, 25 m, 65 m, and 75 m. From the forward modeling we can know the diameter shown in the seismic profile is a quarter wavelength longer than the actual. So the diameter of the smallest subsidence column should be less than 20 meters.

We can clearly see the subsidence columns on two seismic profiles in a crossline section, but it is not easy to identify the smallest one on the inline direction in Figure 3. So it is prone to interpret the subsidence column as fault, but we can easily identify the subsidence column by the variance attribute in a horizon seismic slice.

Gob, Caving Zones and Coal Tunnels

When the underground coal seam is mined, the original stress equilibrium is broken and overburden rocks lose support which results in rock's movement and deformation, sometimes collapsing. The collapse areas, known as gob, can be divided into three zones: caving zone, fracture zone and bending zone, as shown in Figure 4. In the caving zone, the upper rock on gob collapses, then the deformation begins to appear on the rock of the upper caving zone and the deformation is so large that the tensile stress appears at the top rock and the shear stress on both sides, thus a large number of fractures are generated in this zone. From the fracture zone up to the ground the rocks often bend rather than rupture under the action of gravity.

Gob seismic exploration has always been a major difficulty. If the gob can be accurately delineated, the damage to the environment can be reduced and economic loss avoided. It is difficult to accurately delineate the gob by using traditional drilling methods, because the size of gob areas are different and the occurrence of gob is in isolation and the regularity of distribution is poor. In recent years, high-precision 3D seismic that contains a large amount of information has been applied to coal field surveys, making it possible to detect the gob underground.

Figure 5 shows a gob in the PB seismic survey, a part of it has collapsed and underground there are many coal tunnels. The results of seismic exploration show that it is easy to identify the gob and the caving zone with seismic data. In seismic section, the waveform characteristics of the gob is not the same as normal strata. In the caving zone, the rocks are loose, reducing the velocity of rock travel times, so the seismic waves are greatly attenuated in this area, which affects the seismic imaging of underlying strata, as in Figure 6.

These are some features of the gob and caving zone reflected in a seismic profile:

1) The caving zone can make the seismic reflection wave broken, which is the most important indicator to identify the gob and caving zone in coal formations.

2) In the caving zone, the rocks are broken, the seismic waves are absorbed, dispersed and greatly attenuated, so the frequencies of the reflected waves are decreased on seismic profiles.

3) The seismic amplitudes are attenuated in the gob zone, and the seismic waveform becomes irregular, disordered or even distorted, which is another important indicator to identify the gob and caving zone.

4) It is difficult to interpret the lower strata because it is hard to image under the gob and caving zone because of the seismic wave attenuation and scattering.

Application of seismic attributes make the identification of gob, the caving zone and coal tunnels easy. From Figure 7 and Figure 8, we can clearly see the boundary of gob by use of the seismic amplitude attribute in a horizontal seismic slice. The variance attribute can clearly reflect not only the gob and caving zone, but also the isolated columns in the gob shown in Figure 9.

Minor Faults

Minor faults are prone to cause geological disasters in coal mining, such as gas outbursts and flooding, bringing a threat to the safety of mining. With the increasing mechanization of coal mining, the coal exploration's requirements are increasing.

In DJ survey, after years of conventional seismic exploration and coal mining, the faults with fault throw greater than 5 meters have been clearly known on the whole, but minor faults with a fault throw less than 3 meter are not clearly known. After verification in the coal mine, the match rate of predicted minor faults with a fault throw within 2-3 meters and the actual is less than 20% using the conventional seismic exploration. In order to find the minor faults with 2-3 meters fault-throw, the DJ survey conducted a high-precision 3D seismic exploration in 2007. By using the multi-attribute analysis method, we achieved a very good result in identifying the minor faults with throws of 2-3 meters. After about four years of coal mining, the predicted faults with high-precision 3D seismic data have been verified in the actual coal mining operations. In Figure 10, the red lines are the predicted faults, the five parallel blue lines are the coal tunnels, the green round points are the fault points with a 2-3 meters fault-throw found in coal mining, and the blue square points are the faults points with a less than 2 meters of fault throw. We can see that the match rate of the predicted minor faults with a fault throw within 2-3 meters and the actual is up to 85%, but we cannot accurately predict the minor faults with throws less than 2 meters. However, the success rate of predicted minor faults with a fault throw within 2-3 meters by using high-precision 3D seismic data and seismic attribute methods is much higher than using conventional methods.

Conclusions

1) Seismic attributes can clearly reflect the subsidence columns in the horizontal plane. The diameter of subsidence columns measured by seismic data is larger than the actual.

2) It is easy to identify the gob, caving zones and coal tunnels by seismic data, because their characteristics on seismic profiles are obvious. And the boundaries of the gob and caving zone can be delineated by using the seismic attributes in horizontal slices. But the gob and caving zone has seriously affected seismic imaging of the underlying strata, which requires further study.

3) By comparing the results of high-precision seismic exploration and the conventional, we conclude that the high-precision seismic exploration has obvious advantages in the identification of minor faults.

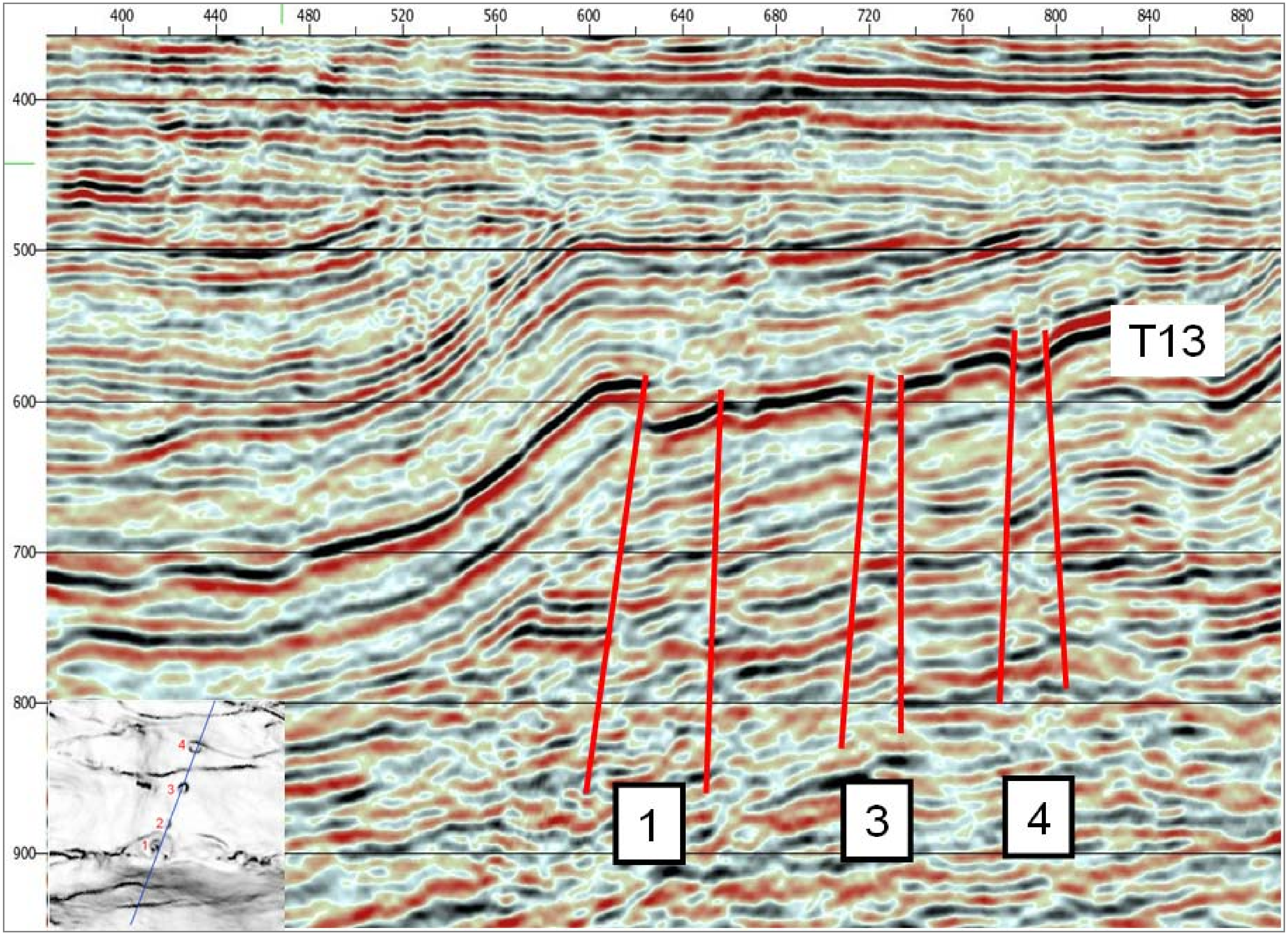

Figure 1. Subsidence column on inline seismic profile.

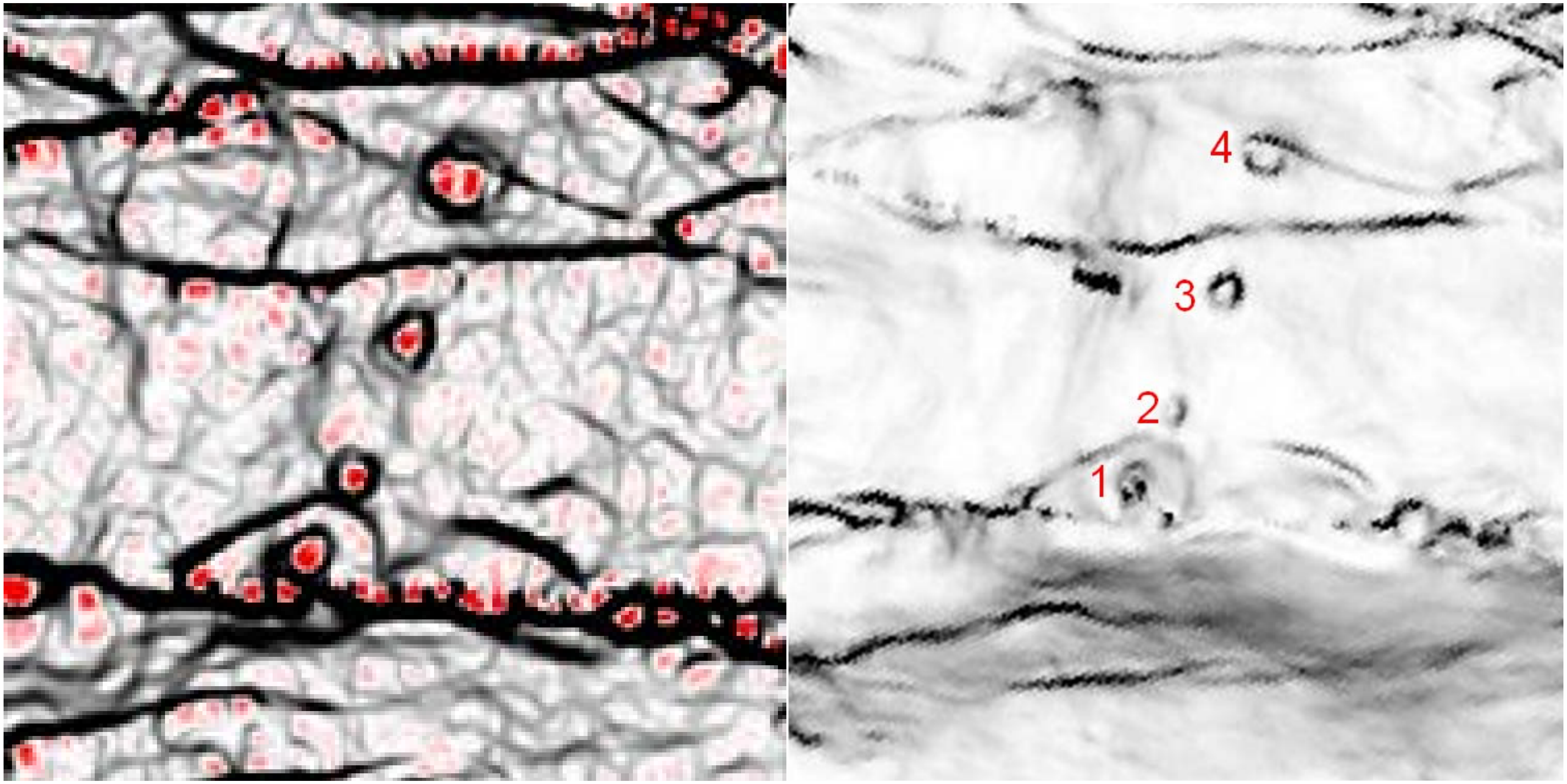

Figure 2. Identification of the subsidence column by the curvature and the variance seismic attribute in horizontal seismic slice.

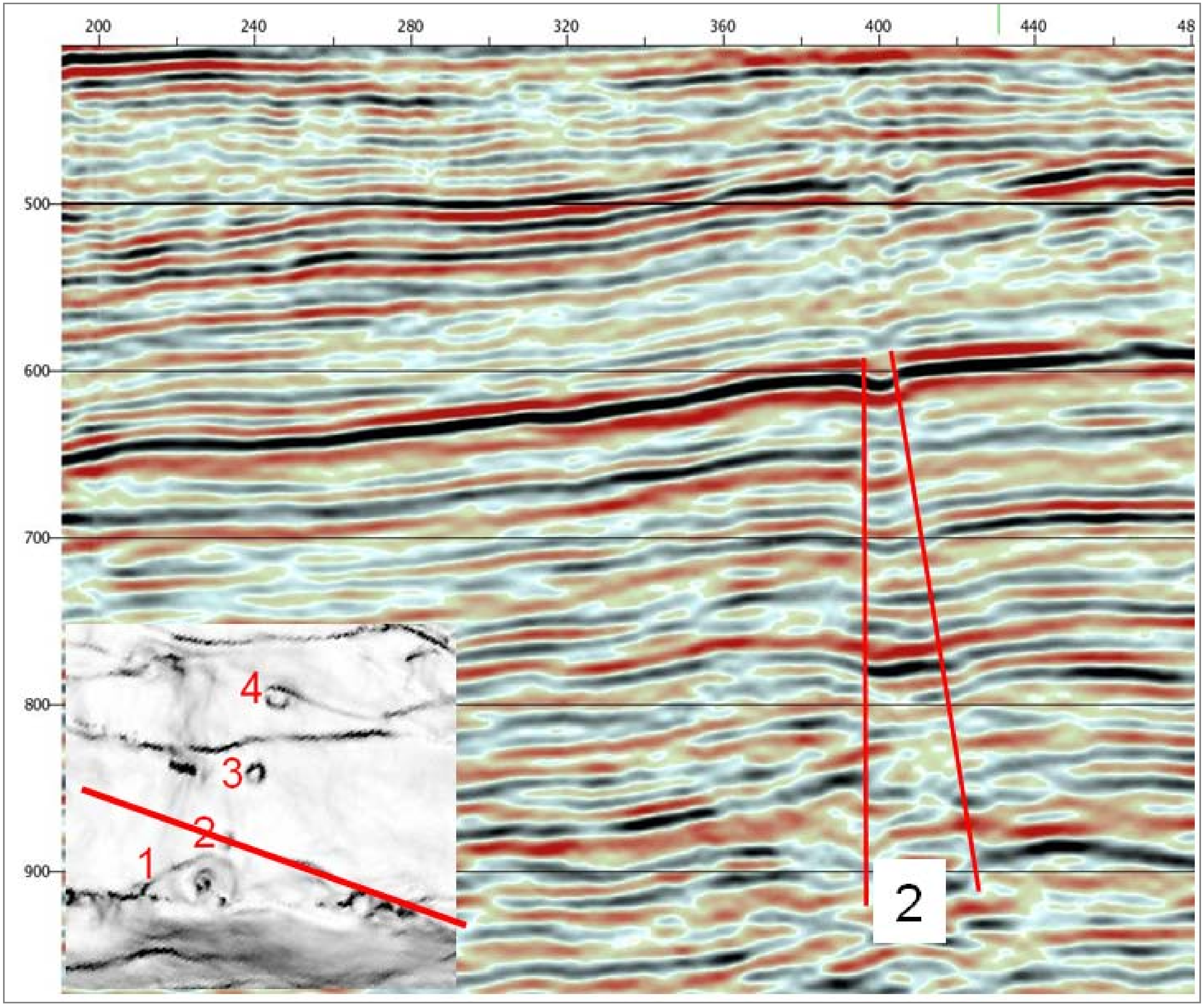

Figure 3. Subsidence column 2 on crossline seismic profile.

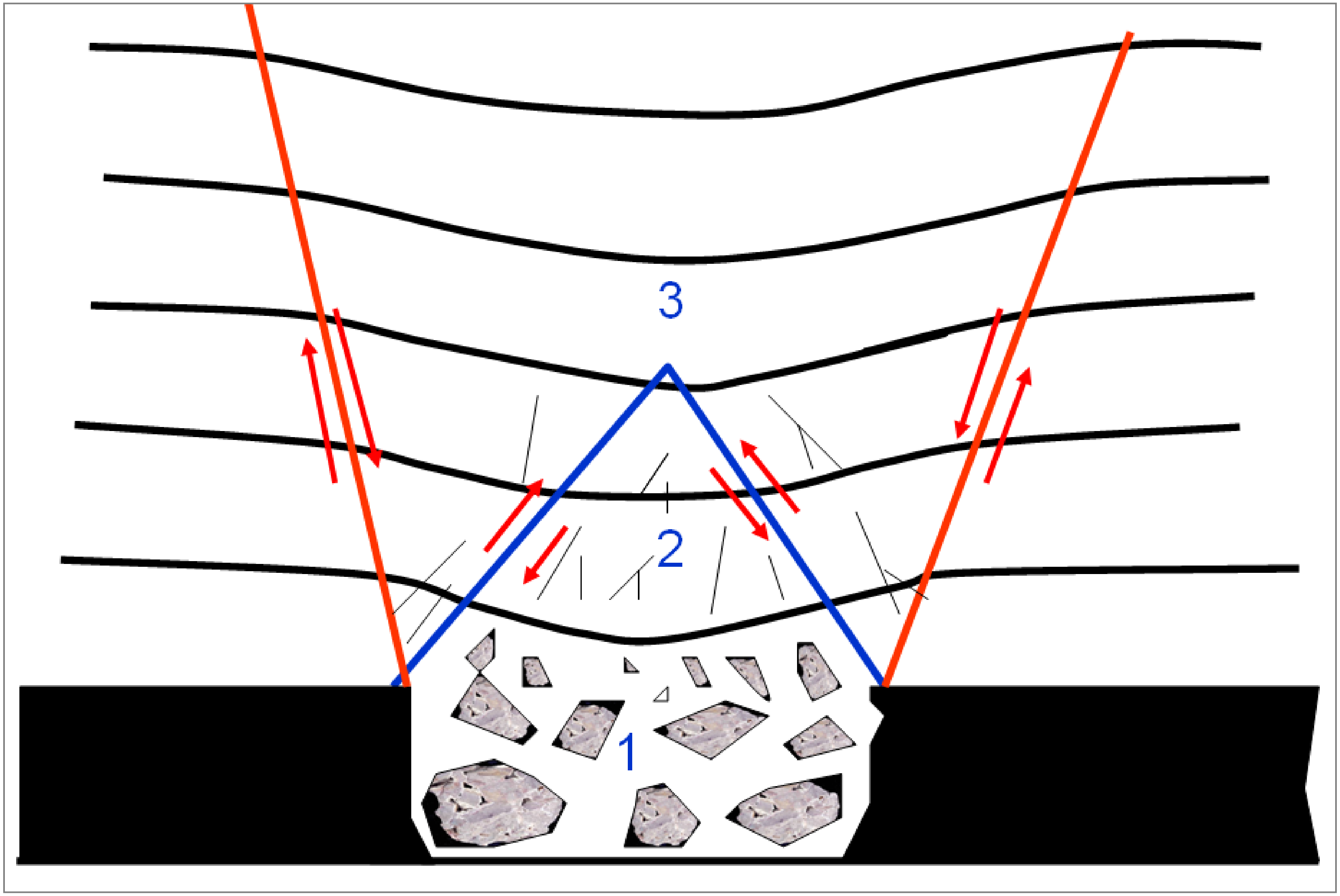

Figure 4. Collapse of gob: (1) caving zone, (2) fracture zone, (3) bending zone.

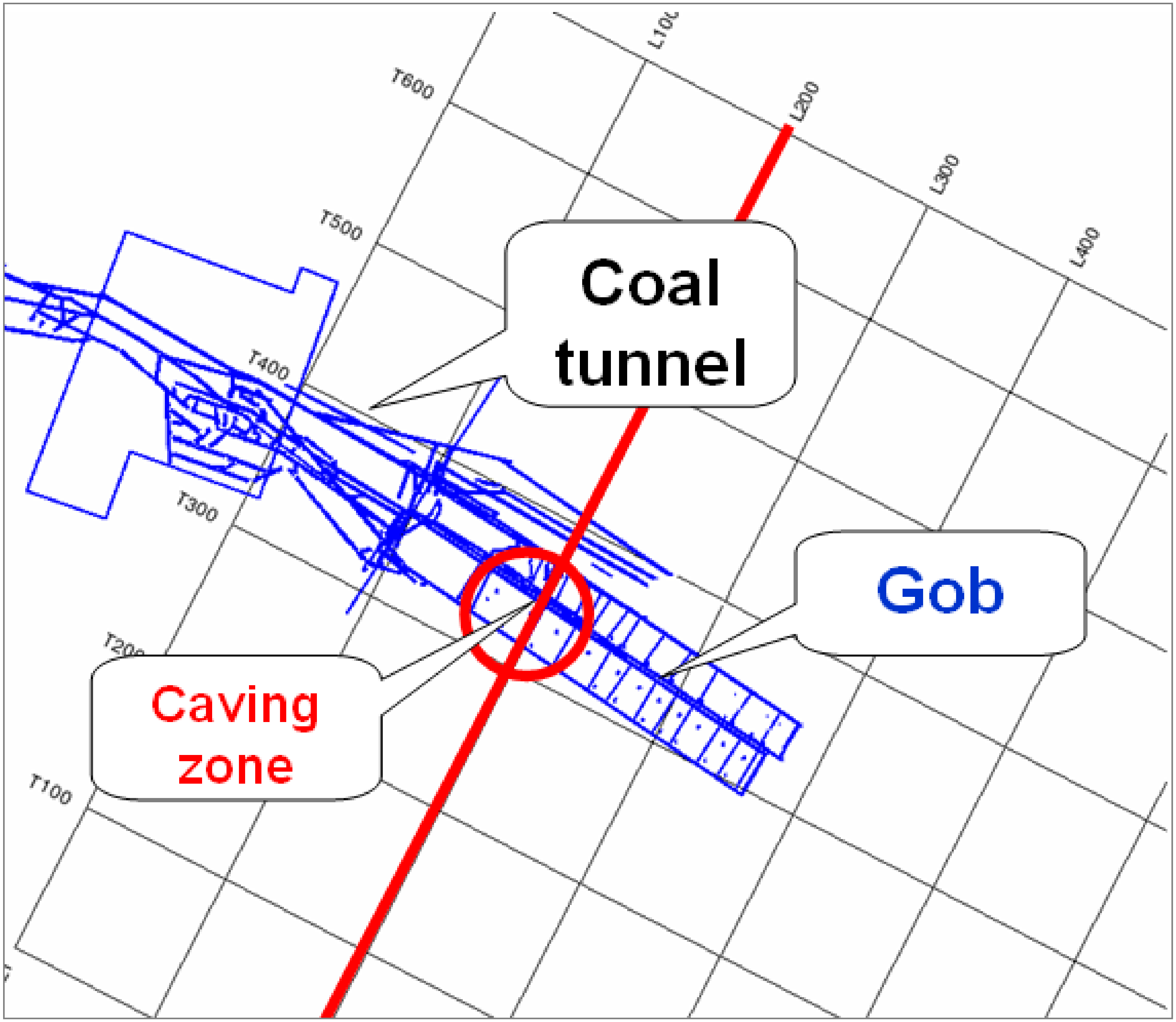

Figure 5. Coal mine map.

Figure 6. The caving zone on seismic line.

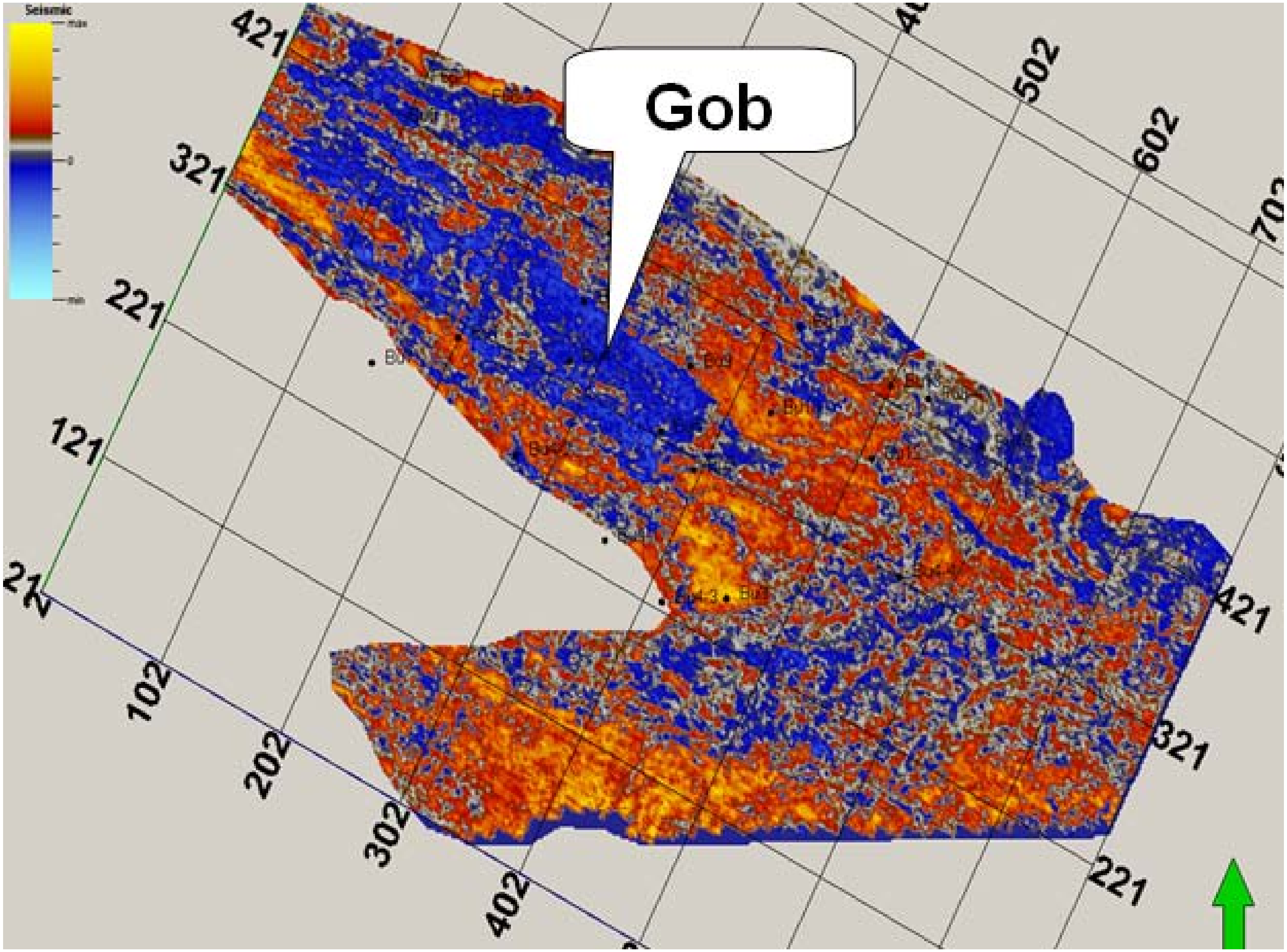

Figure 7. Seismic amplitude horizontal slice reflects the boundary of gob.

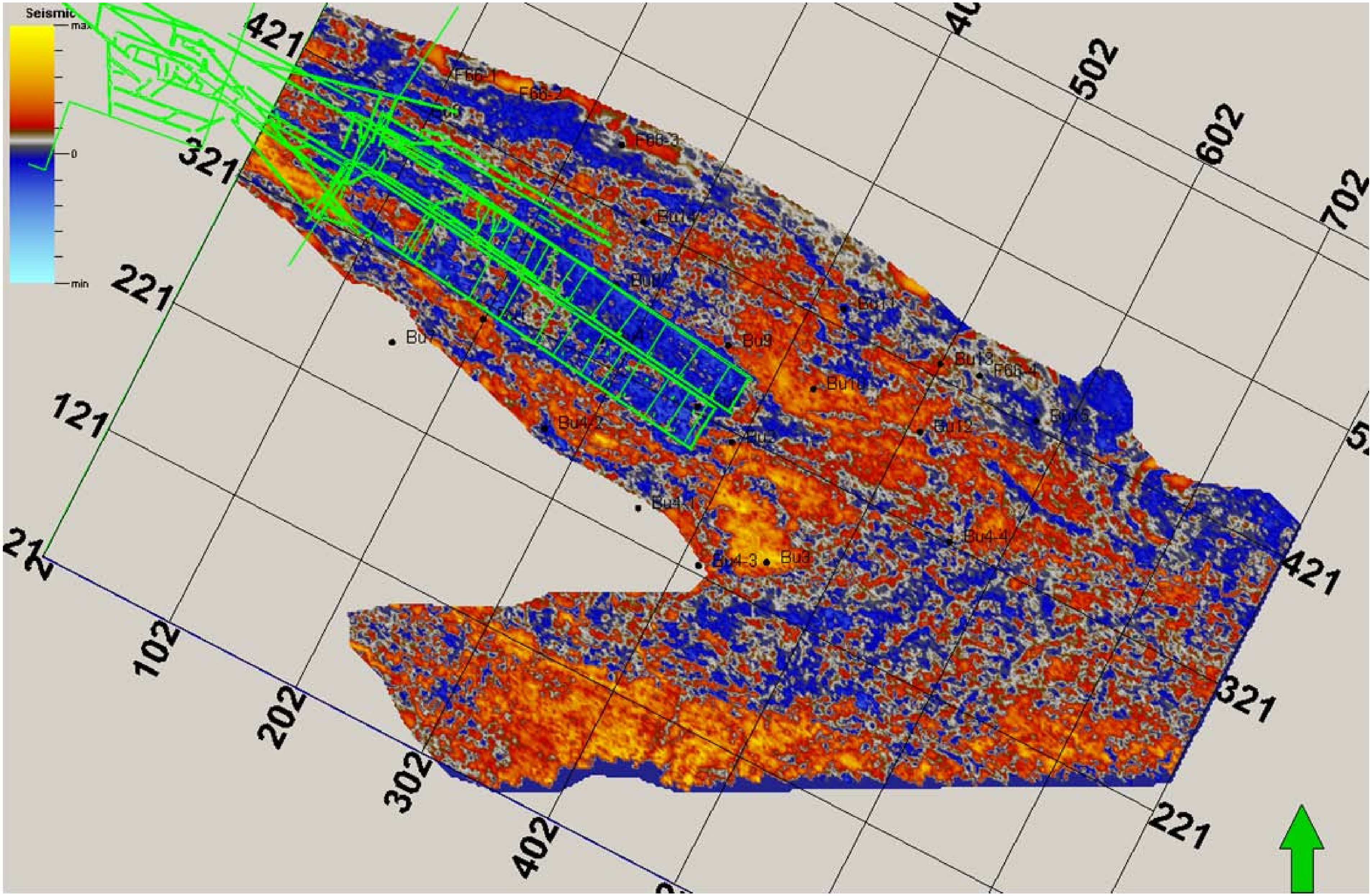

Figure 8. Overlay of the actual mine plan on the seismic amplitude horizontal slice.

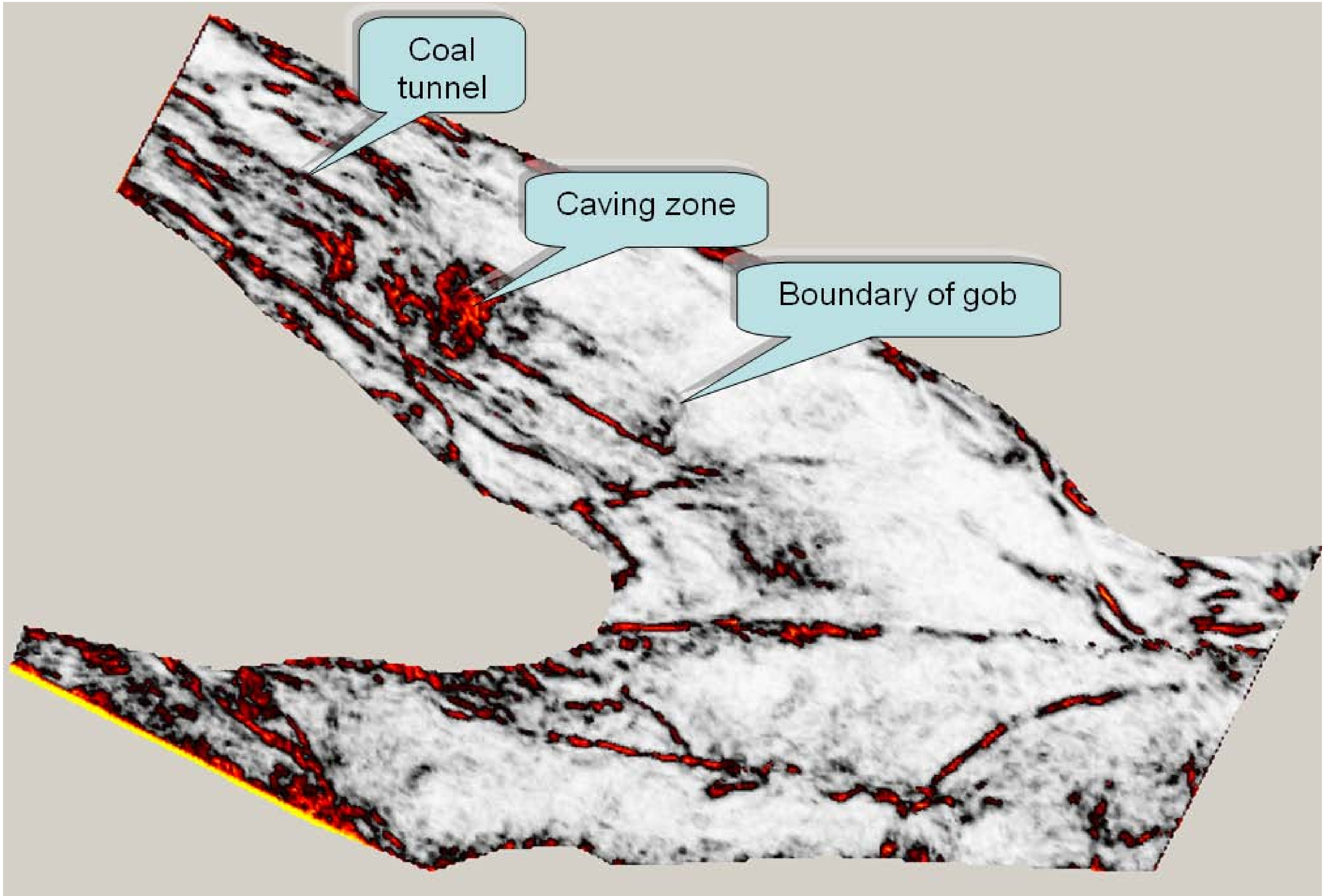

Figure 9. From the variance attribute (horizontal seismic slice) we can identify the coal tunnels, caving zones, isolated columns and the boundaries of gob.

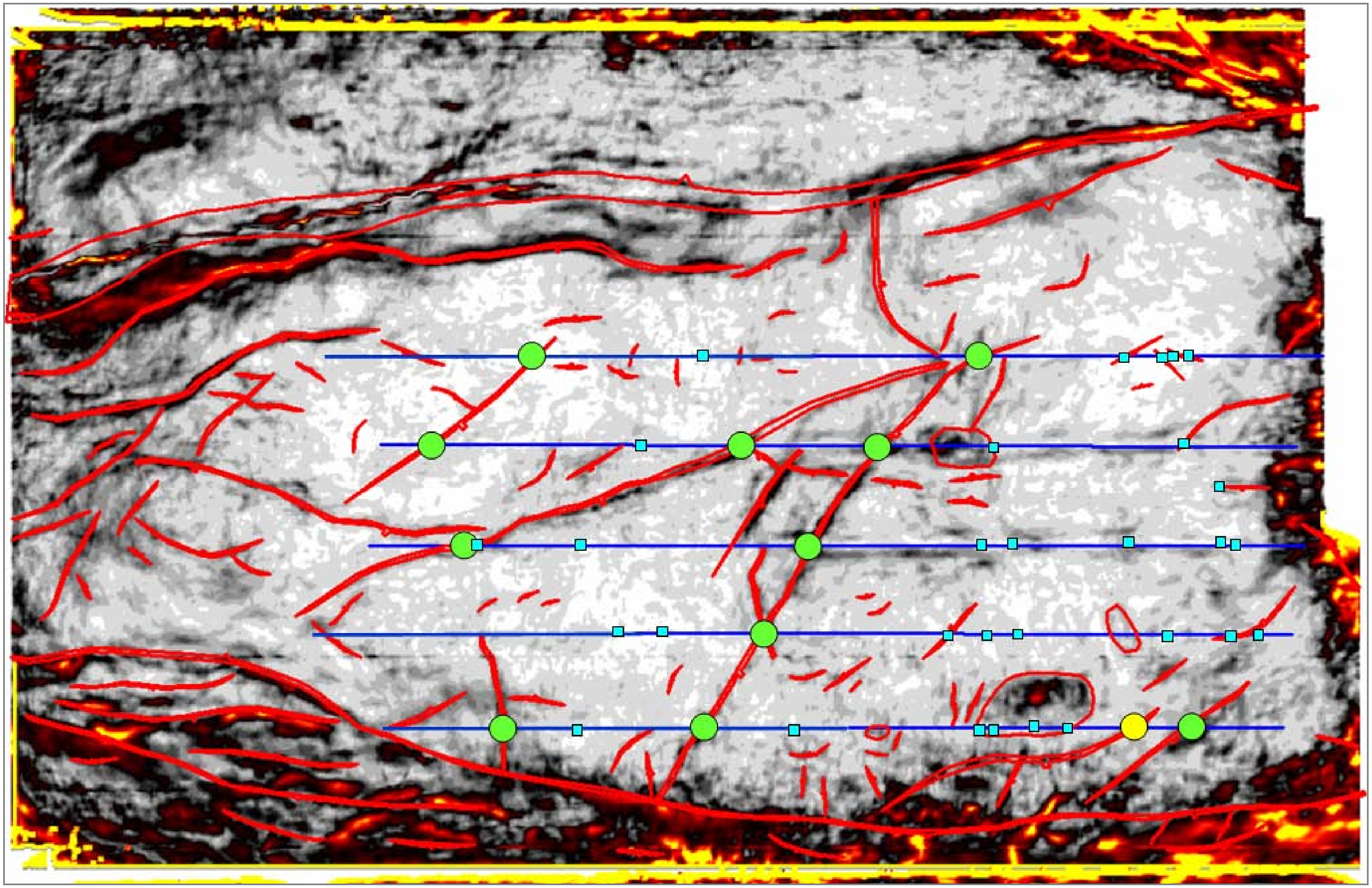

Figure 10. The actual faults, predicted faults and coal tunnels overlain on the variance attribute along horizon.