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# Application of Transient Electromagnetic Methods to the Safety Surveying of Coal Mines Production in the Datong Coalfield, China

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Research Article

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## Abstract

*There were a lot of water hazard accidents in coal mines, due to the lacking of effective methods for the coalfield surveying. The transient electromagnetic approach is one of such methods and was applied to examine the safety surveying of coal mine in the Datong coal mines during last two decades. Although there had been many successful cases of using the methods to the surveying of gobs water, meanwhile there were some difficulties to accurately detect and measure the size and location of gob water points, which still need to refine the advance of transient electromagnetic method.*

**Keywords:** Transient Electromagnetic, Datong, Successful Cases, Difficult Problems, Advance

## Introduction

It is a double discipline coal mine field in Datong coal mine field, with the Jurassic Period a coal mine field on the top and Carbonic Period coal mine field at the bottom. There are 11 coal layers in the Jurassic Period, where there were four coal layers in the Carbonic Period. Multi-layered old gobs that belong to the Jurassic had been formed in several hundred year of mining history. They threaten coal mine safety production. Which the basis of analyzing the research status of geophysical survey techniques on old gobs in the domestic and foreign and the geology-geophysics characteristic of the old gobs and coal-bearing strata in the Datong mining area, the transient electromagnetic detection was proposed, the technical ideas of which is detect the old gobs using both the ground and underground geophysical techniques. The geophysics methods of that are seismic exploration, electrical and electromagnetic exploration, and underground electromagnetic wave imaging technology. There are fracture development and have the intense absorption to the seismic wave energy in the old gobs. The physical foundation of the seismic exploration detect old gobs is that the reflector lost or the amplitude attenuation significantly. The physical foundation of the electrical and electromagnetic exploration detect old gobs is that there are different electrical characteristics whether there is water in the gobs. When the electromagnetic wave dissemination in isotropic coal, its amplitude attenuation according to certain rule; the amplitude attenuation velocity of which will have significantly change when they meet the geologic anomaly body, the velocity size is related with the fillings which is gas or water of the geologic anomaly body.

The design of the working face of mining area working can be instruct by synthetic geophysical techniques used on the ground, while the detection is usually used in roofs, floors as well as the working face in the underground, can pinpointing the position of the gobs. The trend of geophysics detection in mine is that: detect the little gobs and water-logged zone by synthetic geophysical techniques on the ground; detect them which in the roofs and as well as the working face by synthetic geophysical techniques in the underground. The research on synthetic geophysical techniques not only to relate the efficiency and the cost of the observation, but also relates resolution of the date and the effect of the inversion imaging. We can get rich geological information of the roadway using synthetic geophysical techniques in advance, thus achieves to the goal

body's comprehensive perspective. Synthetic geophysical techniques are better than the sole geophysical prospecting method.

Transient electromagnetic methods and underground measurement technology for advanced detection of mining face and driving face in coal mines of Datong coal mine were expounded in brief. Then the research progress of electrical and electromagnetic methods for advanced detection in Datong coal mines was summarized systematically, including the theory of whole-space field, the working principles and the methods, apparatus, etc. In addition, the existing theoretical and technical problems were figured out. In this paper, the method and technology of synthetic geophysical prospecting were summarized according to the working practice of prospecting in the Datong mining area, and the anomaly characteristics were researched using different geophysical prospecting techniques on the ground or in the underground. According to the synthesis detection's examples, we can get that: small multi-turn loop configuration used in transient electromagnetic method is better than the large fixed loop configuration for the detection of gobs on the ground; the transient electromagnetic method in detecting the water in gobs; while the high-density resistivity method is better than the transient electromagnetic method in the accurate localization. In brief, the application examples indicated that the ground and the underground synthetic geophysical techniques have the significantly technical superiority in the detection of old gobs.

## The principle of transient electromagnetic method

The principle of transient electromagnetic method is: through transmitting Transient electromagnetic by non-ground loop aerial or dipole landing, in order to exciting second field by underground conductor, searching the conductors. The detection depth of transient electromagnetic (TEM) field method is described in several aspects (Figure 1). The "smoke ring effect" of the equivalent electric current ring downward extension depth was cited.

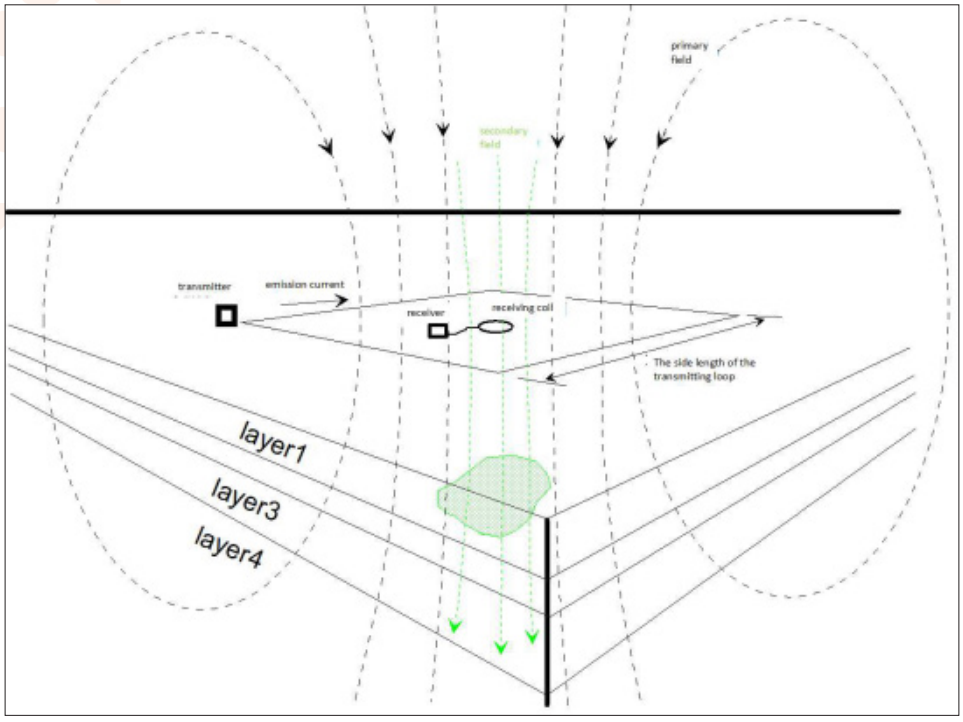



**Figure1:** The principle of transient electromagnetic (large fixed source)

Using the way of ground transmitting and receiving is half-space testing, Using the way of underground tunnel transmitting and receiving is full-space testing. A new sort- Using the way of underground tunnel transmitting and receiving drilling, the shielding effect of the borehole layer can greatly reduce the external interference of the working face during receiving the signal and improve detection accuracy, to ensure safe and efficient mining.

## The antenna of transmitting

The antenna by transmitting had two sorts: the large fixed sources and the dipole source (small circle loop). Figure1 is large fixed source like a flat wave transmitting, the dipole source like a spherical wave transmitting; usually, the large fixed source is more depth to survey, because there are more energy of transmitting; the dipole source (small circle loop) is more exact, it is due to lower volume effect that is benefit raising accuracy of testing, more it use to survive underground, because there are small sizes (Figure 2).

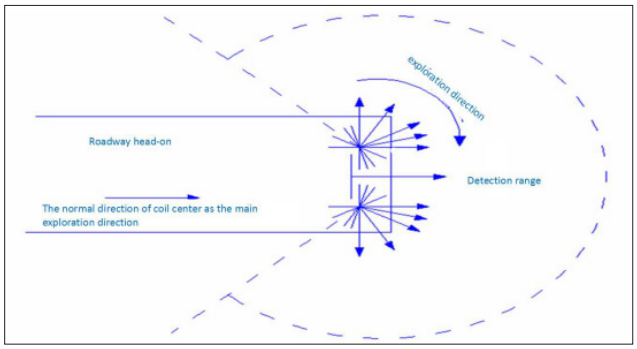



**Figure2:** The dipole sources worked underground

## The turn-off current (time)

Firstly, the transient electromagnetic (TEM) field convolution was given, and change rate of turn-off current is taken as a impact function, the field component of vertical step pulse excitation as the input signal. The convolution result is TEM response of arbitrary shape turn-off current. The current excitation pulse is regarded as a superposition of many vertical step functions (Figure 3). The transient electromagnetic response of arbitrary current pulse excitation is induced by the superposition of step function response. When the measured value of TEM field and the turn-off current form are known, whole-stage apparent resistivity can be calculated by the method of programming, but some times, directly measure by error statistical analysis is very available (Figure 4 and 5).

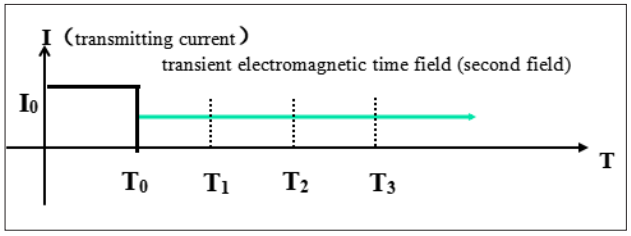



**Figure3:** The transient electromagnetic time field

turn-off current calculated time:

$$t_{of} = \frac{L}{R} \ln \frac{2V}{v + 1.5}$$

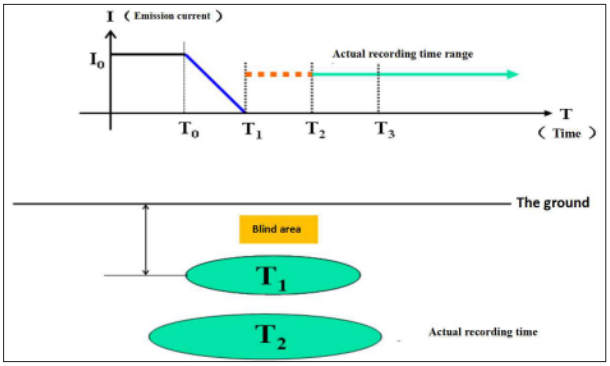
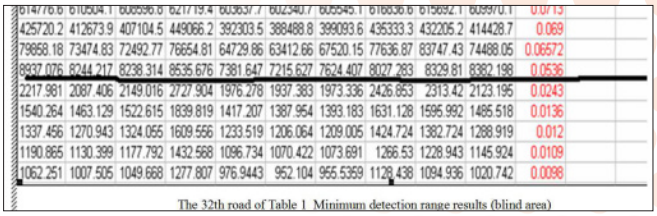



**Figure 4:** The transient electromagnetic time field for turn-off current

For examples1: directly measure by error statistical analysis is very available.



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|---|---|---|---|---|---|---|---|---|---|---|---|
| 425720.2 | 412673.9 | 407104.5 | 449066.2 | 392303.5 | 388488.8 | 399093.6 | 435333.3 | 432205.2 | 414428.7 | 0.069 |
| 79858.18 | 73474.83 | 72492.77 | 76654.81 | 64729.86 | 63412.66 | 67520.15 | 77636.87 | 83747.43 | 74488.05 | 0.06572 |
| 8937.076 | 8244.217 | 8238.314 | 8535.676 | 7381.647 | 7215.627 | 7624.407 | 8027.283 | 8329.81 | 8382.198 | 0.0536 |
| 2217.981 | 2087.406 | 2149.016 | 2727.904 | 1976.278 | 1937.383 | 1973.336 | 2426.853 | 2313.42 | 2123.195 | 0.0243 |
| 1540.264 | 1463.129 | 1522.615 | 1839.819 | 1417.207 | 1387.954 | 1393.183 | 1631.128 | 1595.992 | 1485.518 | 0.0136 |
| 1337.456 | 1270.943 | 1324.055 | 1609.556 | 1233.519 | 1206.064 | 1209.005 | 1424.724 | 1382.724 | 1288.919 | 0.012 |
| 1190.865 | 1130.399 | 1177.792 | 1432.568 | 1096.734 | 1070.422 | 1073.691 | 1266.53 | 1228.943 | 1145.924 | 0.0109 |
| 1062.251 | 1007.505 | 1049.668 | 1277.807 | 976.9443 | 952.104 | 955.5359 | 1128.438 | 1094.936 | 1020.742 | 0.0098 |

The 32th road of Table 1 Minimum detection range results (blind area)

**Figure5:** Turn-off current time directly measure by error statistical analysis

## The turn-off current time Discussing

There are easily seen from Figure3 that the dead zone is direct proportionate to the increased of the turn-off current time; It is longer of length of a side for large fixed source, the turn-off current time is direct proportionate to the increased of the length of a side; it is more circles for small circle loop, the turn-off current time is direct proportionate to the increased of the circles.

It is true that small multi-turn loop configuration used in transient electromagnetic method is better than the large fixed loop configuration for the detection of goafs on the ground, particularly the coal seam covered over shallow (see Figure 6 and 7).

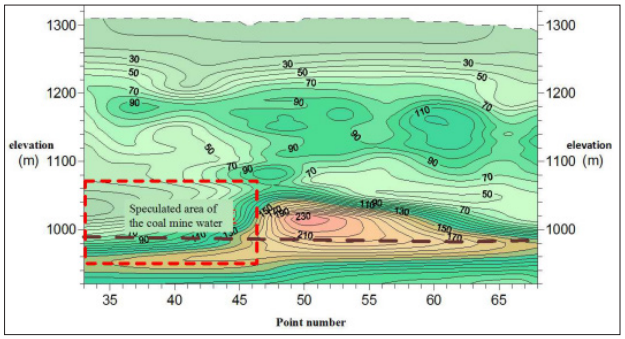



**Figure 6:** Small multi-turn loop configuration results

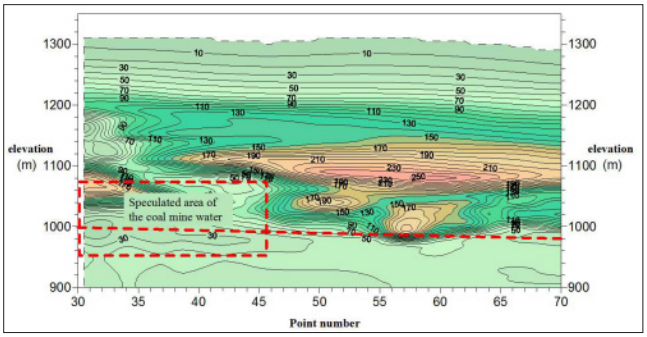



**Figure 7:** Large fixed source results

## The Consistence Principle

The influence of the consistence principle include device, terrain of observation point, collection, processing, and so on. It is not enough attention that caused to fault for surveyed working.

For example, the devices by used at same time, need to test for the consistence principle, the survey points of different local

need to normalization check at same loop and need to partly repeat test the survey points at interfacing loops for large fixed source, it is need to check of terrain of observation point if terrain complex.

The late signal is greatly influenced by the interference. If the collection and filtering processing is not adopted for the interference, it may influence on the analysis of transient signal and the quality of inversion imaging. The mine transient electromagnetic method measured the integrated response from two half- spaces, so calculation of apparent resistivity should be corrected. Statistical analysis of measured data of mine metal interference showed that interference of rails, downpipe and other metal body was far stronger than the metal wire mesh and hoisting belt. These sources of interference should be avoided as far as possible in practical work.

## Dates processing

Dates processing include: pre-processing (dates arrange, local, and so on), filtering, dimensional frequency- time conversion, and time-depth resistivity calculation.

Since the transient electromagnetic signal is a dynamic and transient one, the short time a set pre-processing software based on Lab VIEW was developed to rapidly analyze the transient electromagnetic signal on site. The experimental results show that the pre-processing software is feasible and effective for the analysis of transient electromagnetism and filtering processing, and is convenient for evaluating the filtering effect in time. It provides the basis for further determining the signal filtering method.

The influence of terrain of observation point on data collection and the conversed apparent resistivity of transient electromagnetic method (TEM), the amplitude of influence is not only associated with the change of the terrain, but also with surface resistivity and observation time delay, it is concluded that the digital filtering method based on cosine transform has the highest computing, as shown by the comparison with the analytical algorithm and the reasons of the error caused by conversion methods were discussed and analyzed,which is beneficial to the high precision calculation dimensional forward modeling of transient electromagnetic response.

Sometime consulting other Geophysical methods for the geophysical characteristics of mine voids and overburden strata are analyzed, such as seismic, high density resistivity method, microtremor, radioactive, and ground penetrating radar are introduced. The elastic wave method can determine the crushing range of the surrounding rock, and the electromagnetic method is effective for detecting the water content in mined out area. For the specific geological environment, it is not only essential to determine the effectiveness of different geophysical methods on detection targets, but also is necessary to take comprehensive geophysical methods to improve the reliability of geophysical exploration.

## The examination

It is needed to repeat test for the examination, the point number is not less than 5%.

## For example

## The surveying at Yungang coal mine

Yungang coal mine is a largely coal mine in Tongmei Group Company, extracting the Jurassic Period a coal mine field ,there were a lot of gobs water for doubt in coal mine north, tested 0.5 square kilo-meters by the transient electromagnetic method, using large fixed source method , a side is 600*600, due to the coal seam cover up only 300 meters ,usually it is match between a side to cover up , it is longer of length of a side for large fixed source, the turn-off current time is direct proportionate to the increased of the length of a side, it is suitable 300 meter for a side . a side is 600*600, lead to the turn-off current time become largely, the dead zone is become largely to 200 meter, is bad exact ,high volume effect ,it is vague for abnormal body side, finally, a water hazard accident happened, died four persons.

It illustrates that it is very important to select a suitable side for large fixed source (Figure 8).

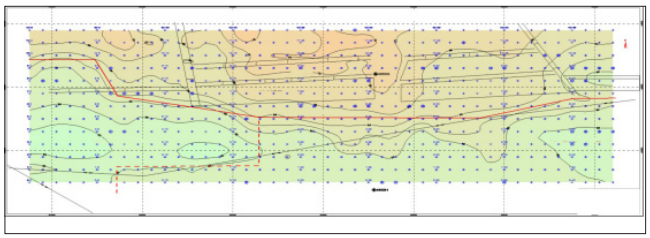


**Figure 8:** The surveying at Yungang coal mine

## The surveying at Sitai coal mine

Sitai coal mine is a largely coal mine in Tongmei Group Company, extracting the Jurassic Period a coal mine field ,there were a lot of gobs water for doubt in coal mine middle, tested 1 square kilometer by the transient electromagnetic method, using the dipole source (small circle loop) method , a side is 40*40 and 4 circles , due to the coal seam cover up only 150 meter ,usually it is match between a side to cover up , it is more circles for small circle loop, the turn-off current time is direct proportionate to the increased of the circles . Using the dipole source (small circle loop) is more exact, it is due to lower volume effect that is benefit raising accuracy of testing, succeeding to search multi- abnormal bodies, discharged water 8 million square (Figure 9).

It shows that it is very important to select a suitable method for shallow depth-- using the dipole source (small circle loop) method.

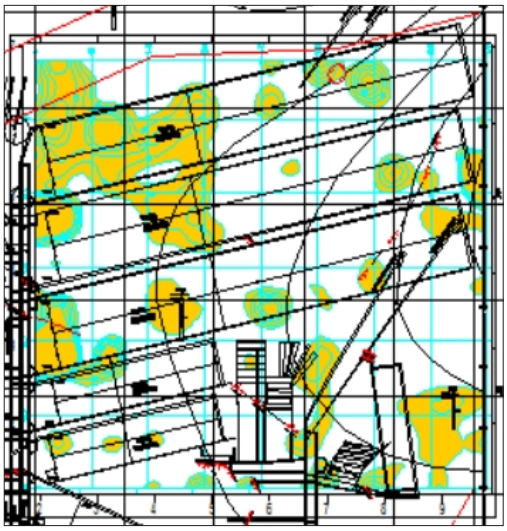
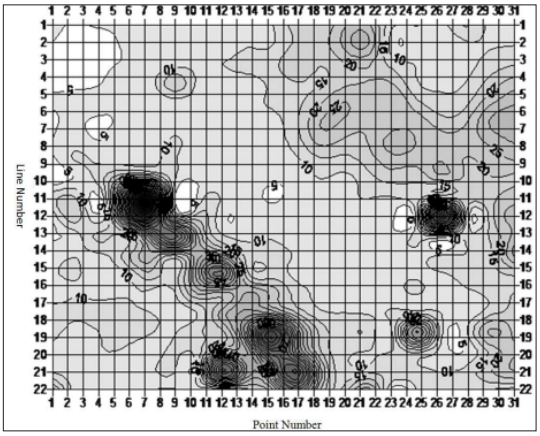


**Figure 9:** The surveying at Sitai coal mine

## The surveying at Yanzishan coal mine

Yanzishan coal mine is a largely coal mine in Tongmei Group Company, extracting the Jurassic Period a coal mine field, there were a lot of gobs water for doubt in coal mine west, tested 0.8 square kilometer by the transient electromagnetic method, using the dipole source (small circle loop) method , a side is 40*40 and 4 circles , due to the coal seam cover up only 240 meter ,usually it is match between a side to cover up , it is more circles for small circle loop, the turn-off current time is direct proportionate to the increased of the circles . Using the dipole source (small circle loop) is more exact, it is due to lower volume effect that is benefit raising accuracy of testing, succeeding to search multi- abnormal bodies, discharged water 32 million square in 8113 workface, but due to too depth for the dipole source (small circle loop), it is fault at interfacing 8111 workface because a small tunnel connects a big gob water out of survey, finally, discharged water 35 million square at 8113 workface the cut tunnel. The small tunnel depth of burial is so deep that was not discovered by the dipole source (40*40).

It indicates that it is very difficult discovered by the dipole source (40*40) for too deep and too small tunnel water (Figure 10).



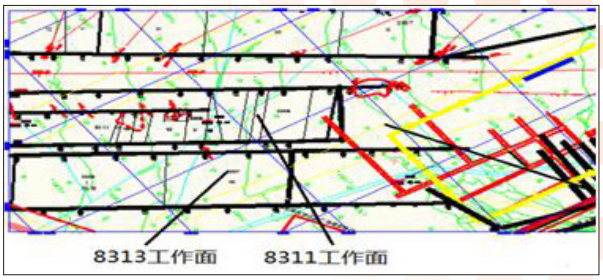




**Figure 10:** The surveying at Yanzishan coal mine

## The surveying at Tongxin coal mine

Tongxin coal mine is a tens of millions of tons coal mine in Tongmei Group C extracting the Carbonic Period coal mine field , there were a lot of gobs water for doubt on the Jurassic Period a coal mine field , tested 1.5 square kilo-meters by the transient electromagnetic method, using large fixed source method , a side is 300*300, due to the coal seam on the Jurassic Period a coal mine field is so more seams gobs water that is difficult to find out the gobs water, at first searching discharged water 709 million square at dozens of workface on the Jurassic Period a coal mine field multi-seam by bored hundreds drills on the ground and underground ; at second searching discharged water 100 million square at a dozen of workface on the Jurassic Period a coal mine field multi-seam by bored dozens drills underground (see Figure 11 and 12).

It shows that it is need more searching for complex coal mine field, so as to ensure the safety of coal mine.

**Figure 11:** The first surveying at Tongxin coal mine

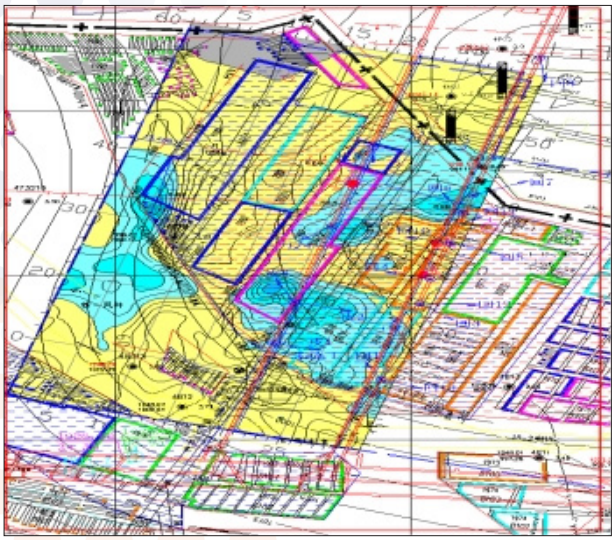


**Figure12:** The second surveying at Tongxin coal mine

## The surveying at Qingciyao coal mine

Qingciyao coal mine is a middle coal mine in Tongmei Group Company, extracting 11 seam coal mine of the Jurassic Period a coal mine field ,there were a lot of gobs water for doubt on 11 seam coal mine, tested 0.3 square kilometer by the transient electromagnetic method, using the dipole source (small circle loop) method , a side is 40*40 and 4 circles , due to the coal seam cover up only 200 meter ,usually it is match between a side to cover up , it is more circles for small circle loop, the turn-off current time is direct proportionate to the increased of the circles . Using the dipole source (small circle loop) is more exact, it is due to lower volume effect that is benefit raising accuracy of testing, succeeding to search multi- abnormal bodies, but not discharged water, only discovered the water in rock seam on two-seam coals through the crevices by multi-seam gobs.

It shows that it is the water in rock seam through the crevices by multi-seam gobs make abnormal bodies (Figure 13).

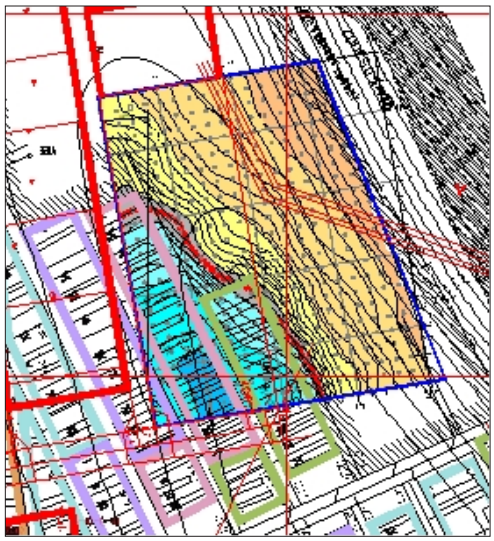


**Figure 13:** The surveying at Qingciyao coal mine

## The surveying at Xingwang coal mine underground

Xingwang coal mine is a small coal mine in Tongmei Group Company, extracting the Jurassic Period a coal mine field ,there were a lot of gobs water for doubt on same seam coal mine, leading tested at the tunnel head by the transient electromagnetic method, using the dipole source (small circle loop) method , a side is 2*2 and 4 circles ,,usually it is match between a side to cover up , it is more circles for small circle loop, the turn-off current time is direct proportionate to the increased of the circles . Using the dipole source (small circle loop) is more exact, it is due to lower volume effect that is benefit raising accuracy of testing, succeeding to search multi-abnormal bodies, discharged water a litter the water of same seam gobs (see Figure 14).

It indicates that it is effective using leading tested at the tunnel head by the transient electromagnetic method the dipole source (small circle loop) method.

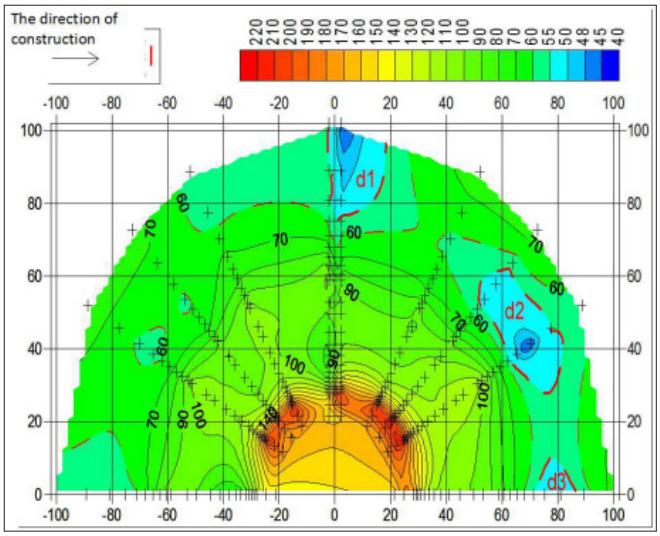



**Figure 14:** The surveying at Xingwang coal mine

## Conclusion

The transient electromagnetic are applied for safety of coal mine in Datong coal mine field, there have been many successful cases of using to survey of gobs water, at the same time, there are some difficult problems of accurately detecting the size and local of gob water, need to advance of transient electromagnetic method.

At the same time, it is not easy that obtaining high quality and accurately detecting result need better the consistence principle, include device, terrain of observation point, collection, processing, and so on. It is not enough attention that caused to fault for surveyed working. If it is very complex to coal mine, we need to think over all kinds of cases, need to select suitable devices, decrease volume effect and depth influence, and benefit raising accuracy of testing for safety of coal mine.

**Author Contributions:** Conceptualization, Y.G. and J.G.; methodology, Y.G.; software, J.G.; validation, Y.G. and

Y.Z.; formal analysis, J.G.; investigation, Y.G.; resources, J.Y.; data curation, J.G.; writing—original draft preparation, Y.G.; writing—review and editing, Y.Z.; visualization, J.G.; supervision, Y.Z.; project administration, J.Y.; funding acquisition, Y.G.

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