

Development of the Array Transient Electromagnetic System and Its Experiments

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Abstract Transient electromagnetic (TEM) technique plays a significant role in mineral exploration. To accommodate the complicated survey environments in the west part of China, we developed a portable array TEM equipment (ATEM-1), which was implemented based upon the idea to apply the GPS timing signal for the synchronization among transmitters and receivers. The structure of the system and its performance are discussed and the case study is also described.

Key words Transient electromagnetic Array Synchronization GPS

Introduction

Transient Electromagnetic (TEM) technique has been further studied in Canada, USA, Australia and Former Soviet Union. Since 1953 the first patent about TEM appeared in the West, many instruments have been produced such as EMP-1 (1964), UTEM-1 (1972), and EM-37 (1980, made by Geonics Corp), etc (Nabighian et al., 1991). And in U. S. A., VETEM (Very Early Transient Electromagnetic) has been developed in recent years (Pellerin et al., 1997). High performance equipment and effective noise suppress techniques are developed mainly for shallow layer high-resolution exploration. In China, study on TEM was begun in the early 1970's. Many research groups have developed their own TEM equipment from then. They are the Changchun University of Science and Technology, the Geology Institute of Nonferrous Metal Industry of China, the Geophysical and Geochemical Exploration Institute of the Ministry of Land and Resource, the University of Technology of South China, the Xi'an Geology College, etc (Jiang Bangyuan, 1998). These equipment are all successfully used in practical environments, but most of these equipment were synchronized by crystal clock or a cable between the receiver and transmitter, consisting of a single transmitter and a single receiver which resulted low efficiency for field work (Zong,

1992). And so they were not fit for area resource exploration in the West Part of China (Lin Jun, 1997; Lin Jun et al., 1997). Besides transmitting large current, the factors such as equipment size, weight, turn-off time of the transmitter and the noise suppression of the receiver can all influence the applications of TEM equipment in the complicated environment of the West Part of China. In recent years, wide dynamic range array and network MT exploration equipment play a significant role in the resource exploration and these new equipment also provide new ideas for the development of new type of TEM equipment.

To be applicable to the complicated environment of the West Part of China, the TEM exploration system should be made portable with an exploration depth from 2 km to 3 km and can be used in multiple applications. Based on the project of the Ministry of Land and Resource "Study on Synchronization Measurement Techniques and Its Applications in Electromagnetic Exploration" (Lin Jun et al., 1998), with modern electronic and computer technique, we developed a portable array transient electromagnetic equipment (ATEM-1) synchronized by GPS timing signal. In this system, one or two transmitters and multiple receivers made up an array, and the distributed receiver system was managed in master-slave mode. Such structure was suitable not only for the area electromagnetic survey in complex environ-

ment such as desert and gobi in the West Part of China, but also for the applications of deep detection depth and high - resolution. The test system has been tested with the model simulation experiments at the lab and the field comparison experiments at Yongji Toudaogou Diggings of Jilin Province.

The implementation of array transmitter and receiver system provides efficiency technique, supporting not only for the prospect, exploration and utilizing of resource in China, but also for the underground electromagnetic survey and mapping structure.

1 The Structure & Performance of ATEM - 1

1.1 The Structure of ATEM- 1

ATEM - 1 consisted of 3 parts: transmitting source (transmitter), data acquisition system (receiver) and software for data processing and interpreting.

1.1.1 Transmitting source

Several important technique problems have been solved, such as the electromagnetic field inducing wave form when multiple transmitters transmitted at the same time, the influence of turn - off time and the output of controllable large current in battery - powered transmitter. With the technique of delay - control of turn - off waveform and fast recording and storage, the transmitter was made portable for the array transient electromagnetic survey.

1.1.2 Data acquisition system

The array receiving system of ATEM - 1 utilized the idea of distributed system. In this system the master receiver was controlled by a note book computer which consisted of an high - precise GPS timing synchronous controller, high - performance data acquisition card produced by QUOTECH in the U.S.A and an anti - saturation low - noise amplifier. It implemented the automation and intelligent data acquisition and storage and visual display of ac-

quired data in whole turn - off time which not only provided sufficient source material for the data processing but also made it easy to find out and process various noise and increased the precision of deducing interpret.

The slave receiver adopted single chip computer as the master controller which consisted of a GPS synchronies controller, a high - speed data acquisition circuit, high - performance preamplifier, large - storage NVSRAM (Non Volatile Static Random Access Memory) and a intellectual communication interface. It could implement full - domain data acquisition, storage, timing and data transfer. Besides, the slave receiver was so portable that it could be configured according to the application requirements.

The TEM exploration system was synchronized by GPS and dual A/D technique is adopted for solving exploration precision and speed. It implemented efficiency noise suppression by array synchronization technique.

1.1.3 The software for data processing and interpreting

The functions of the software with ATEM - 1 are as following: decay waveform drawing on the spot (in dual logarithmic or arithmetic coordinate axis), profile graph (in half - logarithmic or arithmetic coordinate axis), waveform smoothing, filtering, deleting oddity point and error statistic and processing. The general functions include transmitting transient field, data acquisition and superposition.

With the software for data processing and converting equipped with this system, it was easy to draw apparent resistivity profile graph.

1.2 The ATEM- 1's performance

1.2.1 Performance of the transmitter

Maxim transmitting current : 50A/ 30A (powered by generator), 10A(powered by battery)

Maxim transmitting voltage: 800V(powered by generator), 12 ~480V(powered by battery)

The transmitting current waveform : BI - polarity , duty cycle 1 : 1

Fundamental frequency of the transmitting current : 2.5 , 6.25 , 25 , 62.5 , 262.5 Hz

Turn - off time: little than 1.3 us (resistant load)

Weight : 30Kg/ 50Kg

Operating temperature : - 20 ~50

Protection function : over - voltage , over - current , over - heat , warning of lacking of voltage

Synchronization error of GPS : < 1 μ s

1.2.2 Performance of the receiver

| | Master receiver | slave receiver |
|-------------------------------|------------------------|------------------------|
| Input voltage range : | + / - 2.5 V | + / - 2.5 V |
| Sampling rate : | 10 μ s | 20 μ s |
| Sampling time window : | 10 μ s - 2s | 20 μ s - 2 s |
| Gain range : | 1 - 8000 | 1 , 10 , 100 , 1000 |
| Delay time : | 1 - 9999 | 1 - 9999 |
| Input channel : | 1 | 1 |
| Synchronization mode : | reference cable or GPS | reference cable or GPS |
| Operation mode : | menu | controlled by master |
| Begin delay point selection : | set up by program | set up by program |
| Communication interface : | RS232 | RS232 |
| Instrument Weight : | 3Kg (without battery) | 1Kg (without battery) |

2 The Field Array Configurations

2.1 Single transmitter - single receiver mode

In this working mode , several configurations could be made , such as coincident loop , central loop or fixed loop (or large loop) . It is convenient and easy to work because the transmitter and receiver were synchronized by GPS timing signal .

2.2 Single transmitter - multi receivers mode

This is one of the area survey modes and two configurations could be made : fix loop (Fig.1) and moving loop (Fig .2) .

In figure 1 , Rs1 , Rs2 , . . . , Rsn respectively represent the master receiver and multi slave receivers which were synchronized by GPS . The multi receivers acquire data simultaneously when the transmitter is working , which could improve the efficiency of area survey obviously . Compared to the single receiving mode , the measurement speed could be improved when slave receivers are added to the field op-

eration system . The more the slave receivers are added , the higher work efficiency will be gotten . The power consumption will be also saved with this mode .

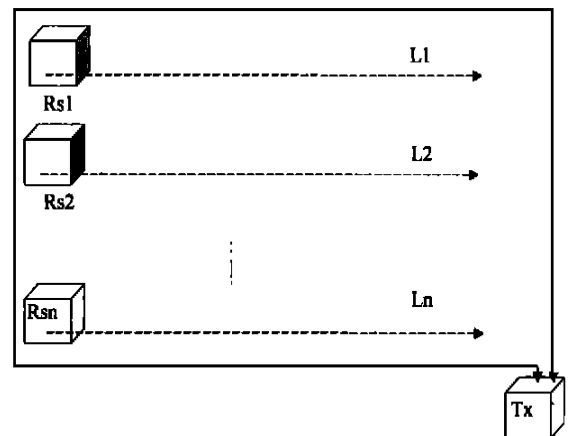


Fig. 1 The configuration of area fix loop field survey

In Fig.2 , the working mode is one special area survey mode , in which three profiles could be measured with one master receiver and two slave

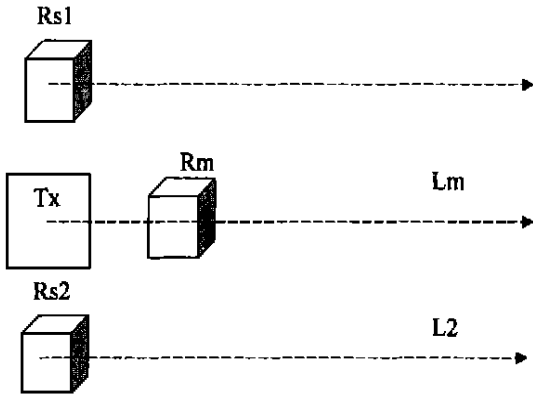


Fig. 2 The configuration of area pole - pole field survey

receivers at the same time. To make data processing and interpreting easy, it is necessary that the measure space should be as same as the space between the transmitter and the receiver.

2.3 Dual transmitters- multi receivers mode

This is another working mode in area survey. And it was benefit from the high - precision GPS synchronization and synchronous acquisition of the multi receivers, as shown in Fig. 3.

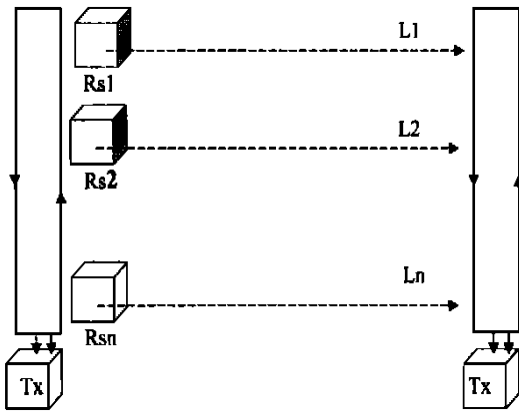


Fig. 3 The field work arrangements of area multi-transmitter larger loop detection

In figure 3, it was demanded that the transmitters on both sides should be synchronized strictly and that the transmitting current should follow the direc-

tion as shown in Fig. 3.

The length of power supply - loop' s border depends on the practical demands. The efficiency of this working mode is the same as that of figure 1, which all depends on the number of the slave receivers. A uniform magnetic field was generated between the two transmitting loops because it was powered on both sides so that it made the data processing and interpreting more easily. Another benefit is that in this working a high - power transmitter could be substituted by multi - low - power transmitters, which was fit for working in a mountainous area because of the mobility.

3 Test Result at Lab

In the experiments, two kinds of model were tested: slope and vertical conductivity metal plate in the air. The conductivity metal plate was a copper plate, 14cm length, 10cm width, 1.2cm thickness and burial depth is 0.5cm.

The metal plate was sloped about 90° (for the vertical model test). The length of the profiling was 46cm, and the interval between two measure points was 2cm, coincident loop configuration was adopted. The area of the transmitting loop was 10cm (10cm × 100 which was the same with the receiving loop). The transmitting current was 1.5A, and the pulse width was 20ms. The sampling time was from 400 μs to 6ms. The experimental results were shown in Fig. 4.

It could be seen from the figure that the response over the thin, vertical bodies was a symmetrical dual - peak in its response profile and that the response over the thin, oblique bodies was a non - symmetrical dual - peak. And the peak on the tendency side was greater than the another one. We can deduce the leaning direction using this character.

4 Field Experimental Result

To verify the field effect of the instruments,

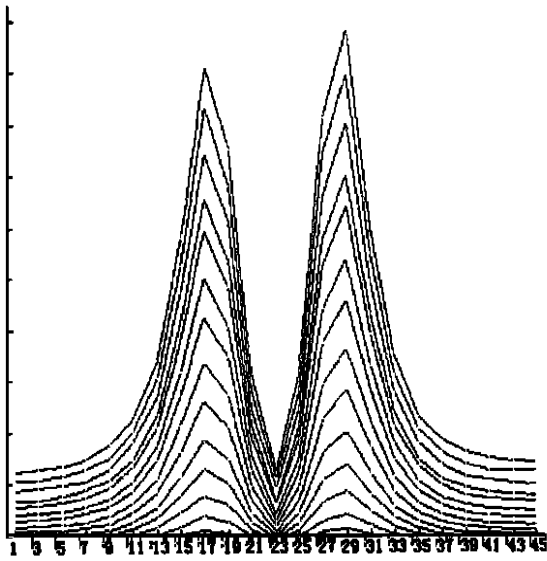


Fig.4 The multi TEM response curve of vertical metal sheet

we did two experiments in Toudaogou diggings of Jilin City in 3/2000 and 4/2000. The digging is a geophysical test site of Changchun University of Science and Technology. Different geophysical methods had been used here.

4.1 The geologic and geophysical feature of the diggings

The Toudaogou Diggings is located in the middle - south of Jilin Haixi Fold Zone. At the west section of Toudaogou - Sanjiazhi it is slope north, in the southwest section of Kouqian - Xiaochengzi fault zone.

4.2 The field working mode and the factor selecting of loop

An in - loop configuration was adopted in the experiment, in which the transmitting and receiving

loops were not coincident. The area of transmitting loop was $50\text{m} \times 50\text{m}$, and the area of the receiving loop was $20\text{m} \times 20\text{m} \times 5$. The borders of the transmitting loop which were parallel with the measure line were laid respectively on the original the 53 and the 54 survey route of the diggings and the practical measured profile was between the 53 and 54, as shown in figure 5. The interval of measure spots was 20 m, and the transmitting current was as much as $3.8 \sim 6\text{ A}$ with a pulse width of 125 ms. The valid observe time was $0.1 \sim 10\text{ ms}$. The end sampling time postponed step by step with the initial delay time.

Fig.6 (a) and (b) show the measured results of the master and slaver on the same survey line (53.5). It shows that the shape and the position of the peak of the profiles measured with the master and slaver are similar.

To verify the field performance and resolution of ATEM - 1 and the corresponding relationship between exception position and practical vein, we plot several profiles including geological section, TEM profiles by ATEM - 1 and the composite profiling plots by other electrical methods. To make it easy to compare, Fig.7 shows composite profiles of line 53.5, combined resistivity profiles and induced polarization (IP) results are taken from the data of line 54.

Fig.7 (a) is the multi - channel transient electromagnetic secondary field response curve. It shows from the figure that the response over the main vein is very obvious. The maxim anomaly appears on the points 73 and 75, and the curve on the right of point 74 is scalar which value is little than the small number spot's. So, the main peak is caused probably by

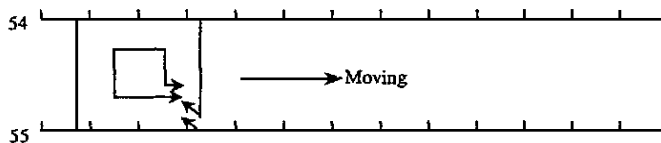


Fig 5 The field working sketch with in - loop configuration

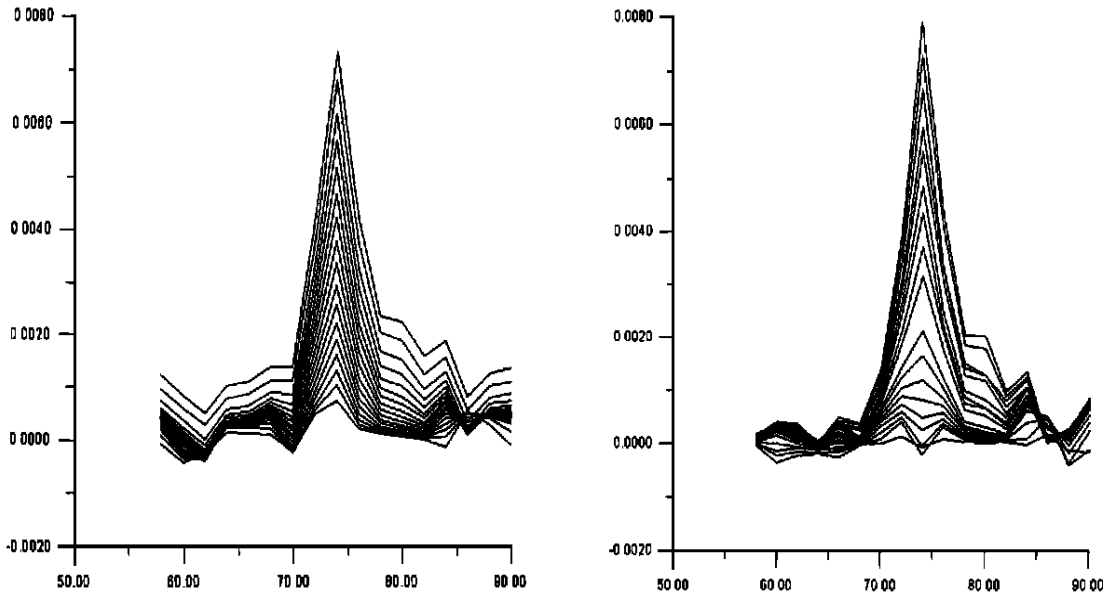


Fig.6 (a) The multi - channel TEM profiles with master receiver at Line 53.5
(b) The multi- channel TEM profiles with slave receiver at Line 53.5

the sulfur- iron ore beneath the point 74 . The value of the curve on the right side of point 74 is higher than the left side , because on this side there is many slagheaps on the ground . Besides , there are two small veins at about 10m to the east of number 80 , which also can cause higher measured value .

Fig.7(b) shows the profiling curves of combined resistivity profiles and induced polarization at line 54 ,in which the low resistivity across point of the combined resistivity profiles is appeared between point 74 and 75 , and higher IP abnormal is appeared between point 74 ~77 , but the maxim point is not appeared at point 74 , which is caused by the influence of mineral residue at the bigger point number site 。 The low resistivity abnormal is appeared between the point 73 and 75 of the IP curve 。 Line 54 is the test line for university student field study and the results are showing no different at the different survey , the abnormal peak is appeared at the point between 73 ~74 。

After comparing and analyzing the above several illustrations , we can find that the anomaly positions

of transient electromagnetic and other electrical survey methods are identical , which are consistent with the vein position in the geological section . So the anomaly observed is believable .

5 Conclusion

ATEM - 1 system is implemented with advanced software and hardware . It can be synchronized by GPS . The system can be easily organized as a single receiver configuration or multi receiver array configuration . The system is portable for area survey under the difficult conditions in mineral exploration . Laboratory and field experimental results show that the system provided here can be applied to practical resources investigation and environment monitoring .

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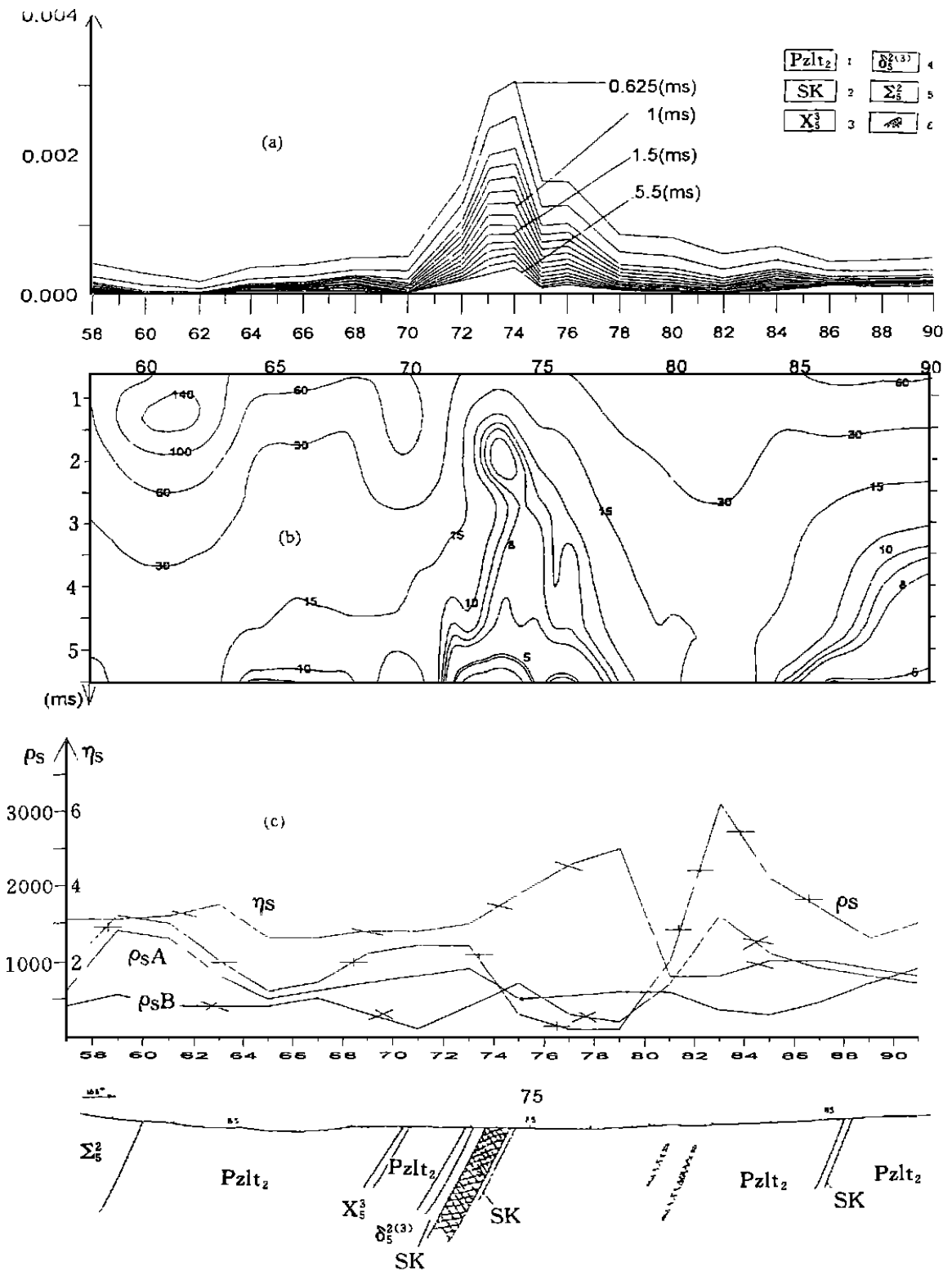


Fig.7 Synthetic electrical profiles and geological profile at line 54

1- Amphibolite of Permian Toudaogou Formation; 2- Scarn; 3- Lamprophyre; 4- Diorite; 5- Ultrabasic rock; 6- Sulfur- diamond

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