

# Geophysical and geo-mechanical methods for estimating roof directional hydraulic fracturing works

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**Abstract.** Directional hydraulic fracturing method (DHF method) for controlling hard roof in coal mines and the means of its implementation is given in the paper. The method allows getting extended, set in a given direction cracks for stratification and cutting off the roof and for providing their controlled caving in different technological schemes. Geo-physical methods are introduced, the monitoring and the mine site experimental testing data on controlling the roofs applying the method of extraction pillar seismic testing on transmitted waves are studied. The experience of applying the method at Kuzbass mines are analyzed.

## 1 Introduction

Nowadays the coal has partially restored its position as a global energy source material which it nearly lost in the first half of the twentieth century. China, the USA, India, Australia and Indonesia take the global leading position on producing coal. China produced about 46.6 percent of the world coal production in 2013. Longwall mining system (long pile mining) dominates in Kuzbass underground mining. And the longwall stopes are equipped with high-productive mechanized complexes (about 84 percent of total coal production).

The increasing scope of powered support application within the past years goes to the development of the hard roof coal seams. Sudden uncontrolled dynamic rock massif failure is dangerous and harmful for people, it also destroys mechanisms and mine workings. Moreover, poor caving of roof brings about the ground pressure concentration on the coal massif in the stope and on its road-heads. It triggers sudden coal and gas outbursts that destroy mine workings and breaks normal operation mode of mining machinery and face ventilation.

While extracting coal out of the seams prone to rock bumps and sudden coal and gas outbursts, poor caving of hard roof increases the stress at the seam walls that causes dynamic and gas-dynamic phenomena. The latest large accidents in underground mines of Kuzbass took place in stopes that used sophisticated machinery for providing comfortable working conditions. One of the main reasons for methane burst was caused by roof caving over a significant area and its further failure. The current trend and the protective measures are not enough for changing negative indicators of labor capacity and underground mining safety, especially in Kuzbass [1...4].

The similar dynamic phenomenon took place at Barentsburg mine (Spitsbergen archipelago) where during hard roof failure the coal combined machine was thrown up with shifting towards the support [5]. It is known that China is the largest coal producing country

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though the share of dynamic phenomena with roof failure and coal outburst in it takes one third of the world total number [6...10]. Last decade saw dynamic hard roof failure in more than a hundred coal mines and it caused massive injuries and fatalities and brought about the destructions of the workings and the equipment.

In Australia “Narabri Coal Operations” company, situated in New South Wales, was extracting Hoskisson seam by the mechanized complex with the length of 300 meters. Directly above the coal seam there was a hard pudding rock with the power from 15 to 20 meters. Geotechnical estimates of its caving ability till the moment of its first failure while exiting out of the installation chamber showed its sustainable caving up till 60 meters [11...17]. Moreover, the fulfilled analysis revealed the potential ability for further periodic dynamic failures. Theoretical analysis and the results of seismic monitoring showed that the majority of the failure sources are in the seams with high strength and integrity, especially with a powerful sand-rock placed directly above the coal seam. This is the reason why in the majority of the countries such roofs are considered the feature of the dynamic phenomena [6,7].

It speaks for the necessity to develop the methods for effective hard roof control in stops and development headings. This methods should be directed on improving technical and economic indicators and occupational safety. The methods for weakening hard cavey formations (front (shooting) torpedoing, hydro-micro-torpedoing etc.)[18] despite experimental long time checking showed negative results.

## 2 Results

If to compare hard and free caving roofs then the basic difference between them is in the following: the first ones are made of solid rocks and the second ones have an ability to peel off along the bed planes. It is possible to influence the solid rocks in advance, for example, creating artificial cracks oriented in parallel of layering. During fulfilling these actions a hard-caving roof can be shifted into free-caving (medium-caving) category as with lessening the thickness of the roof the deformation ability increases.

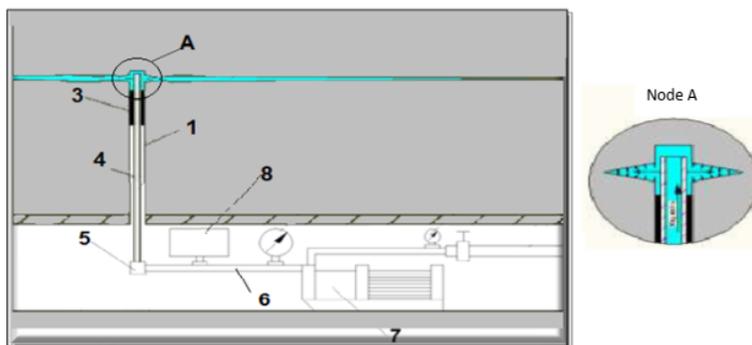
It means that when the plate bends under its weight the stresses that act at the layering point, under other equal conditions, are inversely proportionate to the plate thickness. A two-times thinner layer suffer two-times larger stresses. Basically, this is the reason why the less thick roof plates that bend under their own weights collapse prior.

It is known that roof caving at tailgate and headgate forms vast hollow zones under the caving roof where methane concentrates. Moreover, a part of fresh airflow, meant for a stope ventilation goes into the hollow. As a result, the stope lacks the calculated air volume that causes emergency stops due to heightened methane concentration rate and further it causes the decrease of the productivity.

The emergency situation development mechanism can be introduced as follows. During the stoping, a large volume of methane (it is lighter than the air) concentrates in the upper part of the goaf and in a rock massif above the goaf. At the collapsing moment a dramatic gas outburst from the hollow into the coal workings takes place increasing methane concentration in them. The outburst is accompanied with the shock wave and can cause destruction and electric system short-circuit, coal dust and gas combustion and outburst. During the roof failure, coal dust up-rise takes place, it can cause inflammation and outburst into the coal workings. The increase of horizontal stresses due to the main roof caving after the mining of the previous face brings about the out squeezing of coal pillars into the workings. It should be noted here, that from the hydrodynamic view, at the moment of the roof collapsing a man positioned at the distance of 300 m from the collapsing place can be influenced by air-pressure of 0.02 MPa. And if the airflow rate is more than 15 m/sec. a sudden air-pressure growth  $2 \times 10^{-6}$  MPa can be dangerous for a man [1].

To prevent dynamic phenomena in mines sophisticated directional hydraulic fracturing (DHF) blast-free technologies are being improved and widely implemented [2,3,19,20].

To fulfill a directional hydraulic fracturing in a roof (Fig. 1), in up-hole walls oriented to normal-bedded, with the help of specially designed tool an initiated crack of a given form and size which starts to be a stress concentrator is being cut out. Then the crack is sealed by elastically “expanded-sleeve” and the liquid, in hydraulic fracturing mode, is pumped in (7) along the pipeline (1, 5). A brittle fracturing results in a crack propagation in a given direction. For sedimentary rocks a tensional strength in the direction of layering is the lesser one. That is why the propagation of the crack along the layering is more favorable. Stratification of a solid roof can be done on one, two or more levels (depending on the number of the initiating cracks, created in a hole).



**Fig. 1.** Technological equipment placement scheme: 1 – bore-hole; 2 – initiating crack; 3 – packer; 4 – high-head pipes; 5 – box junction; 6 – “extended sleeve”; 7 – pump; 8 – measuring device.

To implement DHF method a number of mechanized crack formation devices for initiating cracks in bore-holes with the diameter of 46 mm [2,3,20] (Fig. 2a). Sealing of the initiating crack zone was done by hydraulic sealer of “Taurus” type (Fig. 2b). Delivering the sealer to a borehole face was done with the help of special high-head pipes. Pumping the liquid into the initiating crack zone was done basically from high-pressure system of a mechanized complex.

a)

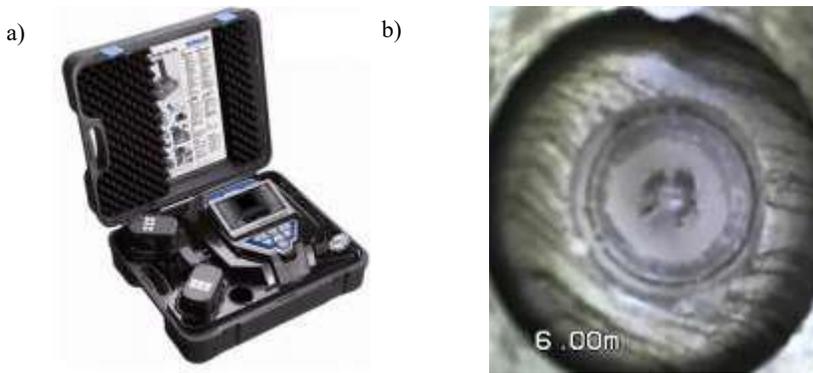


b)



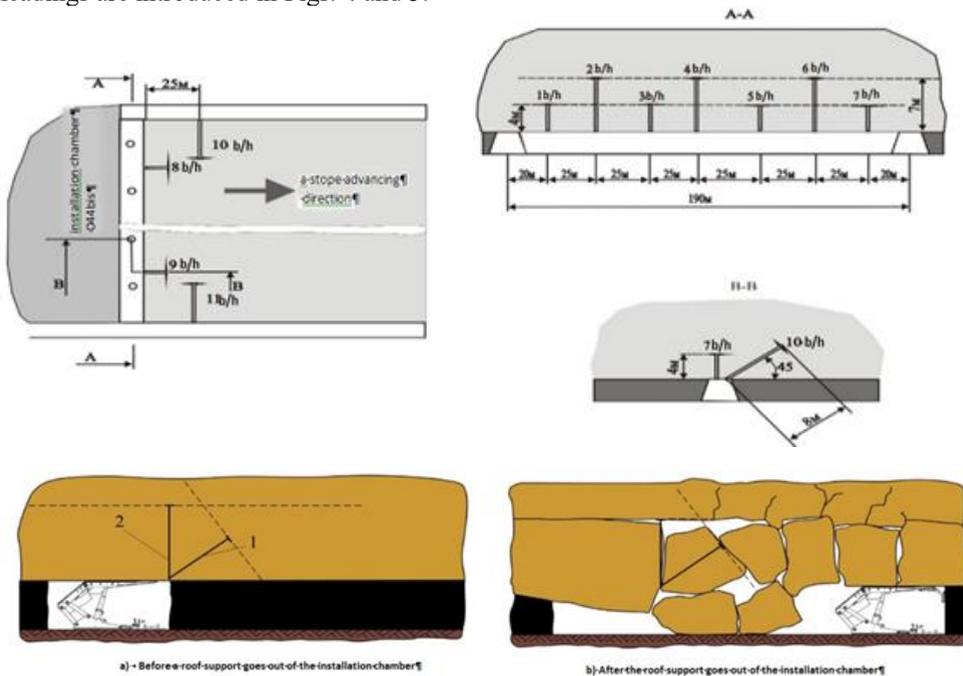
**Fig. 2.** Crack formation device (SCHM – 45/1) (a) and a sealer (b).

The estimation of the initiating crack cutting quality is done by video-endoscope (Fig 3).

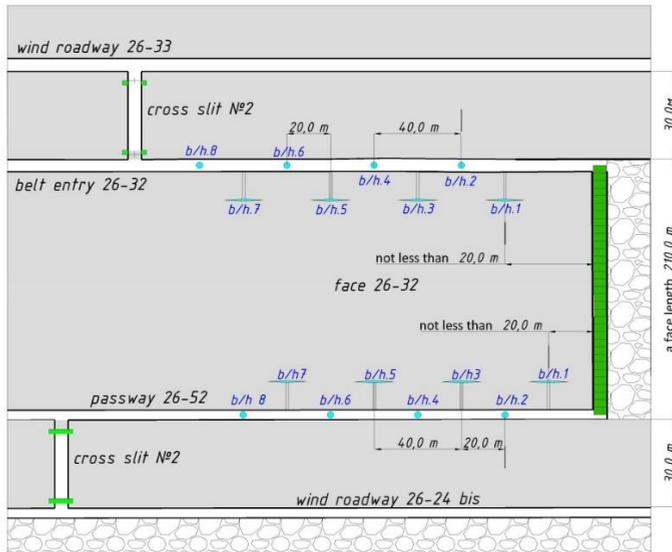


**Fig. 3.** Video-endoscope (a) and a borehole face with an initiating crack (b).

Technological schemes are worked out and multiple testing of applying directional hydraulic fracturing for weakening the roofs in installation and break down chambers, for preserving reutilized workings and reducing coal pillar loads and for coal working soil spring removal are done [2,3,20]. The most frequently applied schemes of primary roof caving in break down chamber and further secondary roof caving from development headings are introduced in Figs. 4 and 5.



**Fig. 4.** A – a typical scheme for positioning boreholes to implement DHF in an installation chamber for the seams with the thickness up to 3 meters: vertical boreholes (No 1,3,5,7 – H = 4 m; No 2,4,6,8 – H = 6 m); inclined boreholes (No 9,10,11,12 - H = 7 m); B – the mechanism for weakening a hard roof by stratification and cutting off.



**Fig. 5.** Technological scheme of DHF method implementation out of the development headings.

After applying the given method at “Pokui” (Poland) underground mine during primary roof caving [20], it started to be used by Polish experts as a method for preventing rock blasts [21]. With referencing to Polish experts works [22] Chinese specialists consider this method to be ideal for controlling hard roofs. Further, they applied the DHF method on two longwall faces LW6305 and LW5307. The positioning depth of the initiating cracks in boreholes easily reached 20 m, and the radius of the crack propagation made over 13 m. It allowed providing safety operation of the stopes [8...10].

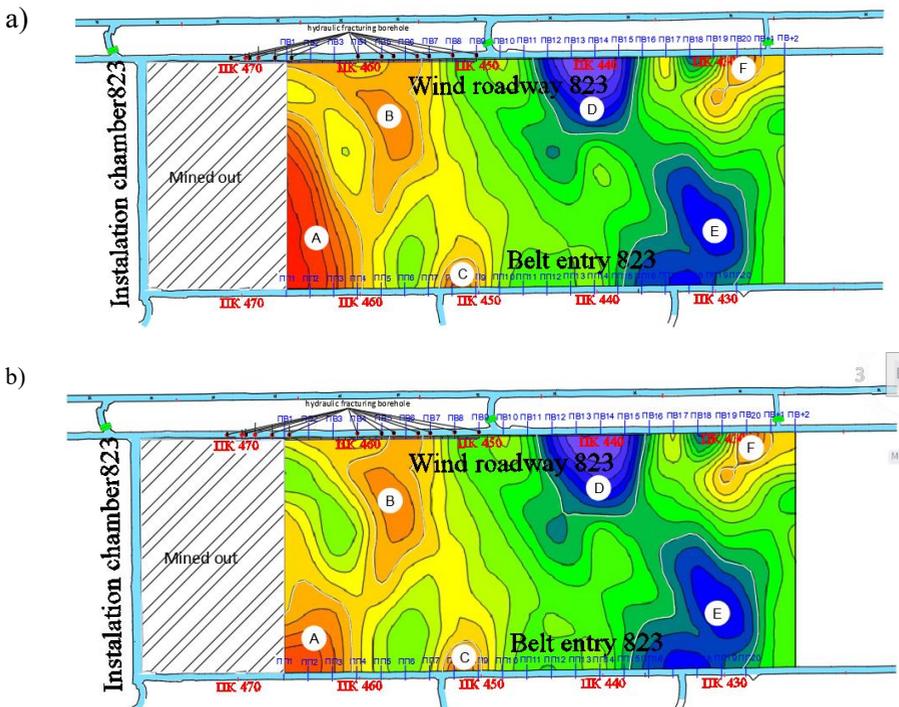
In Australia for stratification of the roof on primary caving in a preliminary prepared stope with horizontal cracks at various depth a very expensive method for cracks creation out of the boreholes of a large diameter drilled in from the surface was applied. The boreholes were with a diameter of 300 mm and the packers were not brought up to the borehole face approximately on 320 mm. Here, by means of calculation the point for positioning the expected fracturing crack along the layering with a shift of each new crack on 2,5 or less up to 30 m radius or more [11...17]. This crack positioning allows fulfilling effectively a preliminary preparation out of the vertical borehole as it is possible to place several cracks out of each borehole. Measuring the growth, distance and positioning of the cracks on two experimental sections and, as a preliminary preparation of No 101 stope starting zone, showed approximately horizontal positioning of the crack but did not prove that the cracks propagated in parallel to each other. Nevertheless, when the stope moved out on 24 meters from the installation chamber the roof failure took place (nearly in 3 times less comparing to the supposed one of 60 m).

Several hundreds of the hydraulic fracturing were carried out from the vertical borehole for weakening powerful and solid conglomerate rocks to carry out a primary caving of a coal mine roof. The carried out field researches at testing sites were done for proving the ability of the horizontal growth of the hydraulic fracturing and for measuring the crack size made depending on the pumping volume of the liquid. In future, to avoid the formation of longitudinal cracks (along the boreholes) which later transform into horizontal ones it is suggested that initiating cracks should be made on the account of abrasive blasting for circular grooves into the borehole wall. Then these grooves were isolated using horizontal packers for getting directional hydraulic fracturing. The data on reorientation of the

hydraulic fracturing were captured from two instrumentation areas of the test borehole. They were analyzed for estimating the influence of the initiation type (axial and lateral) on treating pressure. Vertical boreholes were drilled and the cracks were positioned in the conglomerate rocks at the depth of 140–180 m in the stress field of a far zone and it provided horizontal growth of the cracks. The analysis of the destruction initiation defined that the initiation in abrasively cut circular grooves should take place till axial initiation. The grooves were made for the purpose of defining initiation positions and improving the probability of lateral failure occurrence.

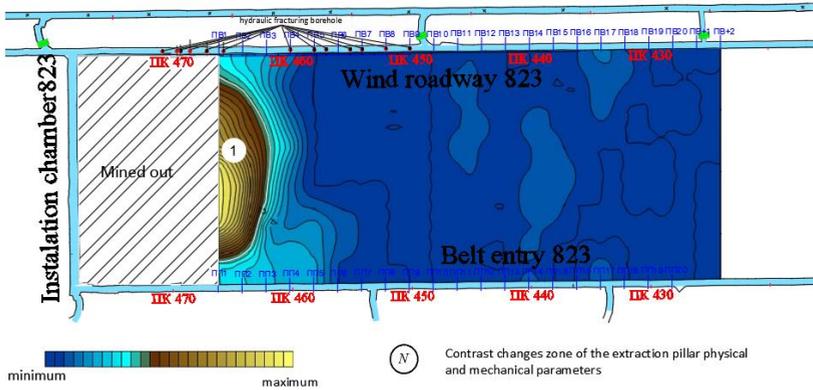
To estimate the carried out activities on weakening the coal seam roof it is necessary to detect zones with changed geo-mechanical characteristics at the area of the extraction pillar. With this purpose we carry out geophysical researches applying the method of extraction pillar seismic testing on transmitted waves [23...25].

Directional hydraulic fracturing method was applied during mining the extraction pillar of 823 Face at “Lestvyazhnaya” Mine in Kuzbass. It allowed decreasing the roof and wind roadway soil convergence of 823 face in the bearing pressure zone. According to seismic testing results before and after DHF (Fig. 6) the changes of the active roof condition were registered. They were expressed in decreasing of a velocity background in the researched area and reducing the area of A, B, C, D zones. In whole, changing the size and mutual location of the indicated zones in the result of hydraulic impact speaks about the roof relieving and decreasing the probability of hard roof section formation in a researched interval.



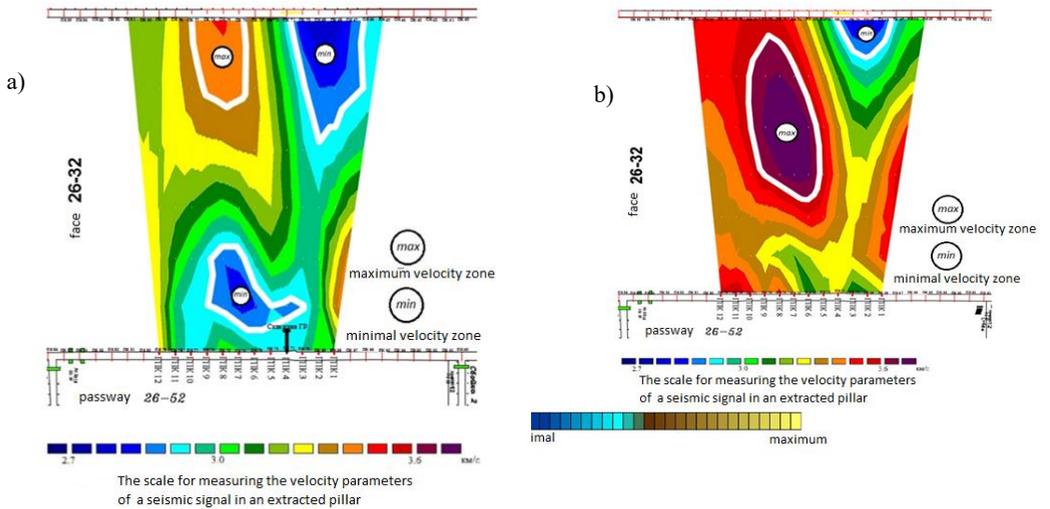
**Fig. 6.** Active roof seismic testing data: before hydraulic impact (a); after hydraulic impact (b).

For estimating the area of relieving distribution, a seismographic cut which characterized the difference between the velocity ratio, registered in measuring data before and after hydraulic fracturing, and the range of their probable change was formed (Fig. 7).



**Fig. 7.** Seismographic cut reflecting the active roof relieving degree registered in measuring data before and after hydraulic impact.

The works applying DHF method were carried out in 26-32 extraction pillar of “Yesaul’skaya” Mine. Resulting from the processed data the tomographic cuts of the velocities changes and the combined cuts reflecting the basic changes characteristics were obtained. The reduction of the general velocities background after carrying out the hydraulic fracturing, the reduction of the distribution and redistribution areas of “max” zone high stresses, widening of the low velocities (“min”) section influencing zone, situated in the limits of 26-32 belt entry (Fig. 8) were defined.



**Fig. 8.** Geo-physical cut of the velocity characteristics distribution in the area of the 26-32 extraction pillar of “Yesaul’skaya” Mine before hydraulic fracturing (a) and after hydraulic fracturing (b).

### 3 Conclusions

1. Directional hydraulic fracturing method (DHF) for controlling hard roofs in coal mines and the means of its application in the process of mining the coal seams with full roof

failure and with leaving inter-longwall face pillars of limited size was introduced. The method allows obtaining extended cracks in a given direction for stratification and cutting off the roofs and for controlled caving in different technological schemes.

2. The developed geophysical methods for monitoring mining experiments on controlling roofs applying the method of extraction pillar seismic testing on transmitted waves allowed not only obtaining a qualitative picture of changes after carrying out directional hydraulic fracturing but also estimating quantitatively the obtained results. It was revealed that the fixed weakening of an active roof expressed by changing the cumulative area and mutual location of maximum velocities zones witness about effective carrying out of directional hydraulic fracturing.

3. To define the sufficiency or the excessiveness of the obtained values it is necessary to calculate stressed-deformed state of a massif when applying DHF method and compare its results with the experimental research data. It allows shifting to criterial estimation methods.

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## References

1. V. Artemyev, G. Korshunov, et al., *Protecting development headings by pillars in coal mines* (Nauka, Saint Peterburg, 2009)
2. V. Klishin, V. Rashevsky, et al., *Hard roofs: the issues and solutions for mechanized faces of coal mines of modern technical level* (Kimmeriyskey Center, 2016)
3. V. Klishin, L. Zvorygin, et al., *Safety issues and new technologies of underground mining of coal deposits* (Novosibirskiy Pisatel, Novosibirsk, 2011)
4. S. Ogonessyan, *Ugol*, **6**, 25-28 (2004)
5. Yu. V. Tsivka, A N Petrov, *Ugol*, **7**, 49-50 (2005)
6. Li, T., Cai, M.F., Cai, M., *Int. J. Rock Mech. Min. Sci.*, **44**, 1149-1171 (2007)
7. L. Dou, C.P. Lu, et al., *Min. Sci. Technol.*, **19**, 585-591 (2009)
8. T.T. Du, L.M. Dou, et al., *Coal Min. Technol.*, **15**, 4-7 (2010)
9. H. He, L. Dou, et al., *Tunnelling and Underground Space Tech.*, **32**, 34-43 (2012)
10. F. Jun, D. Linming, et al., *Directional hydraulic fracturing to control hard-roof rockburst in coal mines* (Elsevier, 2012)
11. R. G. Jeffrey, et al., *Monitoring and measuring hydraulic fracturing growth during preconditioning of a roof rock over a coal longwall panel*, in *Proceedings of ISRM International Conference for Effective and Sustainable Hydraulic Fracturing* (2013)
12. M.J. Jackson, D.R. Tweeton, *MIGRATOM – Geophysical Tomography Using Wavefront Migration and Fuzzy Constraints* in Report of Investigations 9497, Bureau of Mines
13. J. Kear, J. White, et al., *Three dimensional forms of closely-spaced hydraulic fractures*, in *Proceedings of the International Conference on Effective and Sustainable Hydraulic Fracturing*, (Brisbane, Australia. InTech: Rijeka, Croatia, 2013)
14. A. Van As, R. G. Jeffrey, *Caving induced by hydraulic fracturing at Northparkes Mines*, in *Proceedings of the 45<sup>th</sup> US Rock Mechanic Symposium on Geomechanics* (Seattle, WA, USA. Rotterdam, 2000)
15. A. Bunger, R. Jeffrey, et al., *Experimental investigation of the interaction among closely spaced hydraulic fractures*, in *Proceedings of the 45<sup>th</sup> US Rock Mechanic Symposium on Geomechanics* (San Francisco, CA, USA, ARMA, 2011)

16. R.G. Jeffrey, K.W. Mills, *Hydraulic fracturing applied to inducing longwall coal mine goaf falls*, in Proceedings of the 4<sup>th</sup> North American Rock Mechanics Symposium (Seattle, WA, USA. Rotterdam, 2000)
17. R.G. Jeffrey, Z.R. Chen, et al., Measurement and analysis of full-scale hydraulic fracture (Springer-Verlag, Wien, 2015)
18. Instruction on choosing the way and parameters of roof weakening at extraction areas (Leningrad, VNIMI, 1991)
19. O. Tschernov, N. Kyu, FTPRPI, **6** (1988)
20. V.I. Klishin, Adapting mechanized supports to dynamic loading condition (Nauka, Novosibirsk, 2002)
21. Ya. Dzhevetzkey, *Gluck auf*, **2(3)**, (2002)
22. J.A. Dubinski, *Geophysical assessment of the hydraulic injection process in coal seams under rockburst hazard*, in Proceedings of the Conference on Geomechanics (Ostrava, 1994)
23. A. Averbukh, Studying the composition and features of rocks during seismic exploring (Nedra, Moscow, 1982)
24. O. Tailakov, S. Sokolov, Ye. Saltymakov, *Naukoyemkiye technologii razrabotki i ispol'zovaniya mineral'nykh resursov*, **4**, 437-441 (2018)
25. O. Sagaidachnaya, K. Dunayeva, et al., *Devices and Systems of Exploration Geophysics*, **4**, 35-37 (2008)