第四届煤岩动力灾害国际研讨会

4Th International Symposium on Coal and Rock Dynamics Disasters

大型冲击地压演化分析与思考

Analysis and Consideration on Evolution of Large Rockburst

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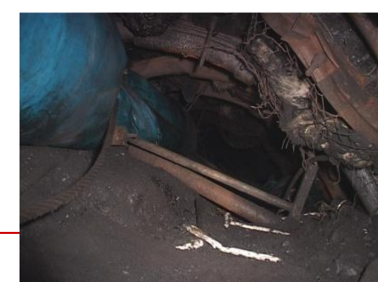
1. 背景 Background

- 目前我国中东部矿井进入深部开采。伴随采深的增大，地质和采矿条件复杂，冲击地压灾害变得更加严重。全国冲击地压矿井的数量已经增加到177对。

Today, Many coalmines in central and eastern China are deep mines With the growth of the mining depth, the geological and mining condition become complicated, and rockburst hazards are getting more serious. The number of coalmines with rockburst hazard in our country has increased to 177.



1. 背景 Background

- 大型冲击地压灾害时有发生，千秋矿“11.3”（2011年，10人死亡）、龙郓煤业“10.20”（2018年，21人死亡）

  Large rockburst had occurred randomly in the past few years, such as 11.3 accident in Qianqiu coalmine (2011, 10 deaths), 10.20 accident in Longyun coalmine (2018, 21 deaths).

- 以上矿井，均具有相对完善的冲击地压预防技术体系和管理体系，但还是无法避免大型冲击地压灾害的发生。说明大型冲击地压灾害致灾机制及演化过程不明确，预防难度很大。

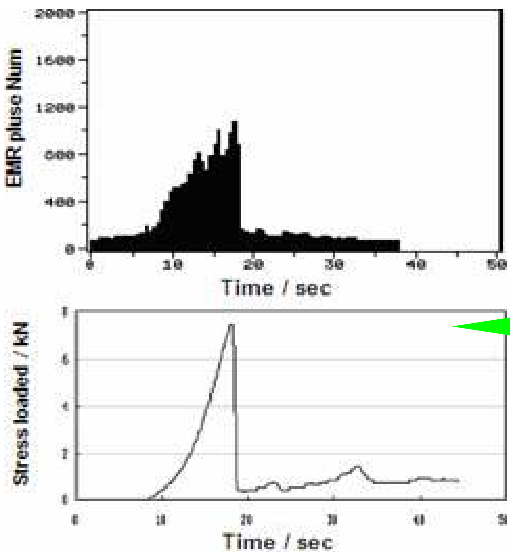
  All of the above mines have relatively perfect technical and management systems for rockburst prevention and control, but it is still impossible to avoid the occurrence of large rockburst. It means that the disaster-causing mechanism and evolution process of large rockburst are not clear, and its prevention or control are very difficult.

2. 煤岩突变破坏的特征

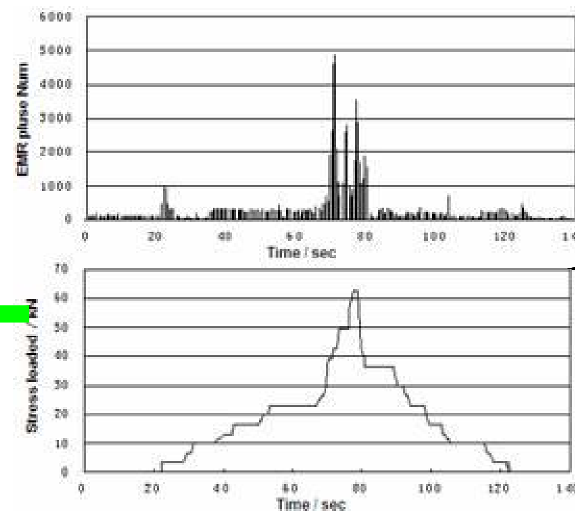
Characteristics of sudden destruction of coal and rock

Coal samples

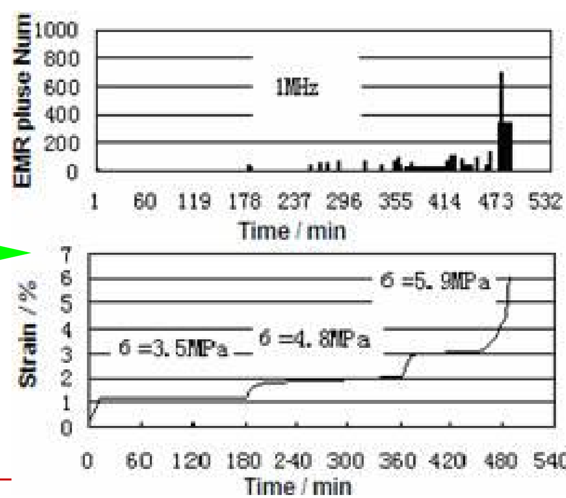
uniaxial compression



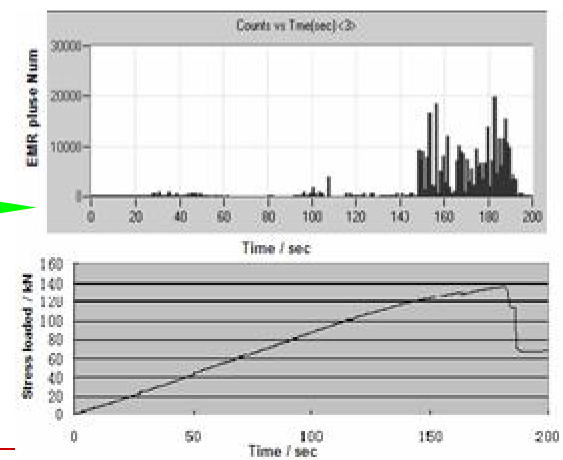
shearing



creep



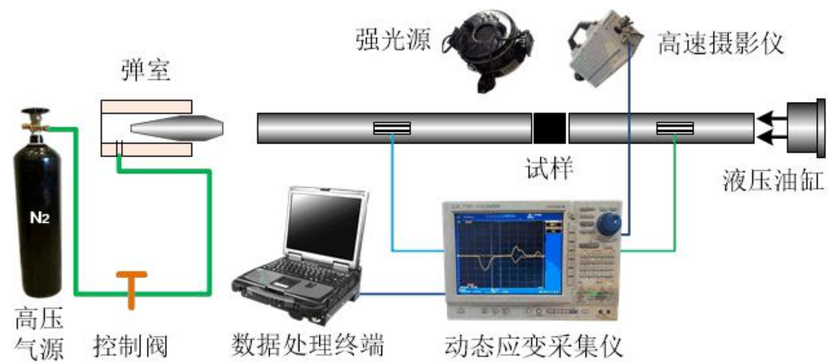
triaxial compression

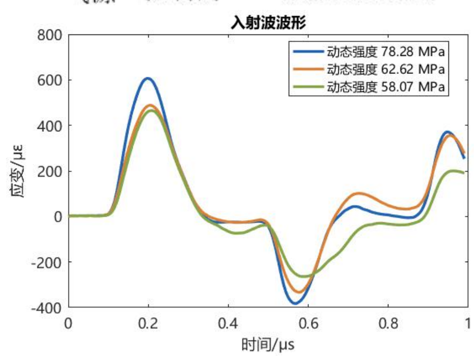


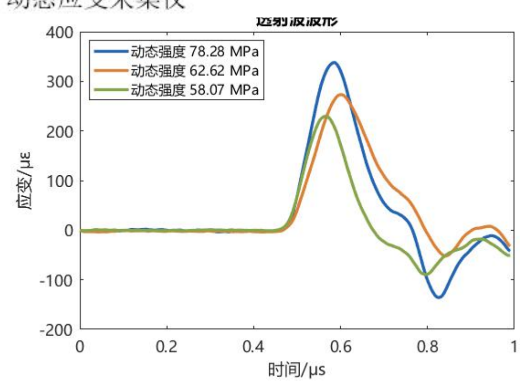
2. 煤岩突变破坏的特征

Characteristics of sudden destruction of coal and rock

煤岩冲击破坏/Coal rock impact damage



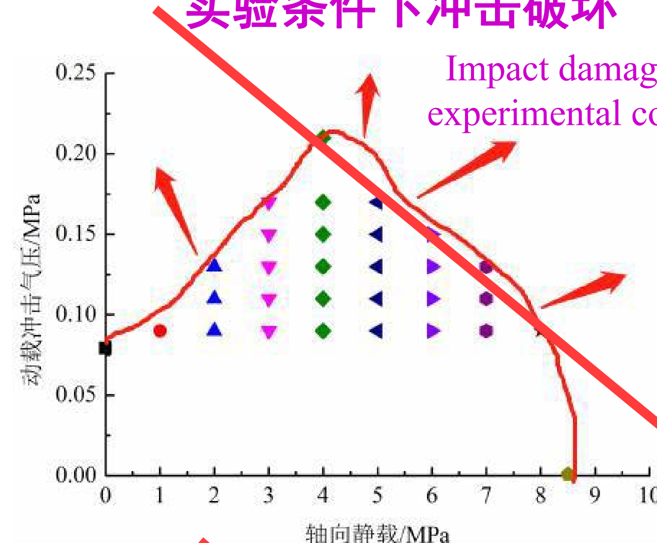




静载+临界动载应力波/Static load and critical dynamic stress wave

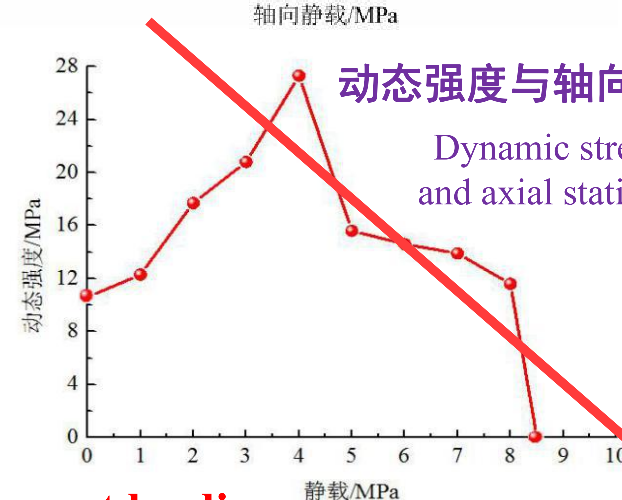
实验条件下冲击破坏

Impact damage under experimental conditions



动态强度与轴向静载

Dynamic strength and axial static load

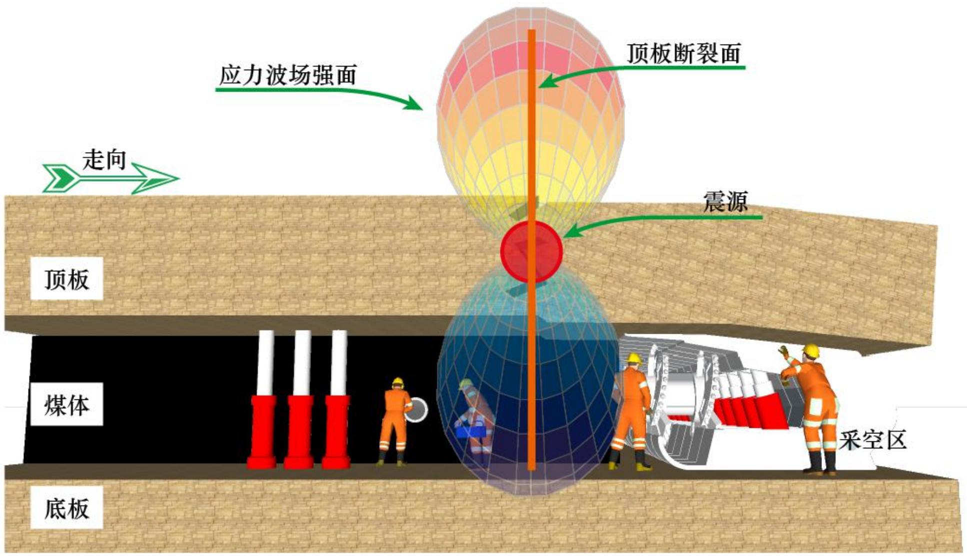


任何煤岩在冲击加载下都能产生冲击破坏

Any coal or rock can produce impact damage under impact loading

3. 煤矿采动震动应力波产生及传播

Coal mine mining vibration stress wave generation and propagation



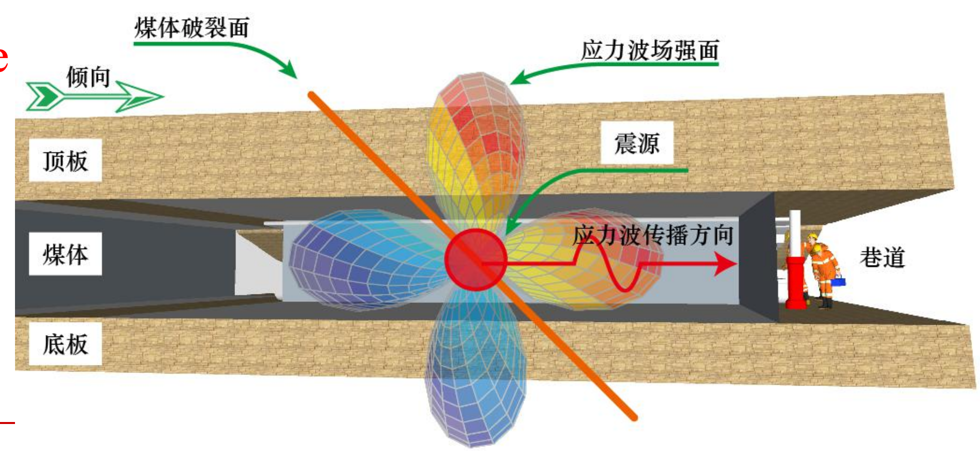
坚硬顶板断裂震源

Hard roof fracture source

$$
\begin{cases}
u_{\mathrm{I}}^{\mathrm{R}}(\boldsymbol{x},t)=\dfrac{\lambda+2\mu\sin^2\theta\sin^2\phi}{4\pi\rho c_{\mathrm{d}}^3}\displaystyle\iint_{\Sigma}\frac{1}{r}\Delta\dot{u}_{\mathrm{I}}\left(\xi,t-\frac{r}{c_{\mathrm{d}}}\right)\mathrm{d}\Sigma \\
u_{\mathrm{I}}^{\Phi}(\boldsymbol{x},t)=\dfrac{\lambda+2\mu\sin\theta\sin\phi\cos\phi}{4\pi\rho c_{\mathrm{s}}^3}\displaystyle\iint_{\Sigma}\frac{1}{r}\Delta\dot{u}_{\mathrm{I}}\left(\xi,t-\frac{r}{c_{\mathrm{s}}}\right)\mathrm{d}\Sigma \\
u_{\mathrm{I}}^{\Theta}(\boldsymbol{x},t)=\dfrac{\lambda+2\mu\sin\theta\cos\theta\sin^2\phi}{4\pi\rho c_{\mathrm{s}}^3}\displaystyle\iint_{\Sigma}\frac{1}{r}\Delta\dot{u}_{\mathrm{I}}\left(\xi,t-\frac{r}{c_{\mathrm{s}}}\right)\mathrm{d}\Sigma
\end{cases}
$$

煤体破裂震源/Coal body rupture source

$$
\begin{cases}
u_{\mathrm{II}}^{\mathrm{R}}(\boldsymbol{x},t)=\dfrac{\mu\sin2\theta\sin\phi}{4\pi\rho c_{\mathrm{d}}^3}\displaystyle\iint_{\Sigma}\frac{1}{r}\Delta\dot{u}_{\mathrm{II}}\left(\xi,t-\frac{r}{c_{\mathrm{d}}}\right)\mathrm{d}\Sigma \\
u_{\mathrm{II}}^{\Phi}(\boldsymbol{x},t)=\dfrac{\mu\cos\phi\cos\theta}{4\pi\rho c_{\mathrm{s}}^3}\displaystyle\iint_{\Sigma}\frac{1}{r}\Delta\dot{u}_{\mathrm{II}}\left(\xi,t-\frac{r}{c_{\mathrm{s}}}\right)\mathrm{d}\Sigma \\
u_{\mathrm{II}}^{\Theta}(\boldsymbol{x},t)=\dfrac{\mu\sin\phi\cos2\theta}{4\pi\rho c_{\mathrm{s}}^3}\displaystyle\iint_{\Sigma}\frac{1}{r}\Delta\dot{u}_{\mathrm{II}}\left(\xi,t-\frac{r}{c_{\mathrm{s}}}\right)\mathrm{d}\Sigma
\end{cases}
$$

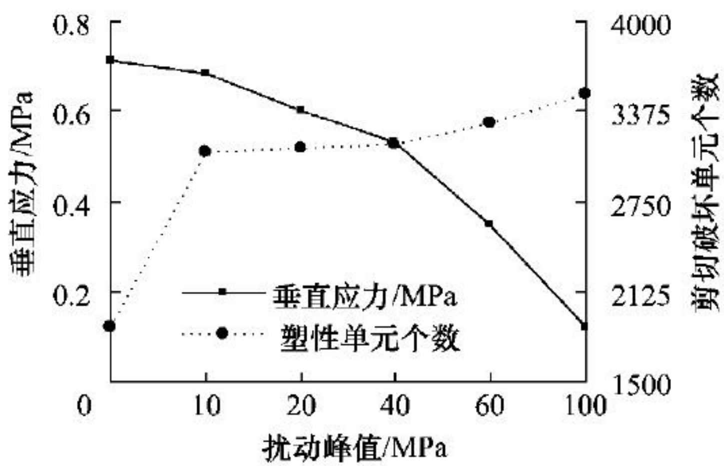


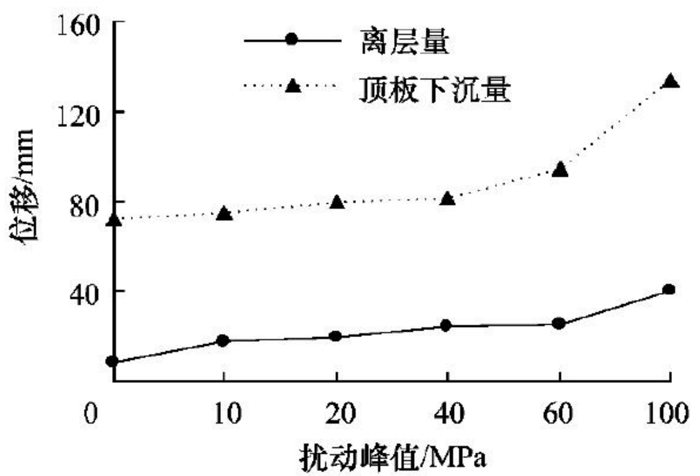
3. 煤矿采动震动应力波产生及传播

Coal mine mining vibration stress wave generation and propagation

应力波扰动强度的影响

Influence of stress wave disturbance intensity





扰动具有频率响应特征，表现为"高频低能，低频高能"频率越低，越不利于围岩稳定。

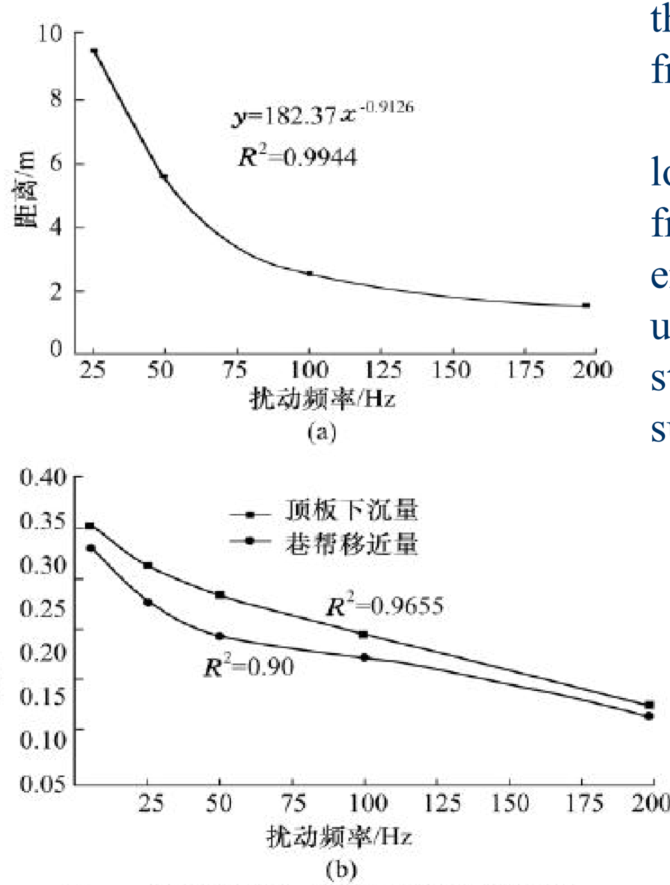


图 6 响应参数与扰动频率关系曲线

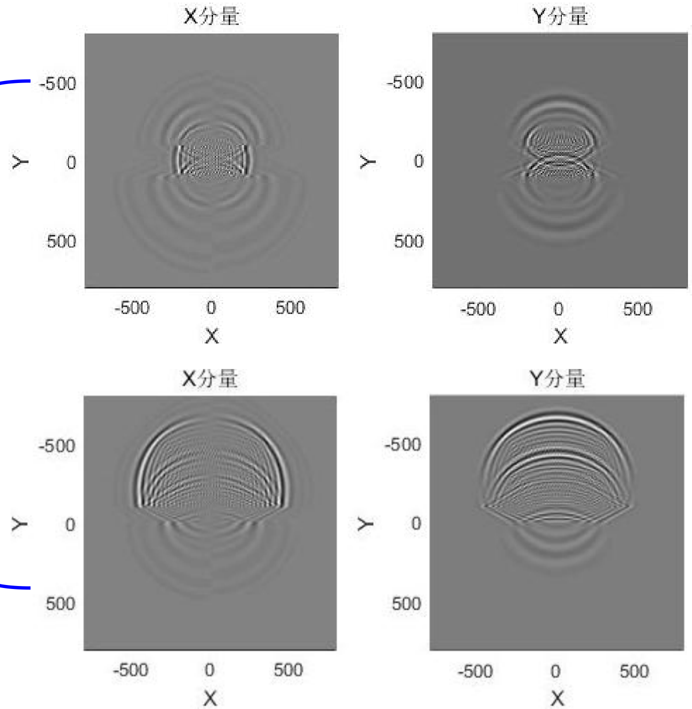
The disturbance has a frequency response characteristic, and the lower the frequency of "high frequency low energy, low frequency high energy" the more unfavorable the stability of surrounding rock.

3. 煤矿采动震动应力波产生及传播

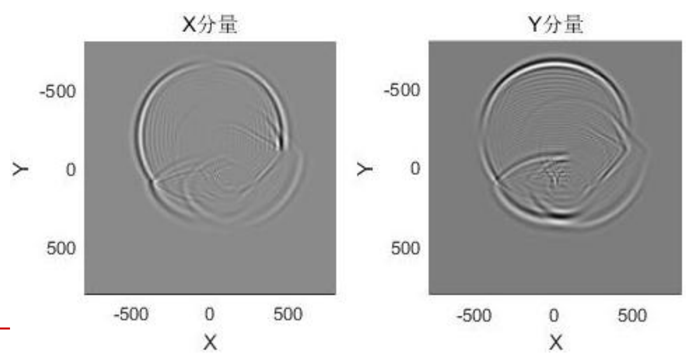
Coal mine mining vibration stress wave generation and propagation

三相介质模型

岩+煤+岩 rock-coal-rock

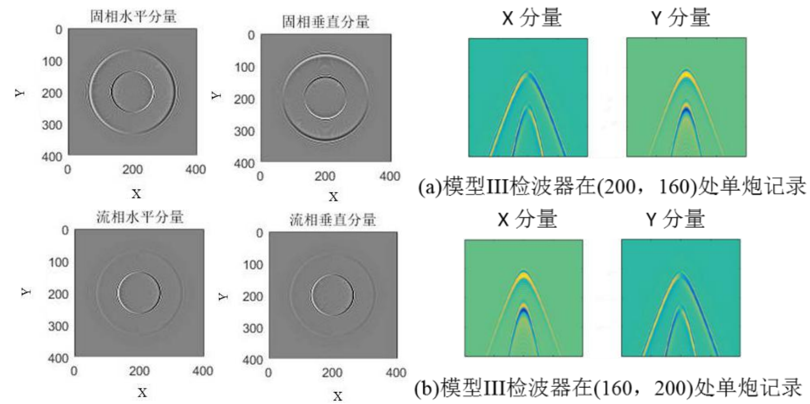


含断层介质模型 Fault Media model

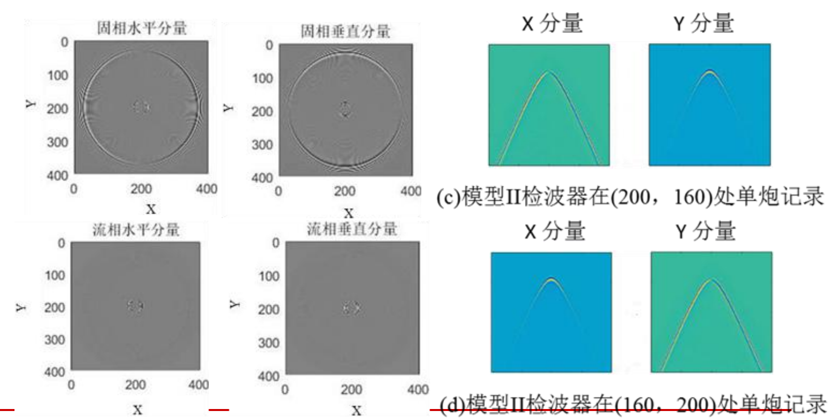


复杂煤岩介质条件下的波场传播特征

Wave field propagation characteristics under complex coal and rock media conditions



双相介质（煤和瓦斯）/coal and gas



双相介质（岩和水）/rock and water

3. 煤矿采动震动应力波产生及传播

Coal mine mining vibration stress wave generation and propagation

弹性波波速与应力耦合模型

Elastic wave velocity and stress coupling model

Raiga模型

$$V = V_m (1-\varphi)^n$$

+

分形岩石力学理论

Fractal rock mechanics theory

$$D = \frac{\ln N(\delta)}{\ln \frac{1}{\delta}}$$

$$D = m_1 * \Delta\sigma + m_2$$

$$N(\delta) = \delta^{-D} = \delta^{-(m_1 * \Delta\sigma + m_2)}$$

↓

轴向

Axial

$$V = V_i \left[1 - (a\Delta\sigma + b) 10^{10(a\Delta\sigma + b\text{-}3)} \right]$$

径向

Radial

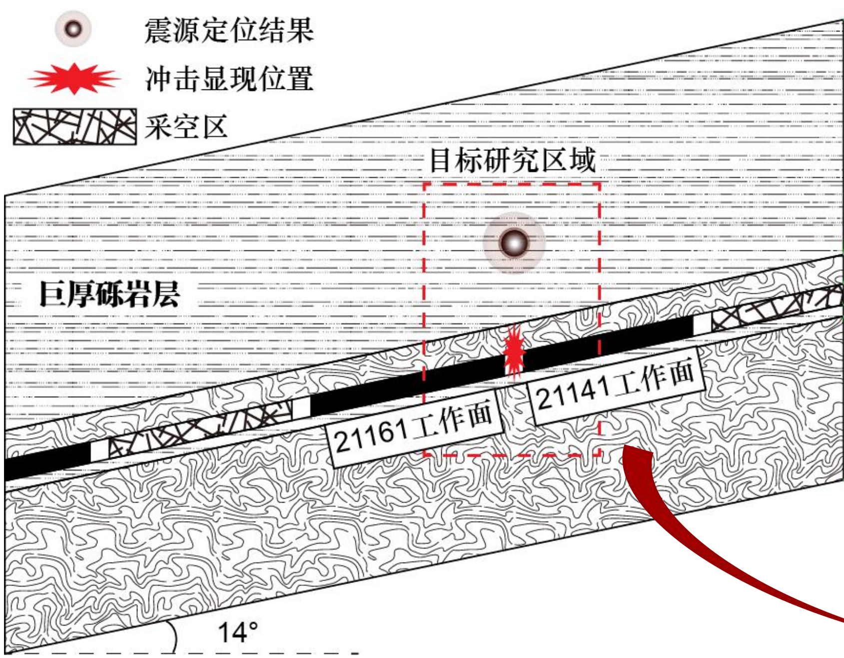
$$V = V_e \left\{ 1 - \left[a(1\text{-}\Delta\sigma) + b \right] 10^{10\left[a(1\text{-}\Delta\sigma)+b\text{-}3\right]} \right\}$$

4. 大型冲击地压演化过程分析—数值模拟

Analysis of evolution process of large rockburst—Numerical Simulation

应力波致灾过程数值模拟方法验证

Verification of numerical simulation method for stress wave disaster process



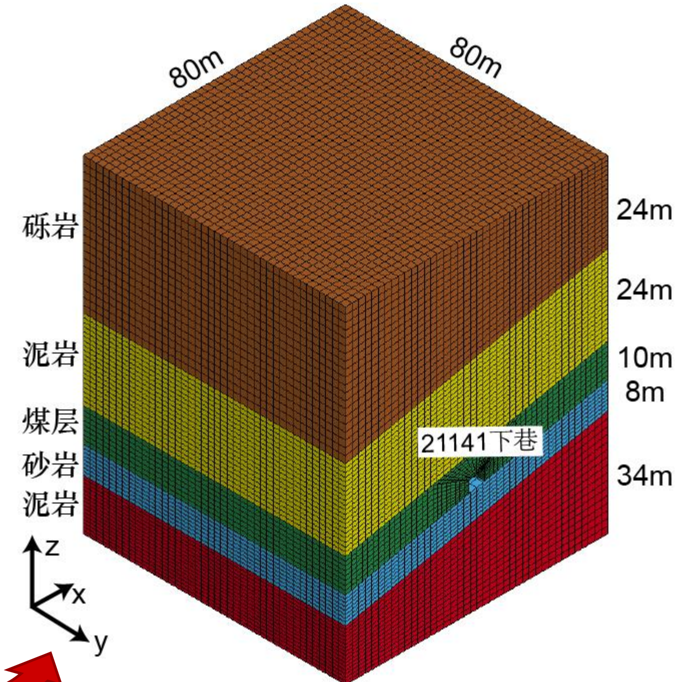
岩性	厚度(m)
砾岩	>400
泥岩	24
煤层	10
砂岩	8
泥岩	>180

采场空间剖面图

Stope space section

顶板断裂震源

Roof fracture source



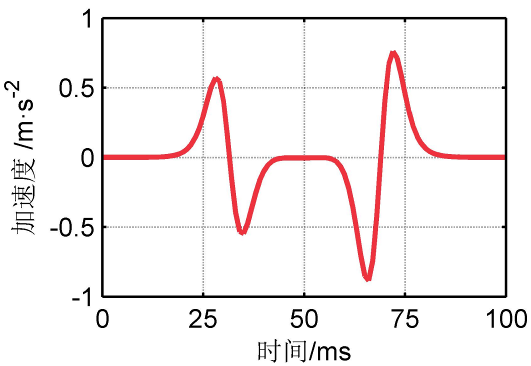
应力波致灾数值模型

Stress wave disaster numerical model

4. 大型冲击地压演化过程分析—数值模拟

Analysis of evolution process of large rockburst—Numerical Simulation

产生
produce

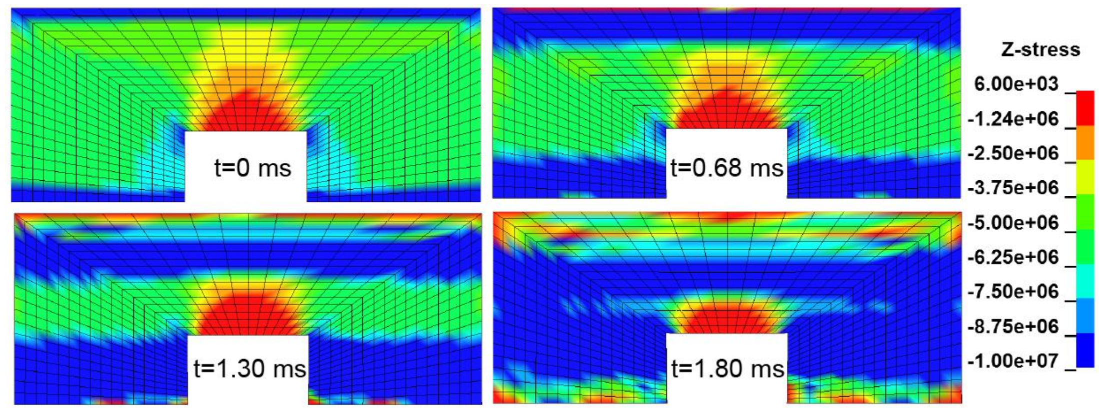


应力波动态加速度

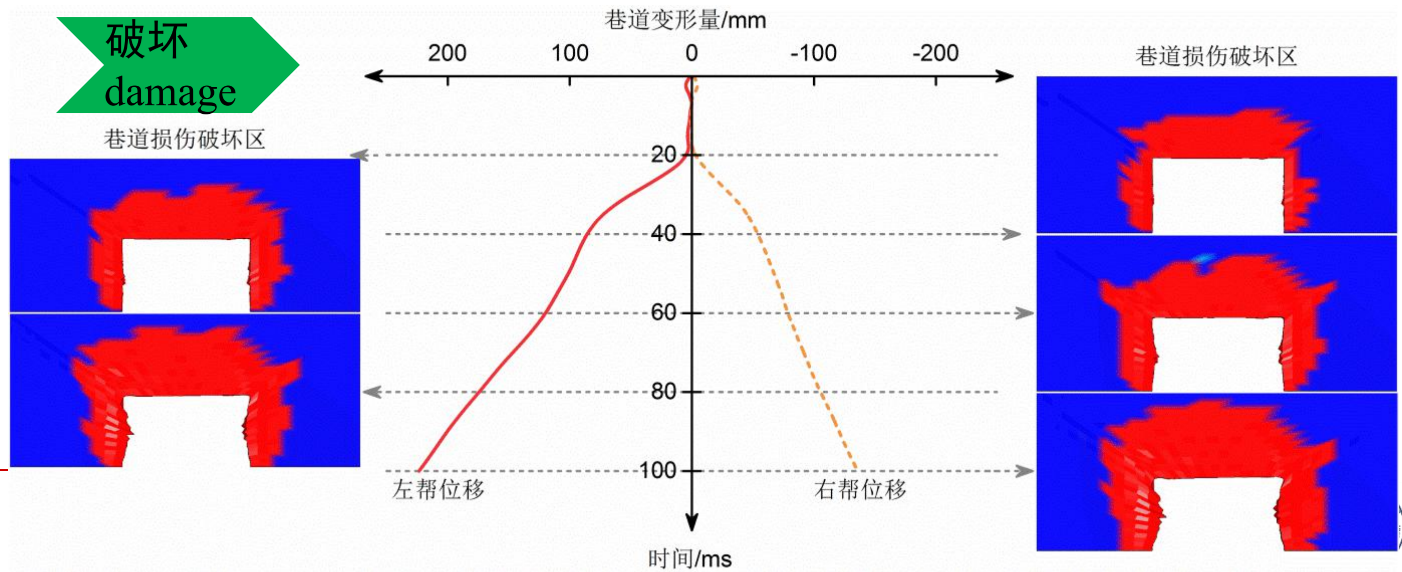
Stress wave dynamic acceleration

传播
spread

顶板断裂震源/Roof fracture source

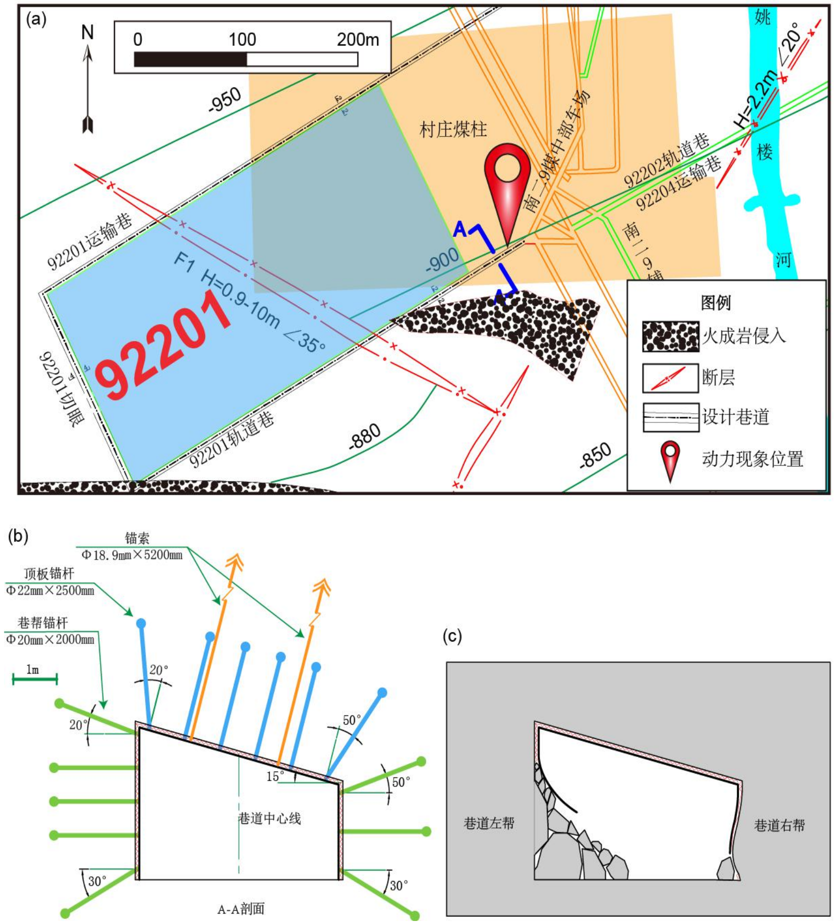


破坏
damage



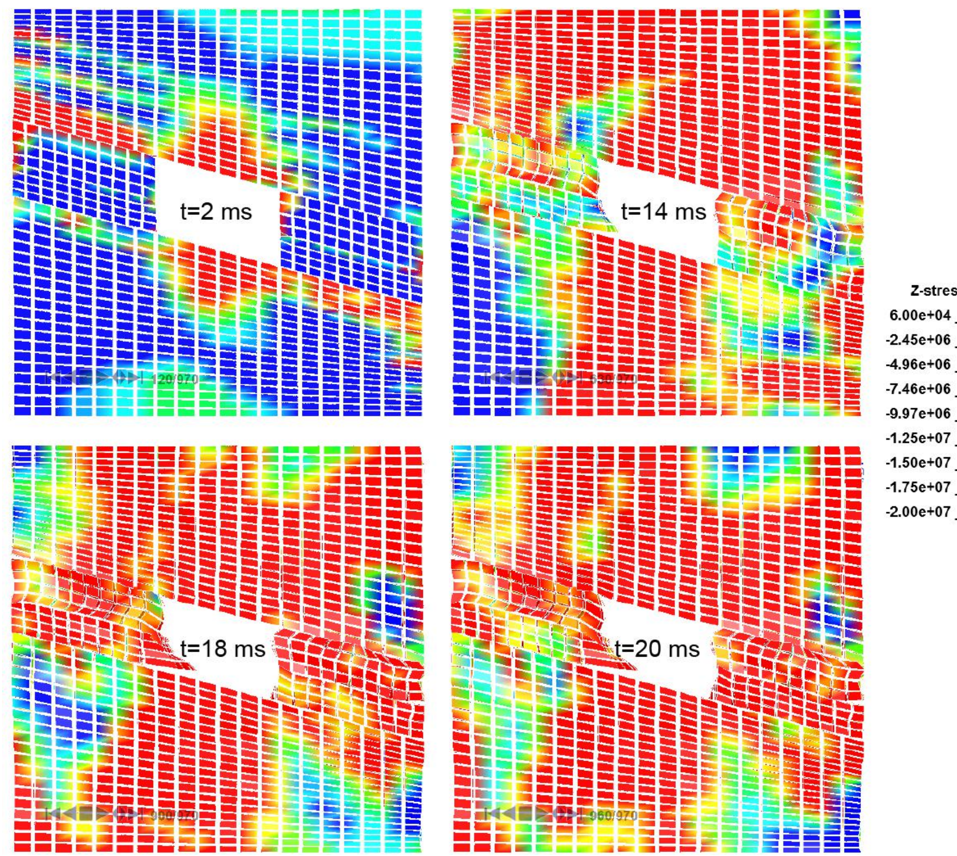
4. 大型冲击地压演化过程分析—数值模拟

Analysis of evolution process of large rockburst—Numerical Simulation



现场冲击地压分析

On-site rockburst ground pressure analysis



4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

- 冲击地压发生前，监测区域的电磁辐射值在时间上（连续几个班次或者几天）呈现一定的变化趋势，具有一定的前兆趋势。

  If EMR value appears as a special time trend over several shifts or days(also called precursor), then a rockburst will occur in this monitoring area.

- 冲击电磁前兆一般有三种形式（**EMR have three types**）

  1) 增长型/Growth type

  2) 增长后下降型/Decline after growth

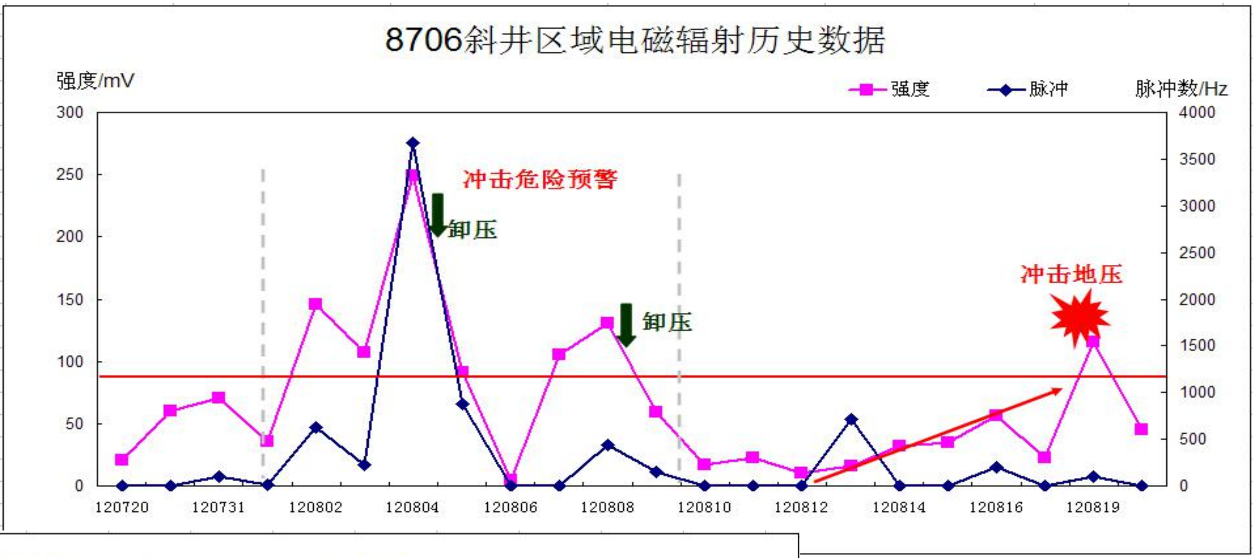
  3) *N* 型/*N* type

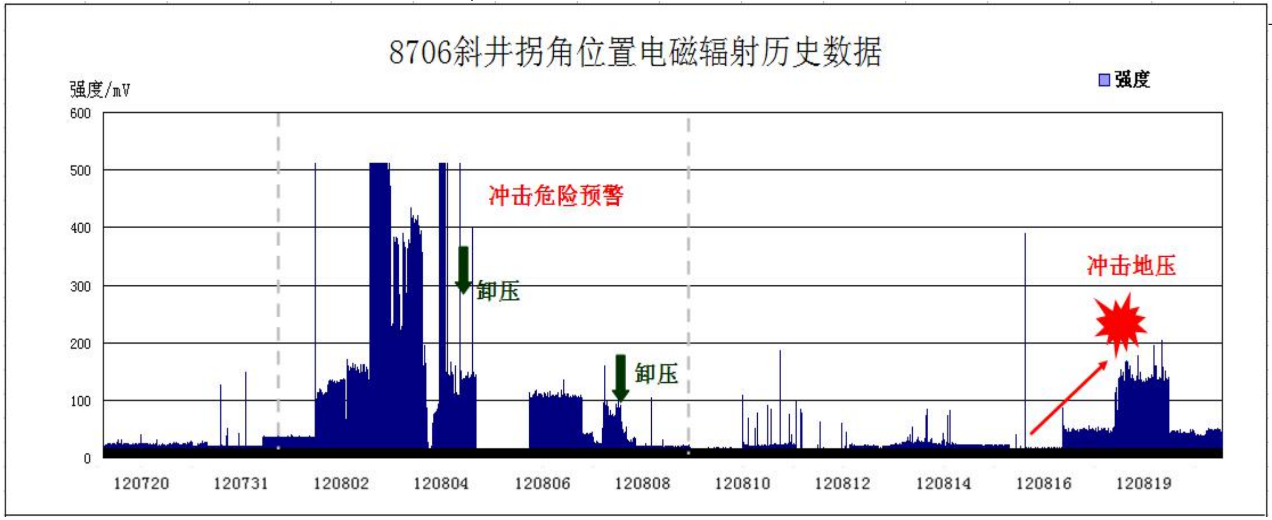
4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

1）增长型

Growth type





某矿盘区车场发生冲击前邻近区域电磁辐射监测结果

EMR Monitoring results in the vicinity of the rockburst occurred in a mining area

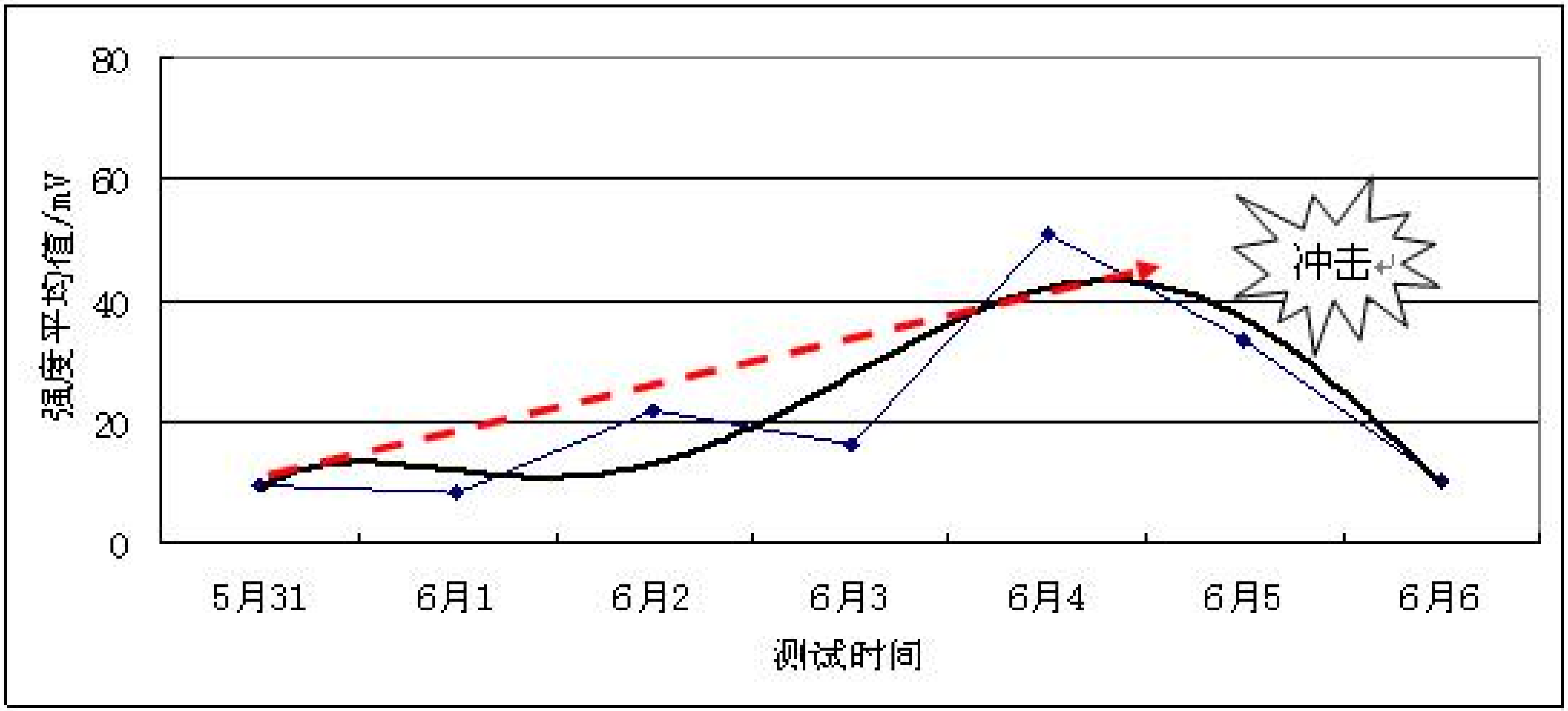
4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

1）增长型/Growth type

桃山矿薄煤层发生冲击前电磁辐射监测结果

EMR monitoring results before rockburst in a thin coal seam of Taoshan mine



79层左四片平巷5月31—6月6日数据变化趋势图

Data change trend chart of the left and fourth flats on the 79th floor from May 31 to June 6

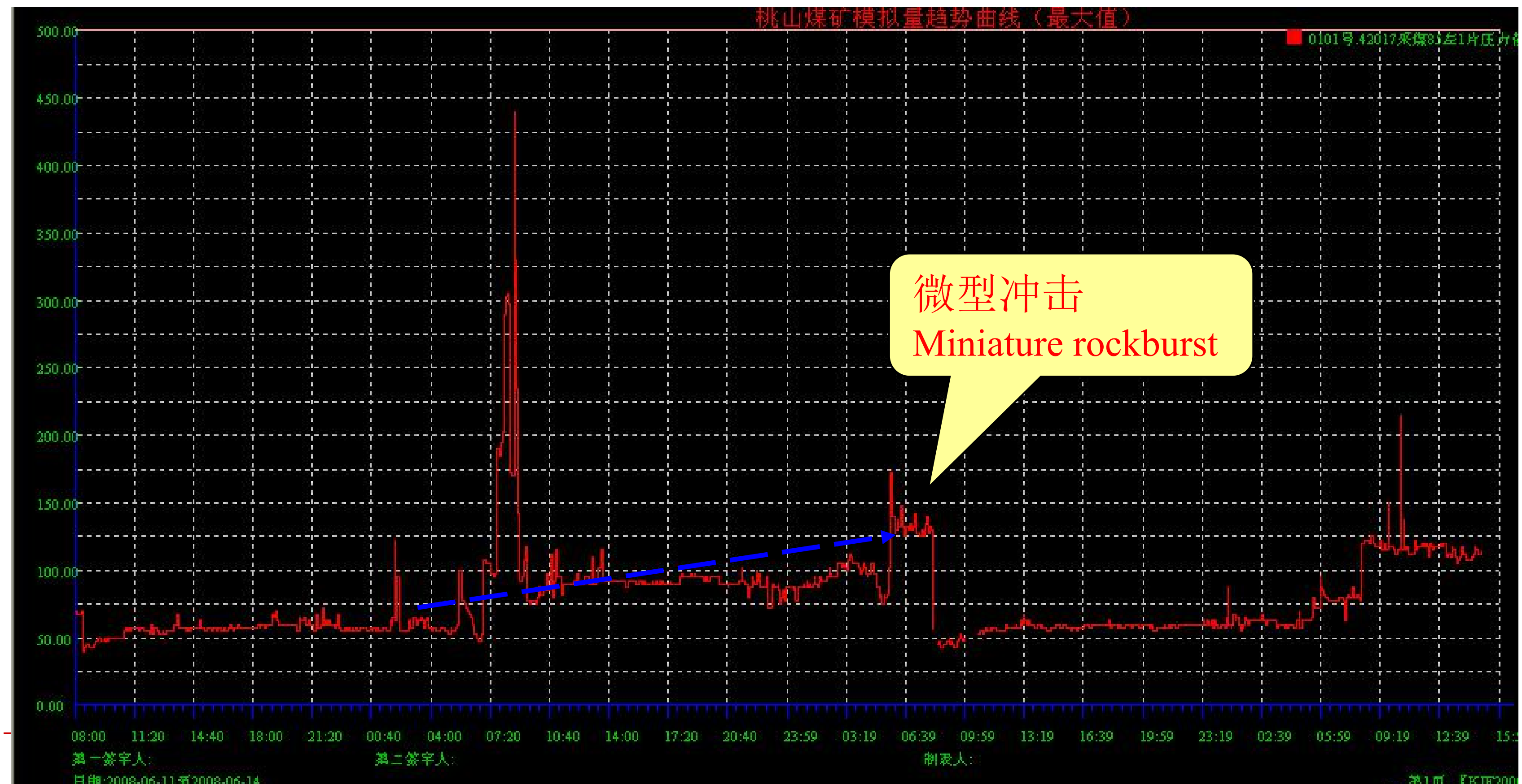
4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

1）增长型/Growth type

某矿在线式电磁辐射 6月11日—6月14日电磁数据

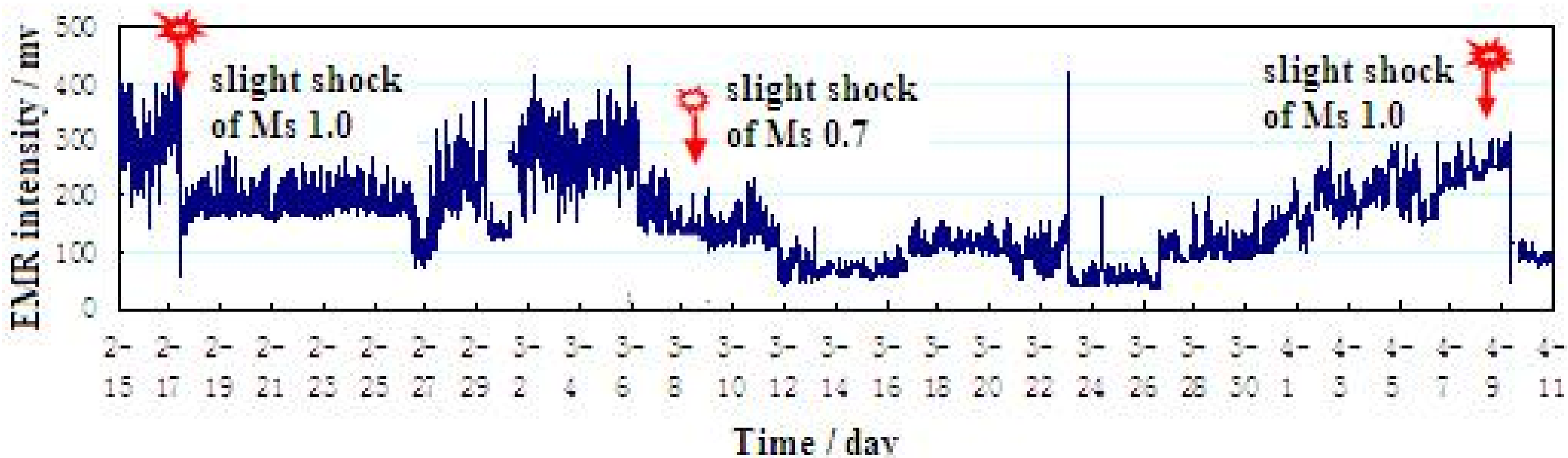
Online electromagnetic radiation of a mine from June 11 to June 14 electromagnetic data



4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

1）增长型/Growth type

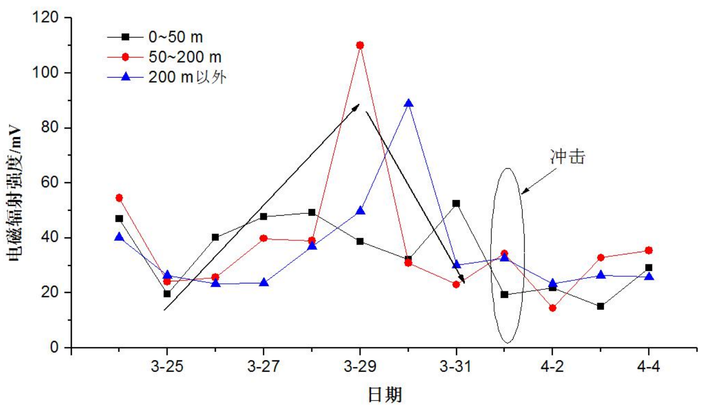


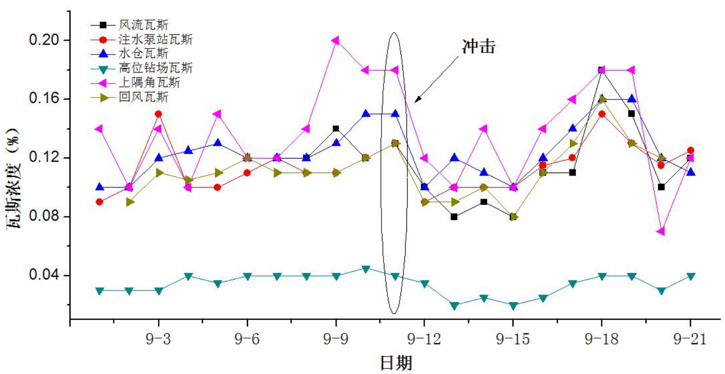
- **EMR forecasting results are consistent with the happened rock burst and the records of slight shock on March 6th to 12th in 1409 laneway in Huafeng coalmine.**
- **When EMR signals is stronger and EMR signals intensity has an largely intensifying trend and changes acutely.**

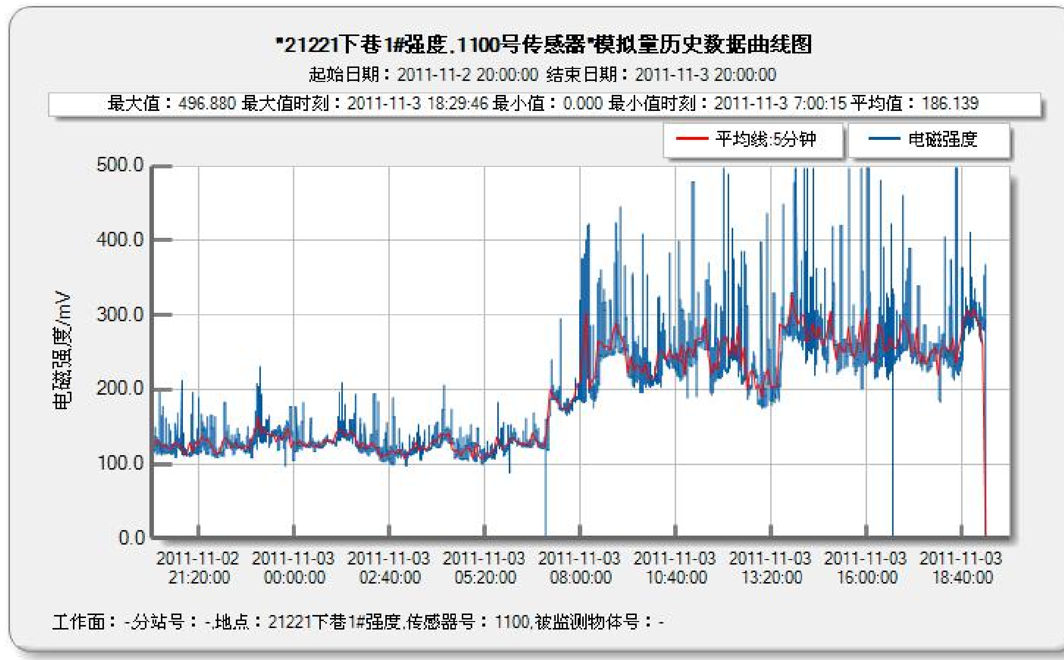
4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

2) 增长后下降型/Decline after growth







千秋矿特大型冲击地压发生前电磁辐射变化

EMR change before the occurrence of extra large rockburst in Qianqiu mine

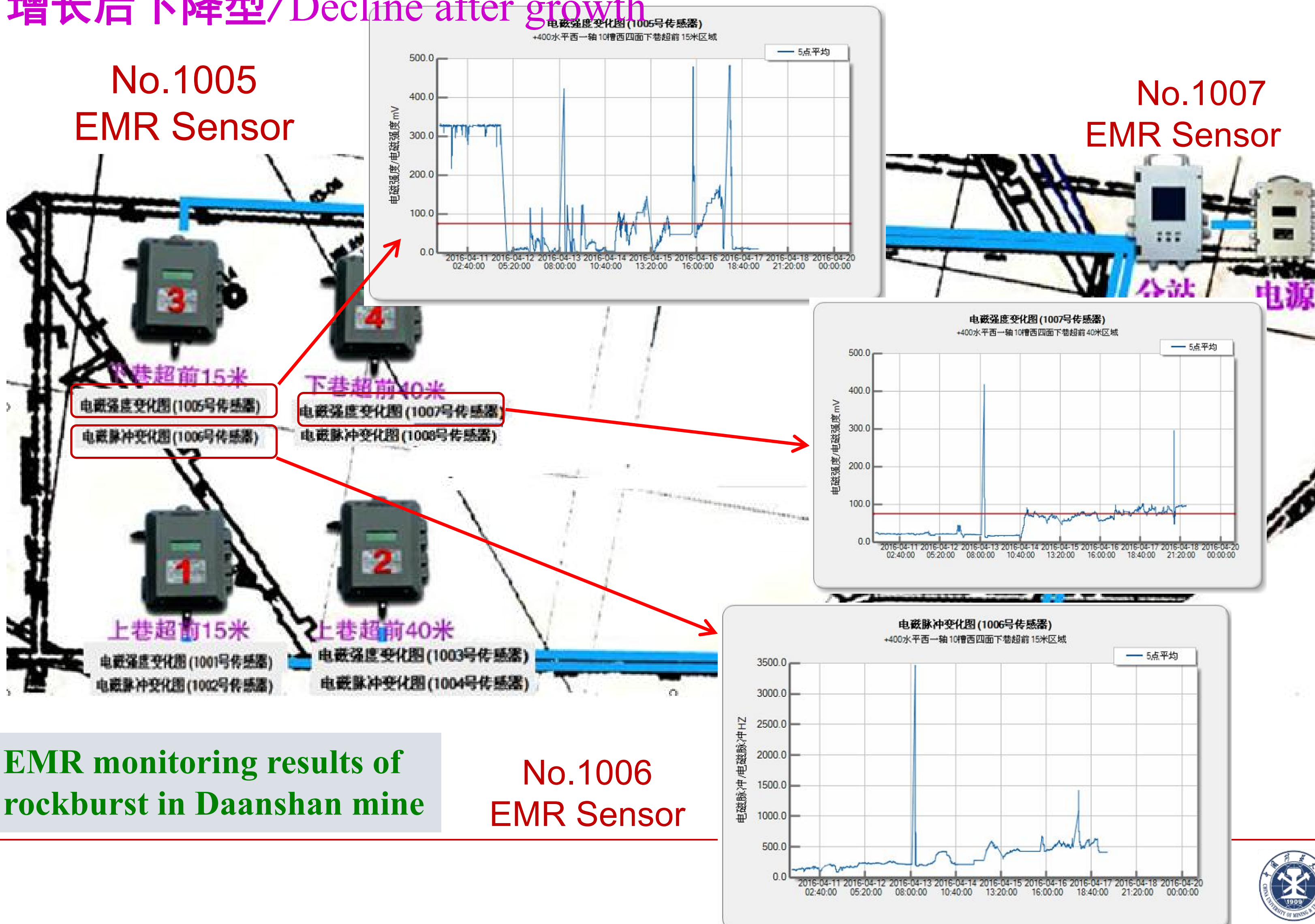
4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

2) 增长后下降型/Decline after growth

No.1005
EMR Sensor

No.1007
EMR Sensor



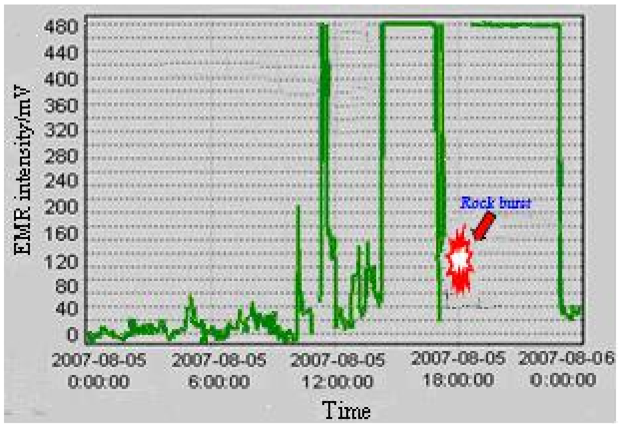
EMR monitoring results of rockburst in Daanshan mine

No.1006
EMR Sensor

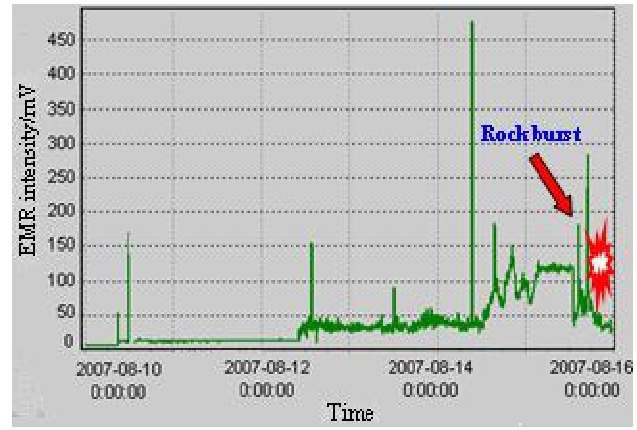
4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

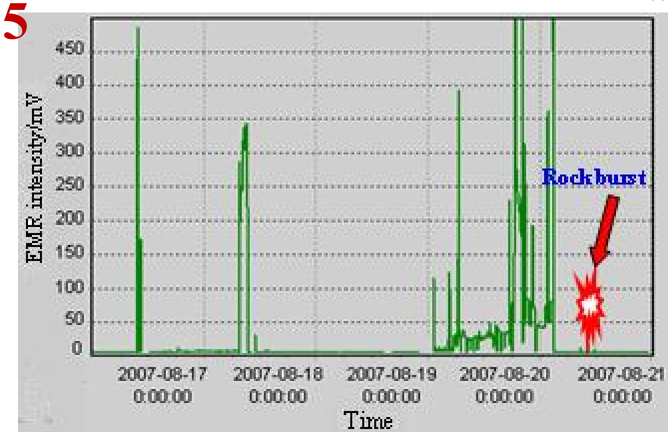
2) 增长后下降型/Decline after growth



magnitude =2.6 on Aug.5



magnitude =2.7 on Aug.15



magnitude =2.2 on Aug.20

五龙煤矿

Wulong coalmine

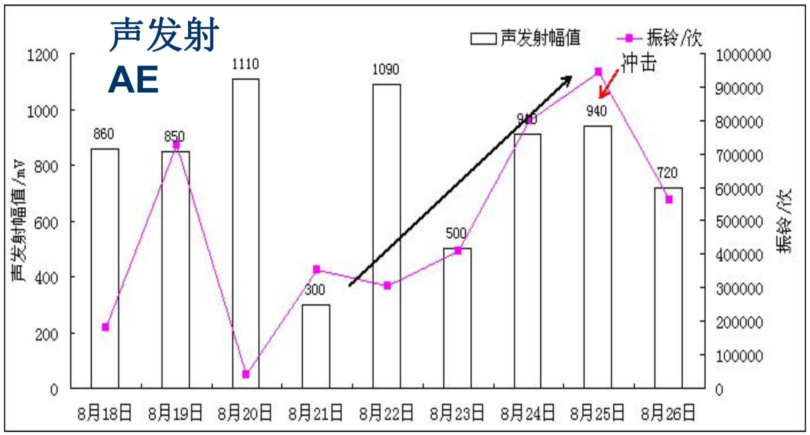
4. 大型冲击地压演化过程分析—现场响应

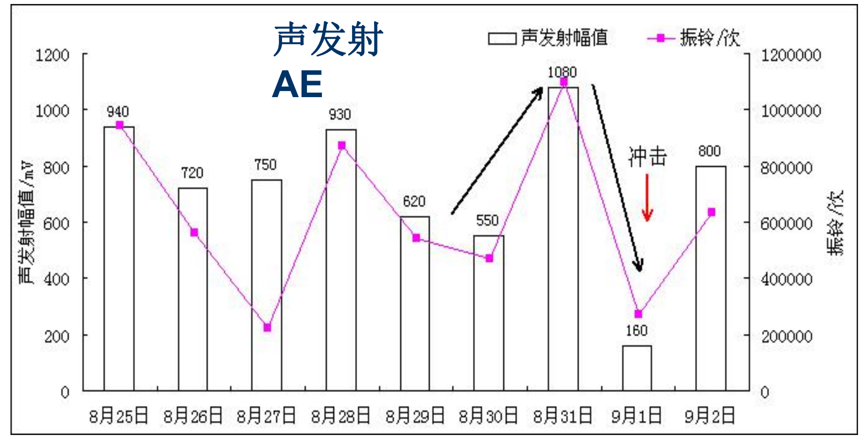
Analysis of evolution process of large rockburst—On-site monitoring response

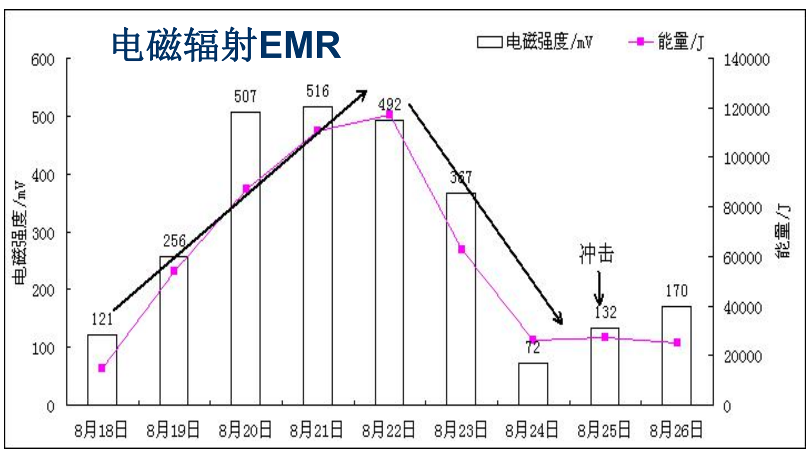
2) 增长后下降型/Decline after growth

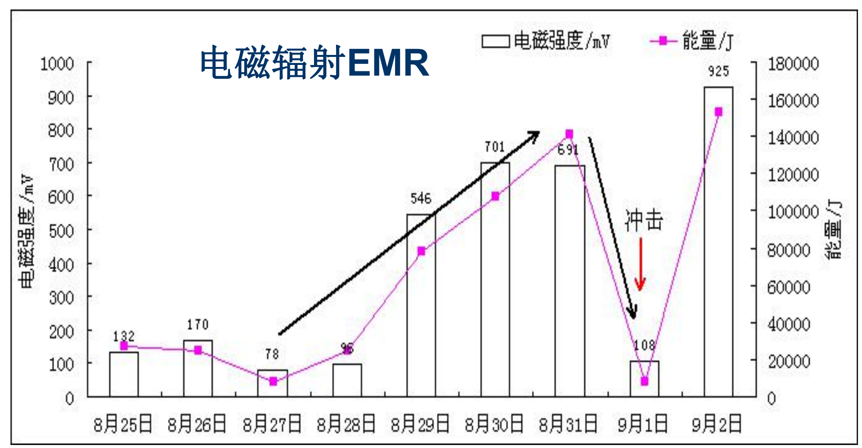
抚顺老虎台矿

Laohutai coalmine in Fushun city





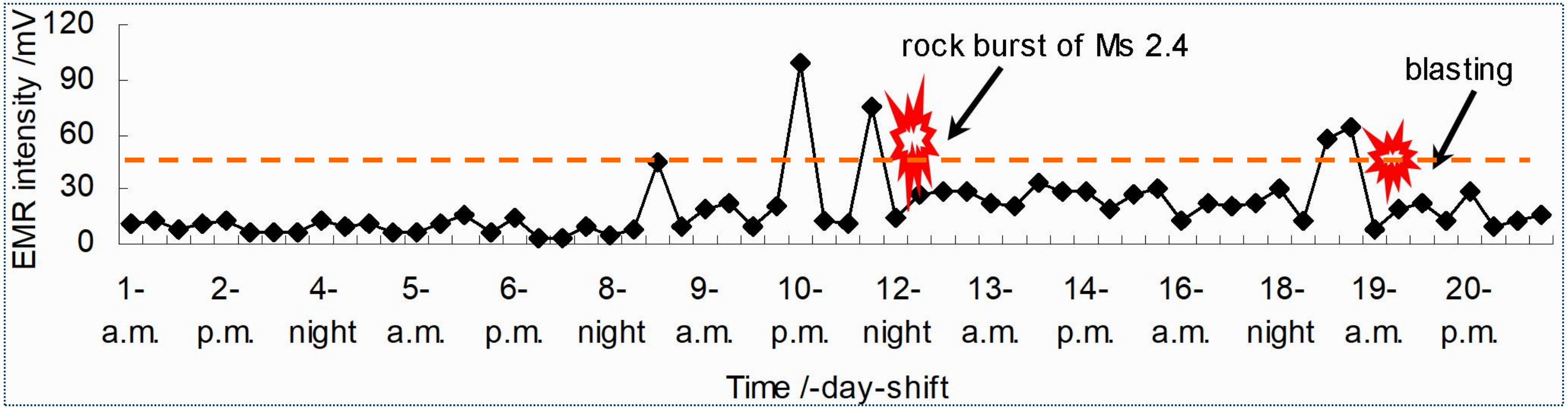




4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

2) 增长后下降型/Decline after growth



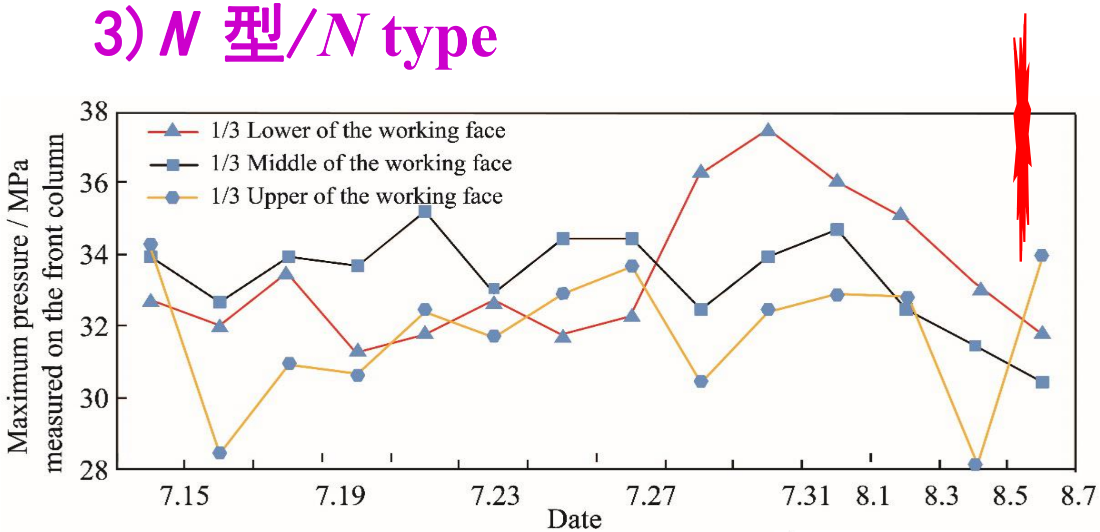
- 南山矿237回采工作面1月12日发生了2.4级的冲击地压，冲击前整体电磁辐射逐渐增强，并伴随有两个周期的电磁辐射波动，且峰值在临界值(30mV)之上。

On Jan.12, there was a rockburst with Magnitude=2.4 on the No.237 gob-surrounded coal face in Nanshan coalmine. The EMR precursor was that there were two rapid EMR fluctuations, EMR value increased, and is larger than the critical value (30 mV).

4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

3) *N* 型/*N* type



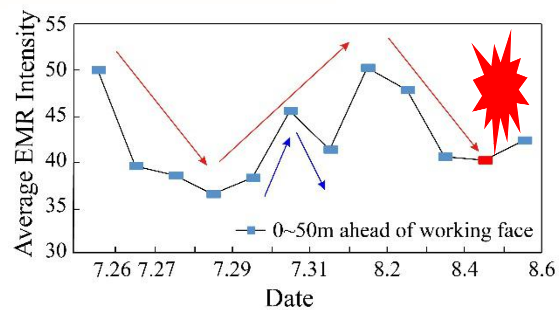
某矿复杂冲击

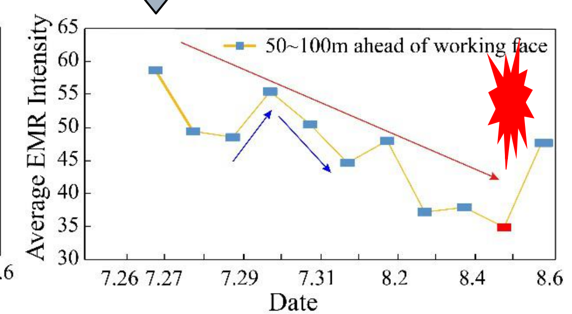
Complex rockburst of a mine

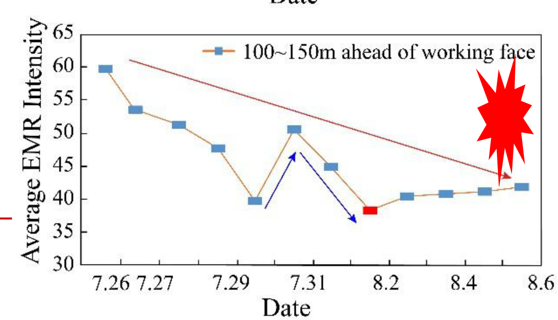
矿压变化

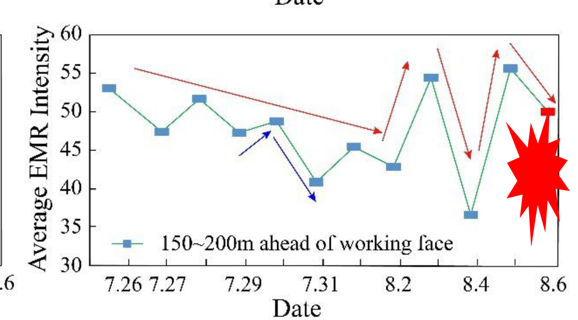
Mine pressure change

电磁辐射变化 EMR change





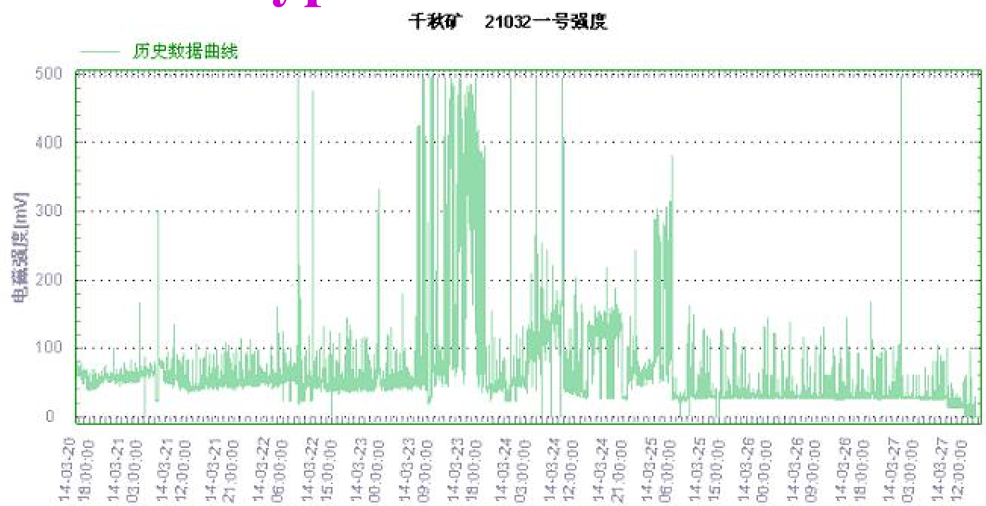




4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

3) *N* 型/*N* type



某矿掘进大型冲击

a large rockburst in a mine

时间：3.27 11时18分

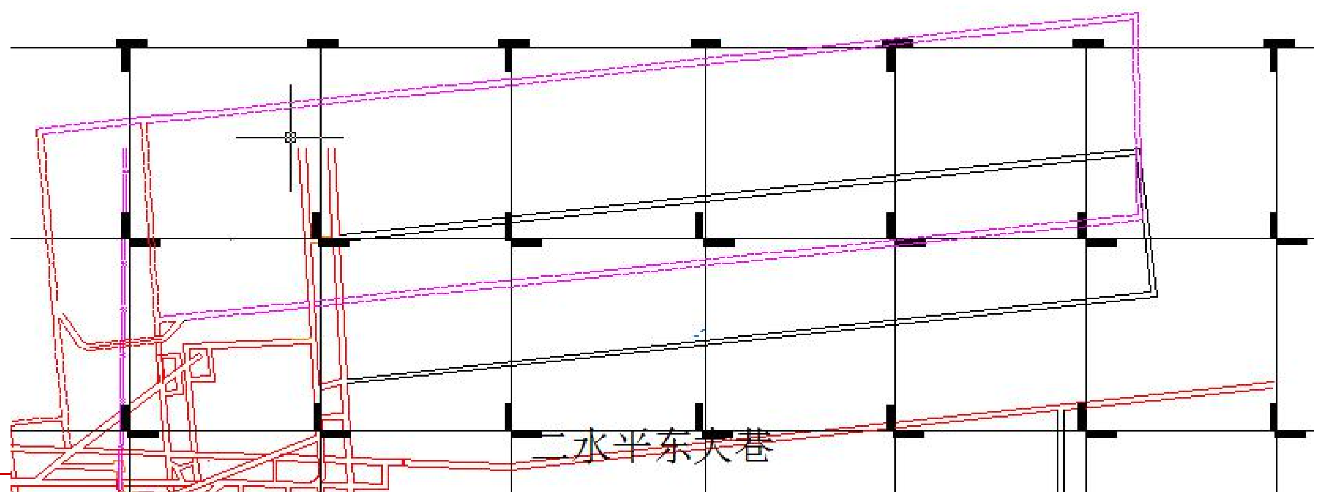
地点：21032掘进面回风上山处

微震(Microseism)：1.1x10^7 J，1.9级(level)

瓦斯(gas)：冲击后9%

24~25日电磁辐射自动预警冲击危险，发生前监测值异常低

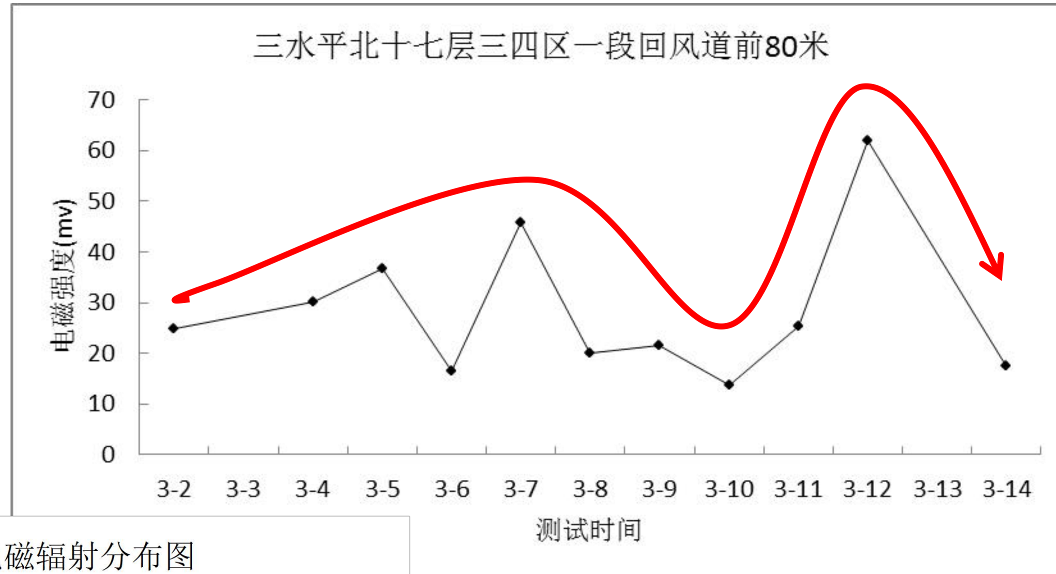
There was abnormal lower EMR value before occurrence, and March 24th to 25th EMR automatic warning of rockburst hazard was represented.

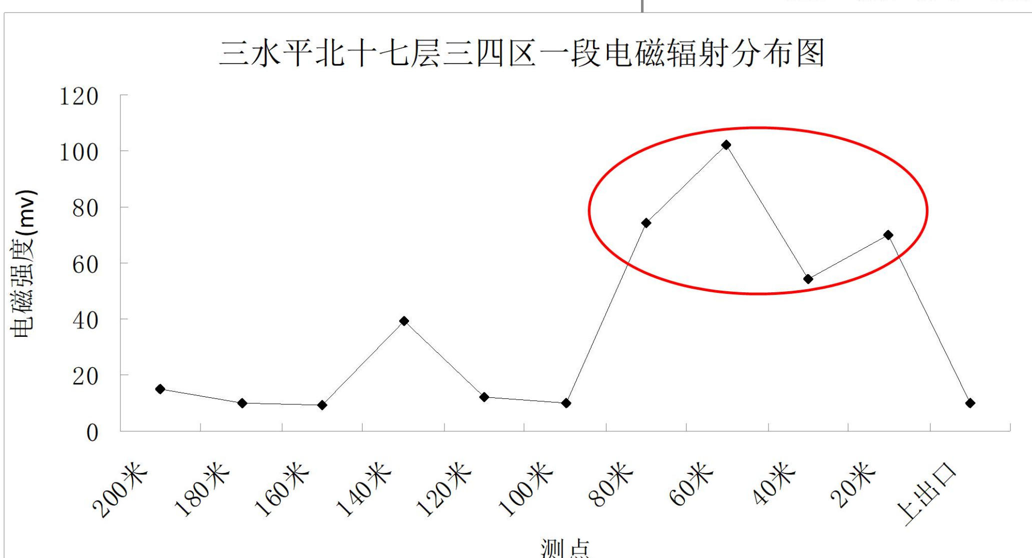


4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

3) *N* 型/*N* type





峻德矿大型冲击前电磁辐射监测3个预警点

Three early warning points for monitoring electromagnetic radiation before a large rockburst in Junde mine

4. 大型冲击地压演化过程分析—现场响应

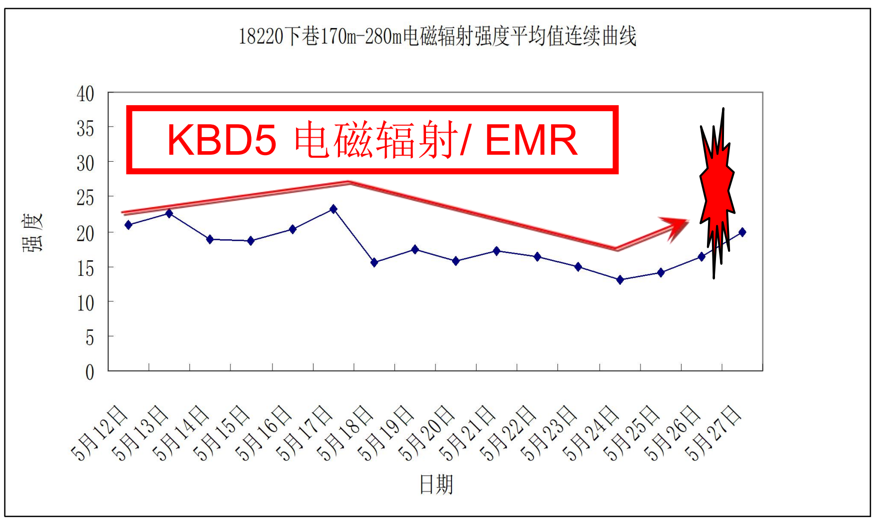
Analysis of evolution process of large rockburst—On-site monitoring response

3) *N* 型/*N* type

义马千秋矿/ **Qianqiu mine**

采动应力无响应

Stress mining induced had no response



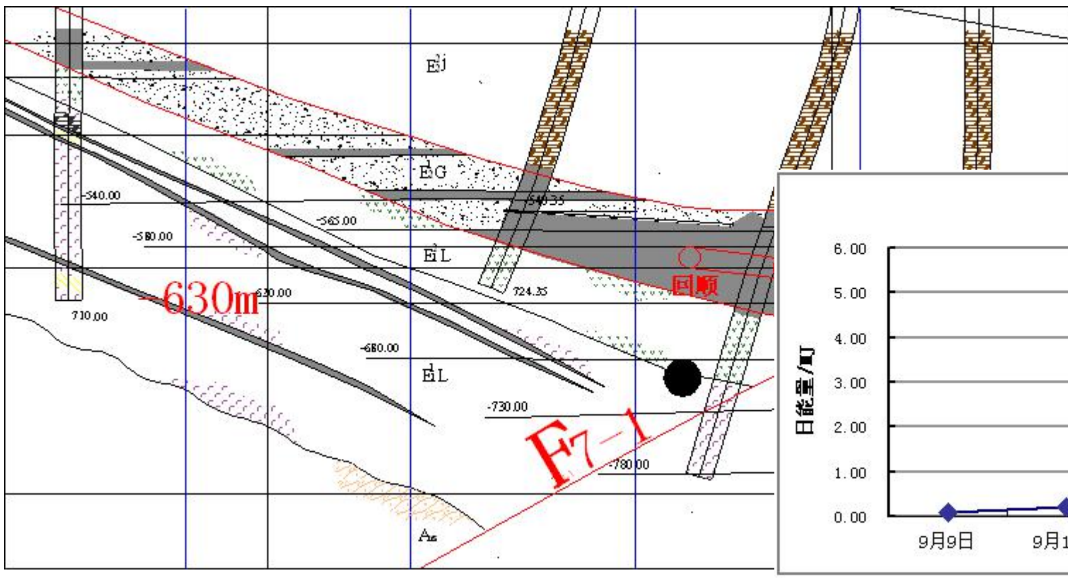
4. 大型冲击地压演化过程分析—现场响应

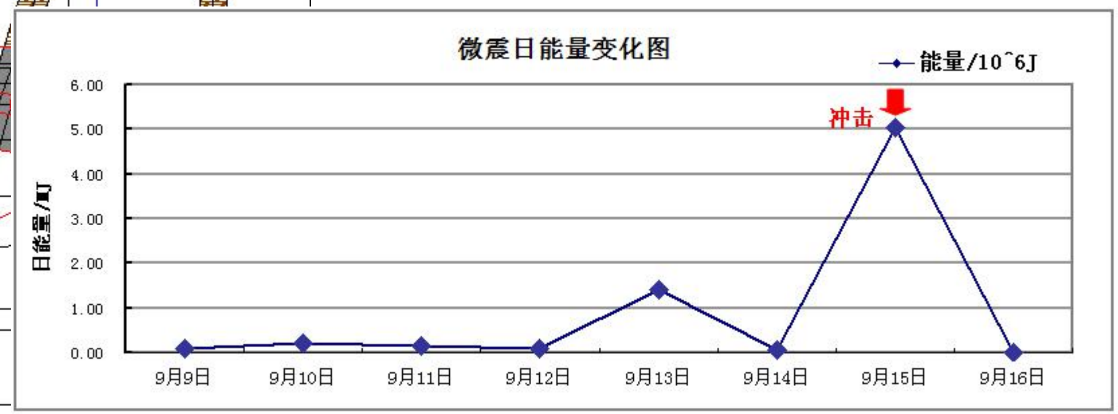
Analysis of evolution process of large rockburst—On-site monitoring response

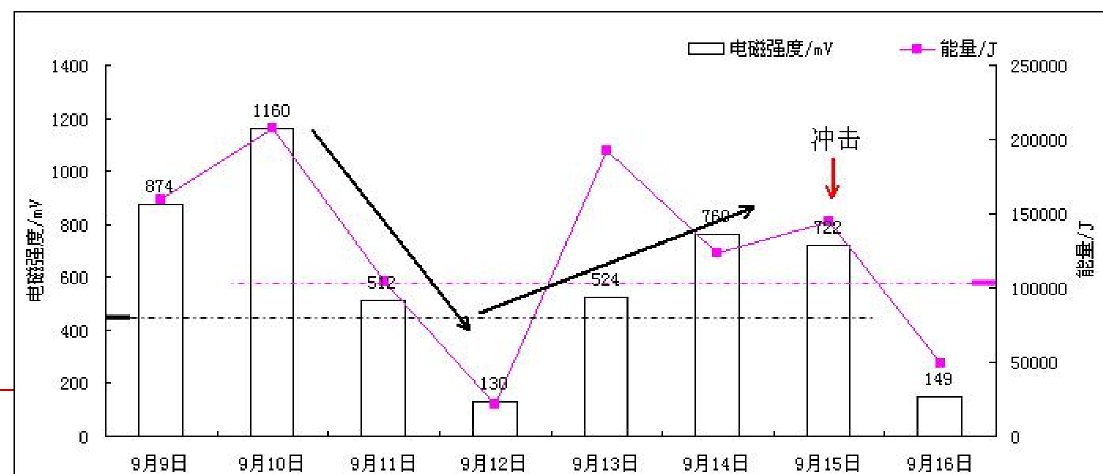
3) *N* 型/*N* type

抚顺老虎台矿发生冲击前YDD16声电监测仪测试结果

YDD16 acoustic and electrical monitor test results before the rockburst of Laohutai Mine in Fushun city







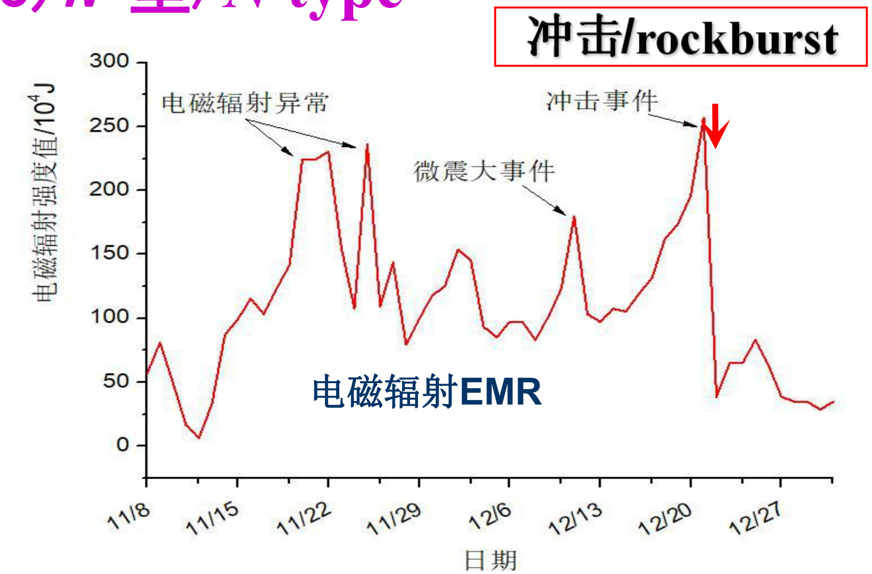
技术人员于14日和15日发出预警

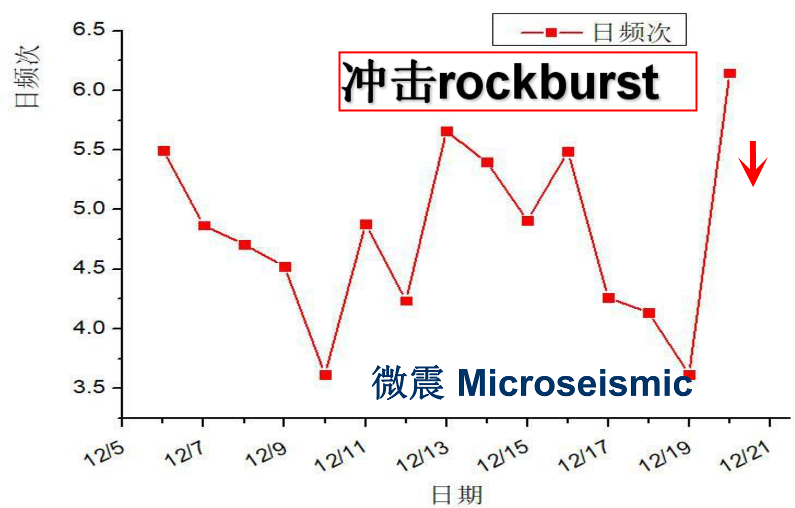
Technicians issued warnings on September 14th and 15th

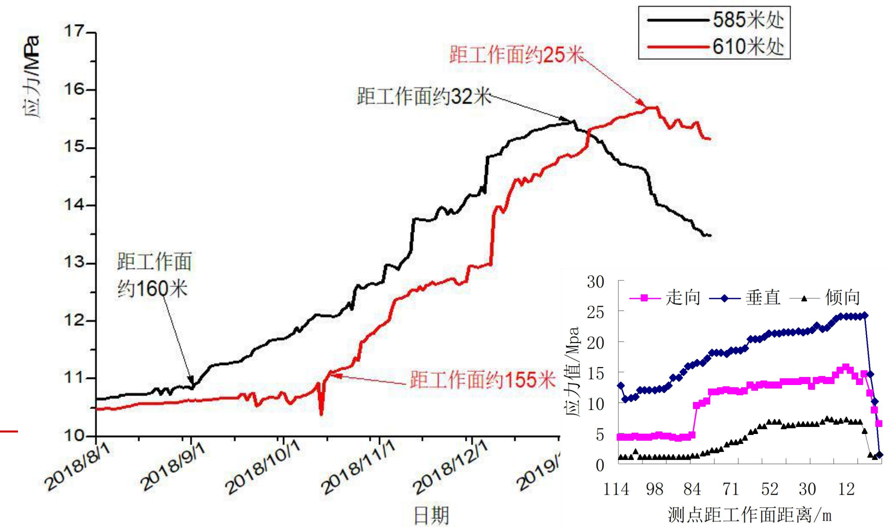
4. 大型冲击地压演化过程分析—现场响应

Analysis of evolution process of large rockburst—On-site monitoring response

3) *N* 型/*N* type







5. 关于大型冲击地压预防的思考

Thoughts on prevention of large rockburst

（1）大型冲击地压是一种非常复杂的时空演化动力现象，但也有很强的规律性、大空间区域性、空间轮换性、时间过程性等特点。

Large rockburst is a very complex phenomenon of time and space evolution, but it also has strong regularity, large spatial regionality, spatial rotation, and time process.

（2）掘时巷道冲击与回采面冲击的信号响应及前兆特征有较大的差异。

There is a big difference between the signal response and the precursor characteristics of the excavation roadway rockburst and the mining face rockburst.

（3）监测手段需要有一定的监测响应范围及动静、载敏感性。

Monitoring means need to have a certain range of monitoring response and dynamic and static sensitivity.

5. 关于大型冲击地压预防的思考

Thoughts on prevention of large rockburst

（4）不同手段的监测响应尺度和敏感性、受干扰因素不同，从监测及响应尺度来说，应力<钻屑<地音<局部微震<电磁辐射<微震，各手段对动静载响应也不同。

The monitoring response scales and sensitivity and interference factors of different means are different. From the monitoring and response scales, the stress < drill cuttings < geophone <local microseismic <electromagnetic radiation < microseismic, the response of each means to dynamic and static loads is also different.

5. 关于大型冲击地压预防的思考

Thoughts on prevention of large rockburst

（5）应该重视中小尺度的监测和分析。电磁辐射和声发射/地音对矿压和冲击地压具有良好的响应，监测反映了中小尺度和小区域性；多点监测能够反映大区域性；前兆信息比较丰富，特征明确，区别于干扰信号，多数能有效识别。

Attention should be paid to the monitoring and analysis of small and medium scales. EMR and AE signals have a good response to mine pressure and rockburst, and their monitoring results can reflect small and medium scale and small regionality. Multi-point monitoring can reflect large regionality, with rich precursor information and clear characteristics. Most of the interference signals can be effectively identified.

5. 关于大型冲击地压预防的思考

Thoughts on prevention of large rockburst

（6）对于任何监测手段而言，都应该加强数据处理分析，进行有效信号和干扰信号的识别，结合现场地质、开采条件及其它显现，来提高冲击地压分析与预警的准确性和可靠性。

For any monitoring means, data processing analysis should be strengthened, identification of effective signals and interference signals should be carried out, and on-site geology, mining conditions and other manifestations should be used to improve the accuracy and reliability of rockburst ground pressure analysis and early warning.

（7）预防大型冲击地压要考虑大范围采场结构的时空演化。

In order to prevent and control large-scale rockburst, it is necessary to consider the space-time evolution of large-scale stope structures.

谢　谢！

Thanks!