

採掘地域における活性断層

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Reactivated Faults in Mining Area

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Taking some related cases as examples, the paper outlines that human mining activities have made some faults reactivated in mining area. Reactivated faults could result in surface fissure, crown hole, gas emission, coal and gas outburst etc. Some of these geological hazards could persistently occur during tens of years even after coal mines have been abandoned. The direct causative factor of fault reactivation should be surface movement in mining area. Coal extracting, ground water draining or recharging could respectively play key roles in promoting surface movement at different developing stages in mining area. A few research methods of reactivated faults have been introduced, and it is emphasized that necessary forecast and prevention of reactivated faults should be taken account into the rebuilding plans in current and abandoned coal mining areas.

Key words: Coal mining, Geological hazard, Reactivated fault, Mining area

1 WHAT IS REACTIVATED FAULT

Under the influence of human mining action, some faults developed in geological history in mining area could have changed their stress and strain states and be reactivated or have reactivation tendency. The faults with reactivated features or tendency in mining area have been known as reactivated faults in the paper. Even though more and more geological hazards accompanied with reactivated faults have been found all over the world, it has not yet been paid enough attention on the fact that reactivated faults could result in some geological hazards and could take place again and again in a quite long period, even so long after end of mining action in the area.

2 GEOLOGICAL HAZARDS RELATED WITH REACTIVATED FAULTS

According to researches on some mining areas in Ukraine⁽¹⁾, Great Britain⁽²⁾⁽³⁾ and China⁽⁴⁾⁽⁵⁾, fault

reactivation has been a common feature. The reactivated faults could not only result in damage of road and construction (Fig. 1, 2, 3), but also seismic events (Fig. 4). The fault in Fig. 1 had been activating even though the last coal mine in the area was closed forty years ago. During coal mining, some accidents, such as coal-gas outburst, roof falling and water



Fig.1 Fault step in Donetsk coal mining area, in Ukraine (After L. J. Donnelly, 1994)

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breakout, could be related with reactivated faults as well. Besides, some linear damages on surface in mining area, such as surface steps, crown holes and fissures, could be induced by reactivated faults directly or indirectly (Fig. 5, 6, 7).

Furthermore, the reactivated faults with tensional mechanical nature usually provide channels, through which the underground hazardous gases, such as carbon monoxide and methane, could move up to the surface and result in environmental pollution and tree death (Fig. 8), even inflammation and blast.



Fig. 2 Fissure on high way at Houghton, UK (After B Young, 2001)



Fig. 3 Structural damage in Staffordshire, UK (After L. J. Donnelly, 2006)



Fig. 4 The effect of pre-existing faults on seismicity in the North Staffordshire Coalfield, UK (After N. H. Al-saigh and N. J. Kusznir, 1986)



Fig. 5 Fault scarps in South Wales, UK (After L.J. Donnelly, 2006)



Fig. 6 Aligned crown holes in Fuxin coal mining area, Liaoning, China

3 ORIGINS – HUMAN MINING ACTIVITIES

The human mining activities should be the direct causing factor of reactivated faults because most of them take place in mining area. According to Alejanoa et al.⁽⁶⁾, two types of ground movement and fractures could be developed due to the extraction of a very inclined coal seam (Fig. 9); otherwise, during extracting

slowly inclined or flat coal seam, surface subsidence varies with the distance to a basin's center and the thickness of extraction (Fig.10). That means that there is a subsidence difference in mining area. The subsidence difference results in local tensional or trantensional stress fields and deformed zones in mining area. It is explicable that mining-induced redistribution of stresses causes significant deformation within and around preexisted faults ⁽⁷⁾, and promotes them reactivation.



Fissure in Jinchuan No. 2 nickel mine, Ganshu, China (After X Lia *et al*, 2004) Fig.7 Fissure in Jinchuan No. 2 nickel mine, Ganshu, China (After X. Lia *et al*, 2004)



Fig.8 Dying trees induced by emission of gases through a reactivated fault in Fuxin mining area, Liaoning, China

Except of normal mining-induced subsidence, there are other factors as well which result in subsidence difference in mining area. Following are some examples.

Volumetric shrinkage with degas and pillar failure would develop renew subsidence and result in subsidence difference in mining area; Evolution of mining workings (Continuing or renewed subsidence of underlying mine workings, such as collapses due to roof fall and pillar failure) could affect on surface subsidence; Mine water pumping or recharging makes mine water levels variation, which could change the underground effective stress and result in different grades of subsidence at different developing stages in mining area.

Figure 11 and 12 show the rebound underground water levels at coal mines in Pittsburgh, USA. The underground water levels rose up 75 m in 12 years and 60 m in 10 years at two different coal mines in the examples⁽⁸⁾.



Fig. 9 Imaginative illustration of the two types of ground movement, parallel and perpendicular to the strata due to the extraction of a very inclined seam



- S: maximum subsidence within a subsidence trough
- M: extraction height or thickness
- W: extraction width of longwall panel
- h: average depth of coal seam
- Fig. 10 Subsidence difference with the distance to a basin's center and the thickness of extraction



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Fig. 11 Rebound underground water level at Gateway coal mine, USA (After J. J. Donovan, 2004)
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Fig. 12 Rebound underground water level at Shannopin coal mine, USA (After J. J. Donovan, 2004)

The subsidence difference could cause the reactivation of preexisted faults and other weak surfaces. Because there could be different main influencing factors inducing subsidence difference at different developing stages in mining area, fault reactivation could take place periodically in a long time even after mining activities have cleared away in the area.

4 APPROACHES TO STUDY ON ACTIVE FAULTING

The geological research methods of active faults and faulting have been applied to reactivated fault study in mining area. The common methods include geological mapping based on GIS and GPS, modeling and forecast, geophysical and geochemical exploration.

(1) Geological mapping based on GIS and GPS

Based on geological and mining maps, such as topographic geological map, mining engineering map and geological structural map etc, active geological features are surveyed and mapped by use of GIS and GPS. The active geological features include fissure, fault step or scarp, crown hole and structural damage on the surface in mining area. The distribution of reactivated faults could be forecast through general analysis in the mining area by tracking the active geological features.

(2) Modeling and forecast

Numerical analysis theories and computer modeling techniques, such as finite element, boundary element and discrete element simulation, have been applied to study on active faulting in mining area. By use of these methods, the influence of faults on environment or safe operation could be simulated in order to take necessary measures in advance against possible hazards based on some engineering designs. For example, Islam applied finite element to model stress distributions around a large-scale fault affected by multi-slice longwall mining in Bangladesh, and gave a scientific forecast of possible water hazard.⁽⁹⁾

(3) Geophysical exploration

Geophysical exploration approaches of reactivated faults mainly include seismic, electrical. electromagnetic methods. When reactivated faults have cut through Quaternary deposits, shallow seismic exploration could provide valuable information about reactivated faults, such as their location, shape and other natures. Ground penetrating radar (GPR) could be applied to explore reactivated faults less than 30 m deep. High-density resistivity method could be used to investigate reactivated faults up to hundreds meters in depth. The Fig. 13 is a real case of reactivated fault exploration by use of high-density resistivity, showing an obvious low abnormal zone of apparent resistivity along a reactivated fault plane on the inversed image of high-density resistivity exploration.



Fig. 13 The profile of high-density apparent resistivity showing a reactivated fault under a falling hole

(4) Geochemical approach

Geochemical approach is to detect the abnormal distribution of some elements and gases in soil and find active faults. Some markers, including Rn, Hg, He, CO_2 , SO_2 , O_2 , CH_4 and other hydrocarbon, could be helpful for exploring active faults ⁽¹⁰⁾. Some gas isotopes, such as ¹³C and ³He / ⁴He, have been detected as well for active fault exploration. CO_2 and CH_4 could be more obvious for exploring insidious active faults in coal mining area.

In addition to the above approaches, surface survey

and seismic inspection could be used as well to explore active faults in mining area.

5 PREVENTION OF REACTIVATED FAULTS IN COAL MINING AREA

Because main origin of reactivated faults is human mining activities, suitable prevention techniques during coal mining should be applied in order to mitigate geological hazards resulted from reactivated faults. The following approaches have been proved impactful:

(1) Leaving coal column to separate fault

Coal column with suitable size could availably prevent roof falling, coal-gas outburst and water breakout in the faulting zone; therefore, it is helpful to alleviate fault reactivation.

(2) Striding over fault with larger cross angle

When the coal excavating faces have to stride over a fault, the cross angle between excavating face and the fault surface should be as large as possible to reduce uncovering area of fault at a single mining cycle.

(3) Injecting slurries

There are two important purposes injecting slurries in faulting zone: the first one is to prevent surface subsidence, and the other to keep the scale of fault reactivation under control in order to avoid possible destructive seismic events around the reactivated fault.

6 CONCLUSION

Under affection of human mining activities, some faults have been reactivated owe to some causes, such as difference of subsidence and change of underground water level existed in mining area. The fault reactivation has resulted in serious geological hazards, including not only damages of structure, road and cropland on surface, but also underground coal-gas outburst, roof falling and water breakout. The dangerous function of reactivated faults on safe environment should be paid more attention both in current and in abandoned mining area. While designing rebuilding plan in mining area, necessary exploration should be carried out and possible preventing measures should be taken aiming at reactivated faults in order to reduce geological hazards.

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概要

本論文では、関連するいくつかの事例を紹介することにより、人間による採掘活動が採掘地 域において断層を再活性化させることを概説する.

最活性化断層は地面の亀裂,王冠陥没,石炭ガス爆発などに繋がりえる.いくつかの地質的 な災害は,炭坑の閉鎖後も何十年にわたって持続的に発生した.石炭の抽出,地下水の排水や 再注水はそれぞれ,採炭地域における各開発段階で,地表の動きを促進する重要な役割を果 たした.いくつかの再活性断層の研究手法を紹介し,再活性断層の予測と予防が,採炭中お よび閉鎖された採掘地域における再開発計画で考慮すべきであることを主張する.

Key words: Coal mining, Geological hazard, Reactivated fault, Mining area

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