Induced Seismicity Workshop
Davos, Switzerland 10. - 13. March 2015,

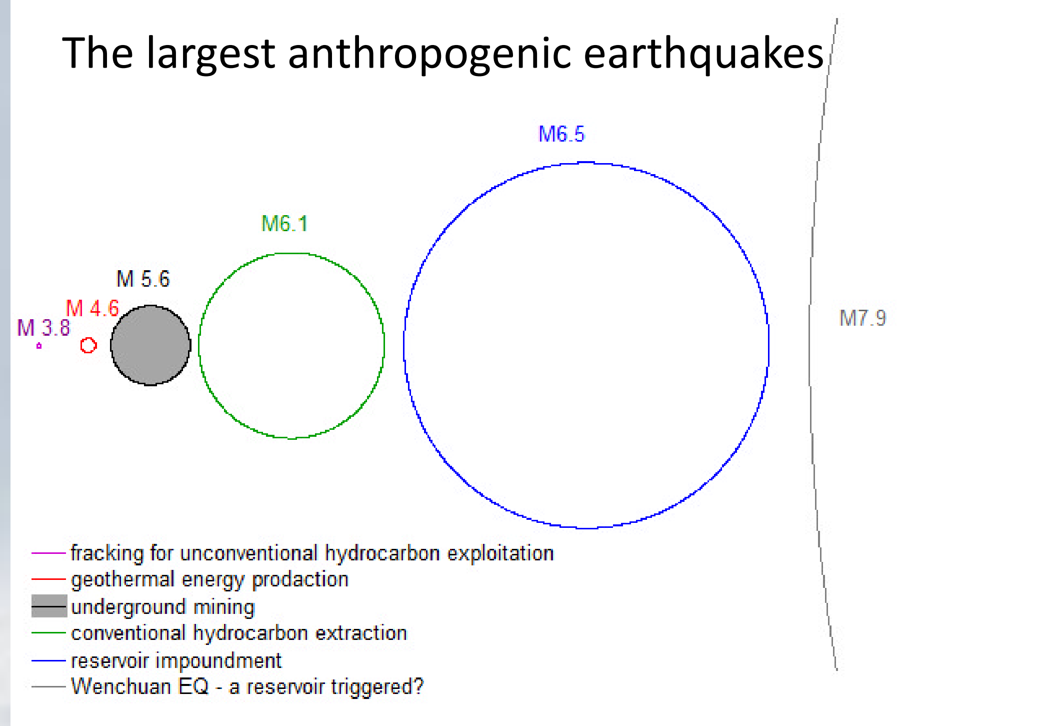
From Hazard Assessment to Hazard Management
The Case of Mining-Induced Seismicity

Stanisław Lasocki
Institute of Geophysics, Polish Academy of Sciences
Department of Seismology
email: lasocki@igf.edu.pl

MINING-INDUCED SEISMICITY

The first chronicled rockburst in Derbyshire, England, 1738

The strongest event M5.6 Ernst Thaelmann Potash Mine, Volkershausen, Germany, 13/03/1989



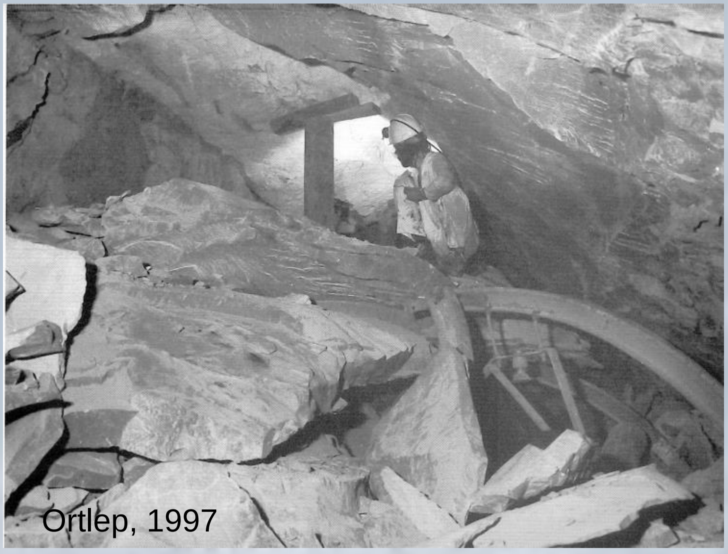
Geographical Distribution:

Austria, Czech Rep. Finland, France, Germany, Poland, Russia, Spain, Sweden, UK, Ukraine

Canada, USA, Chile, Rep. of South Africa

China, India, Japan, Australia

Stronger Mining Induced Seismic (MIS) Events Cause Material Loss, Injuries, Sometimes Fatalities



Ortlep, 1997

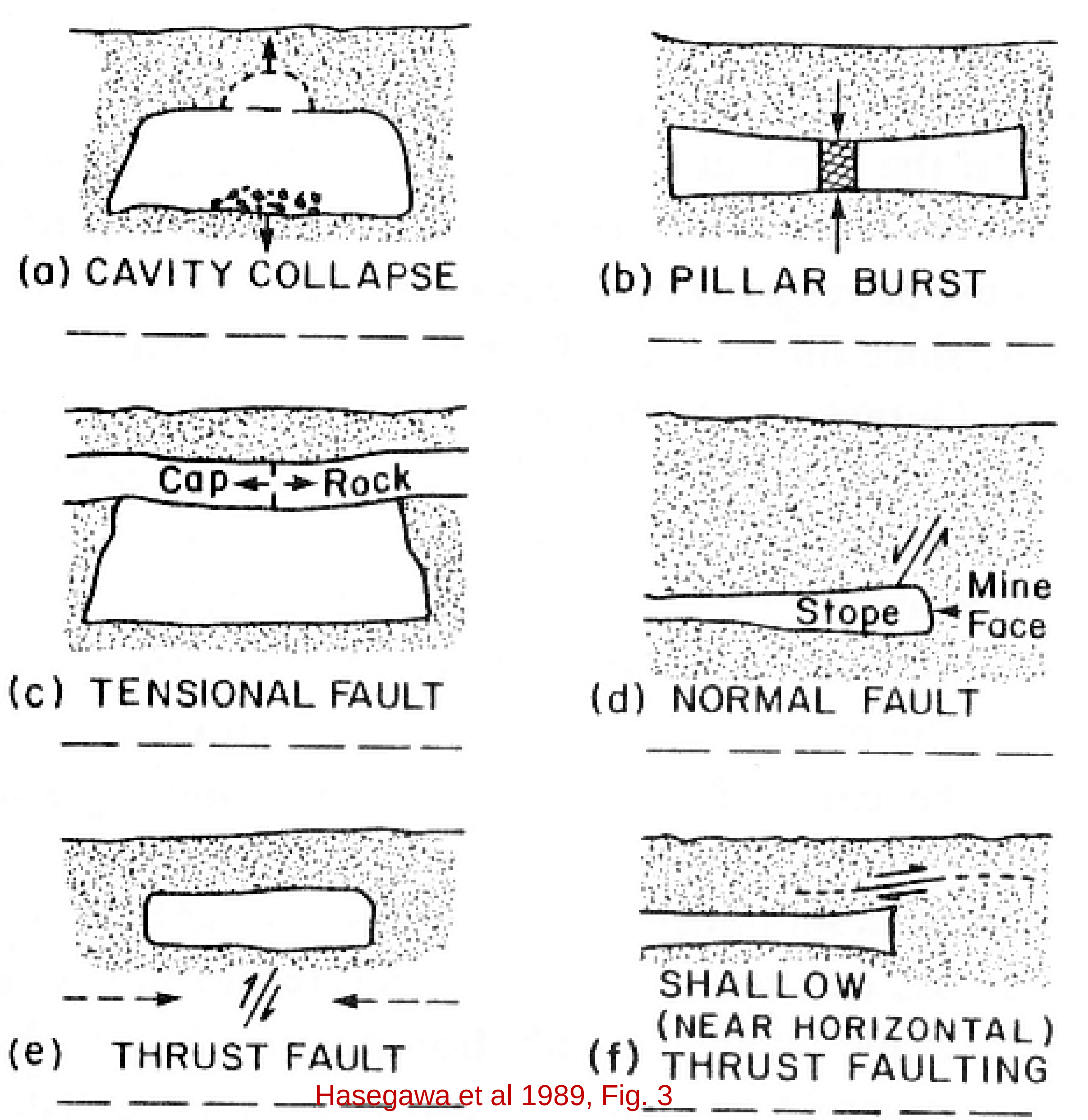
Underground

INSTITUTE OF GEOPHYSICS
POLISH ACADEMY OF SCIENCES
Ksiecia Janusza 64, 01-452 Warsaw, Poland, www.igf.edu.pl e-mail:office@igf.edu.pl
SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR, LITHOSPHERE RESEARCH, GEOMAGNETISM, PHYSICS OF ATMOSHERE
HYDROLOGY AND HYDRODYNAMICS, POLAR RESEARCH, CENTRAL GEOPHYSICAL OBSERVATORY AT BELSK

Ground effects

Mining Seismicity is Induced

Strains in the rockmass that lead to seismic events are primarily due to the stress field changes caused by mining openings.



Hasegawa et al 1989, Fig. 3

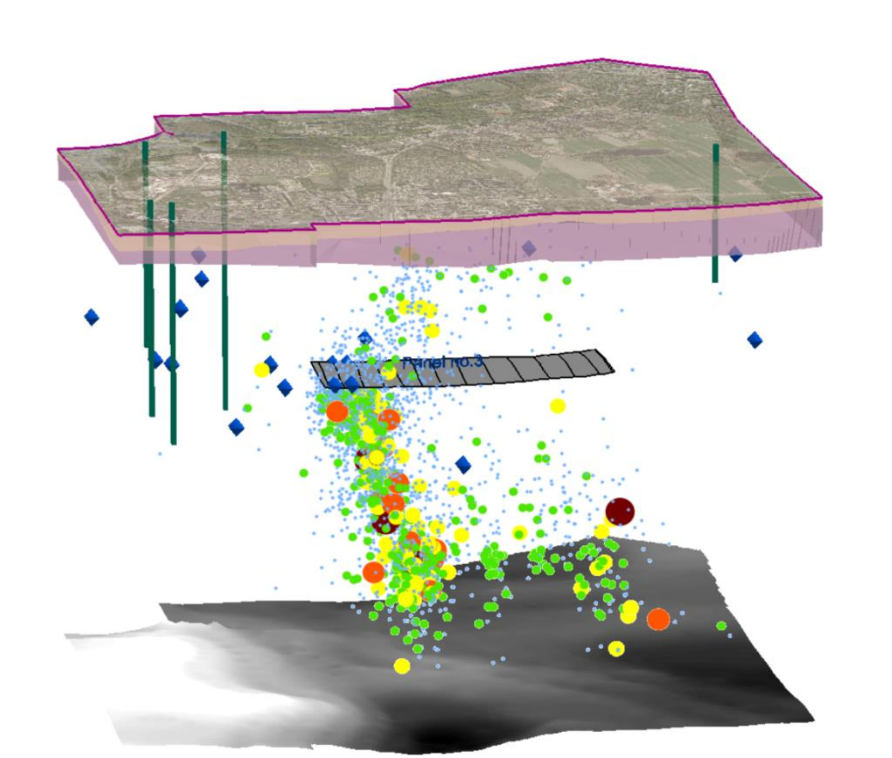
Internal Division of MIS Events

INDUCED: linked directly to mining operations. Cluster around mining stopes and follow mining works.

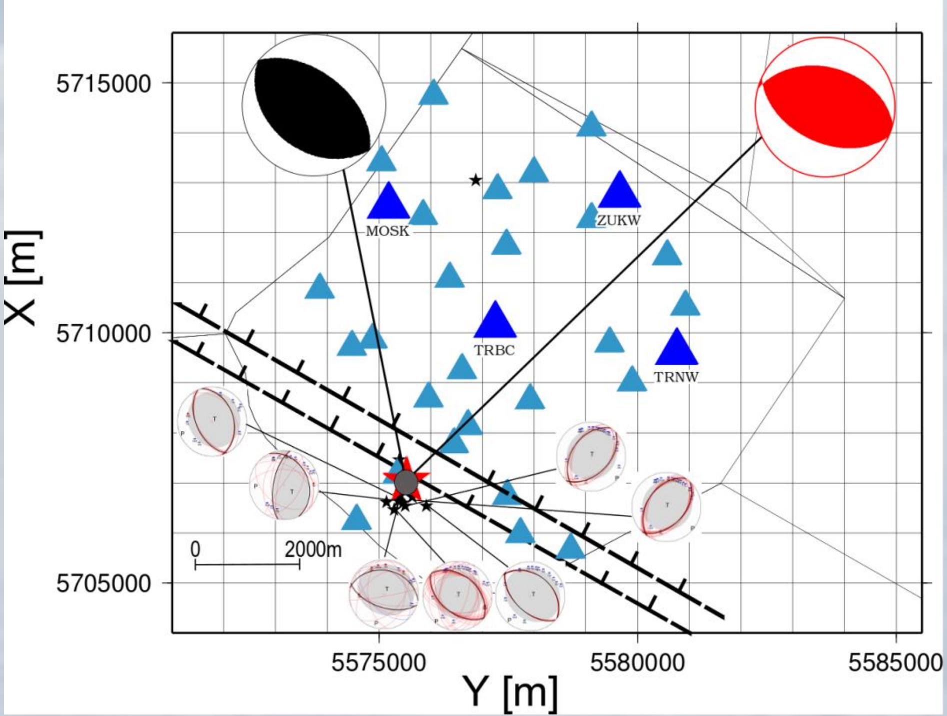
&

TRIGGERED: result from regional stress redistribution caused by mining. Occur farther from mining works in geologically disturbed areas.

Johnston and Einstein, 1990



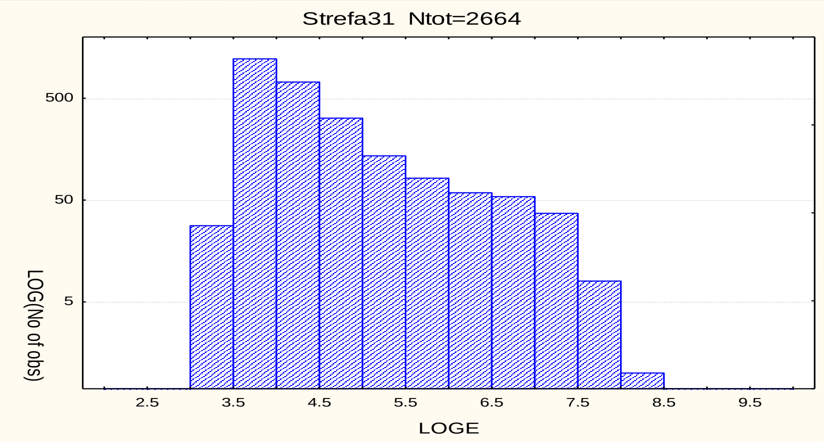
Central Mining Institute, Poland, 2014

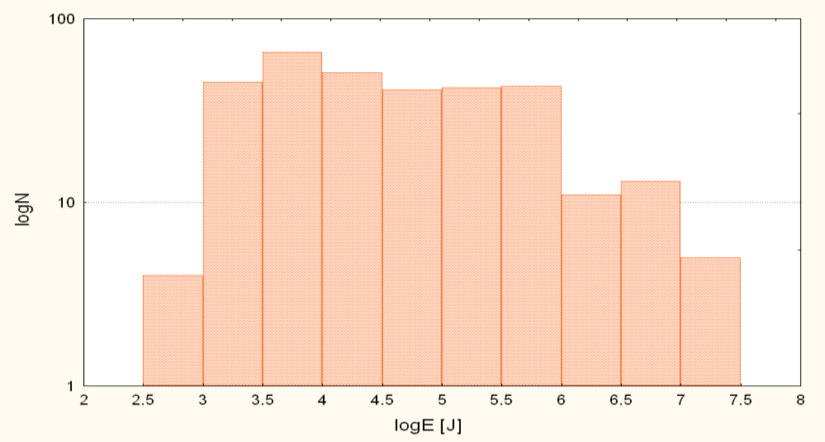


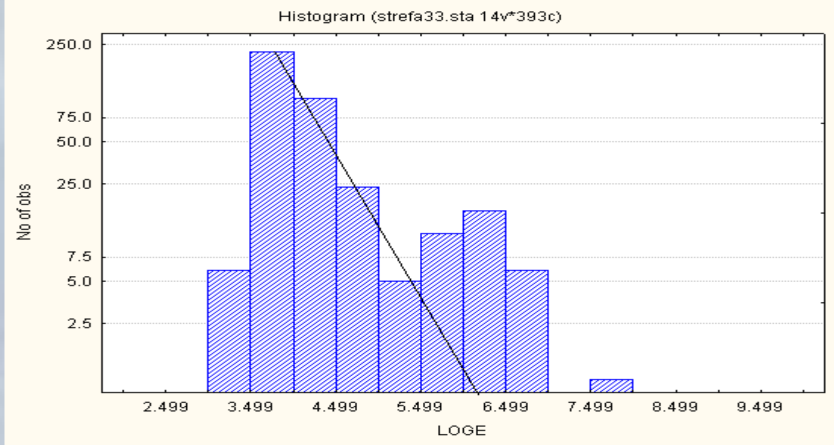
Lizurek, et al., 2015

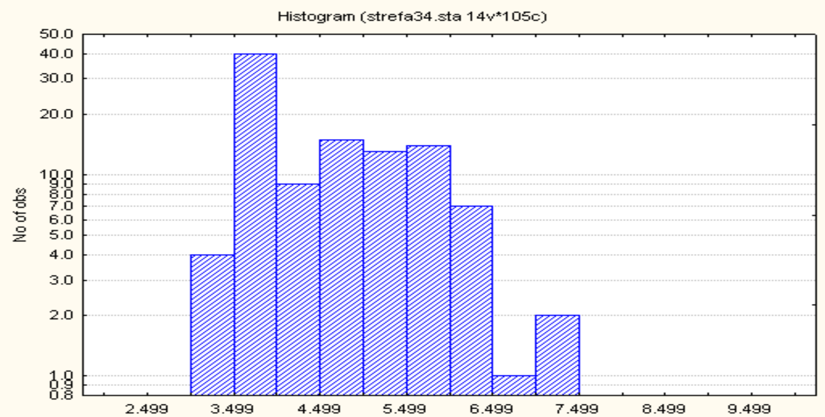
MIS Population is Mixed f At Least Two Components: The Directly Linked To Mining And The Triggered By Mining

⇒ Magnitude distributions are complex and often multimodal. The Gutenberg-Richter distribution model is not relevant (*the feature of all kinds of AS*)









Lasocki, 2001; Urban et al., 2015

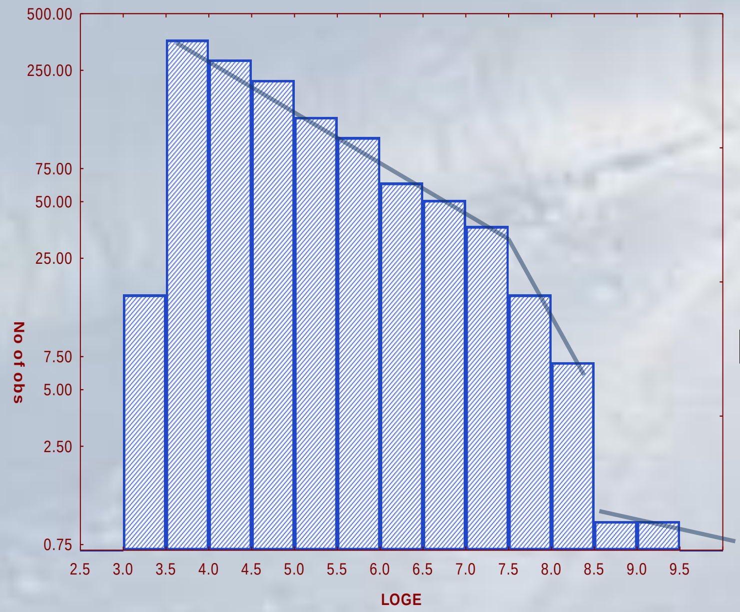
⇒ A model free approach is used to estimate MIS magnitude distributions, based on non-parametric kernel estimators

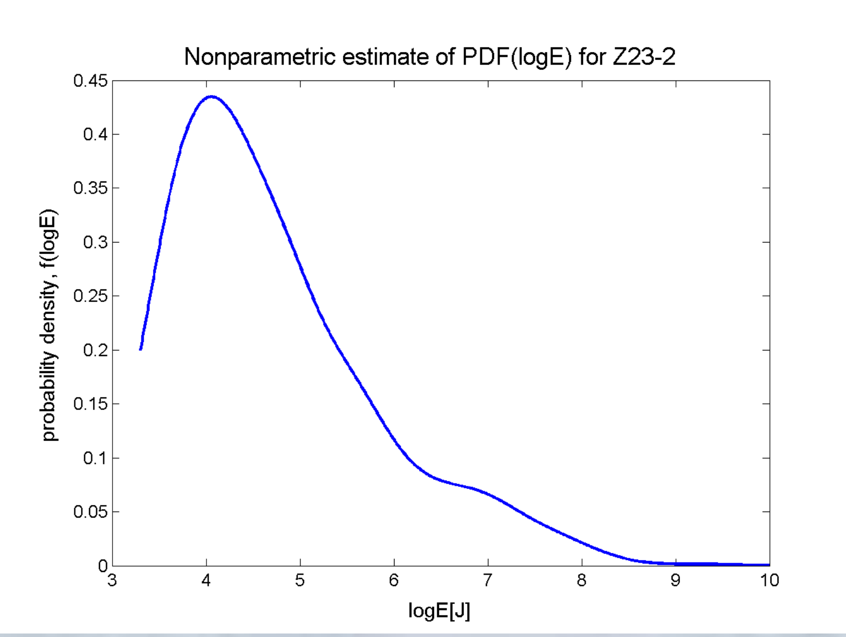
Kijko et al. 2001; Lasocki and Orlecka-Sikora, 2008

$$\hat{f}_m^{\,a}(m)=\frac{\left(\sqrt{2\pi}\right)^{-1}\sum_{i=1}^{n}\frac{1}{\alpha_i h}\exp\left[-0.5\left(\frac{m-m_i}{\alpha_i h}\right)^2\right]}{\sum_{i=1}^{n}\left[\Phi\left(\frac{m_{\max}-m_i}{\alpha_i h}\right)-\Phi\left(\frac{m_{\min}-m_i}{\alpha_i h}\right)\right]}$$

$$\hat{F}_m^{\,a}(m)=\frac{\sum_{i=1}^{n}\left[\Phi\left(\frac{m-m_i}{\alpha_i\cdot h}\right)-\Phi\left(\frac{m_{\min}-m_i}{\alpha_i\cdot h}\right)\right]}{\sum_{i=1}^{n}\left[\Phi\left(\frac{m_{\max}-m_i}{\alpha_i\cdot h}\right)-\Phi\left(\frac{m_{\min}-m_i}{\alpha_i\cdot h}\right)\right]}$$

$$\hat{m}_{\max}=m_{\max}^{obs}+\int_{m_{\min}}^{\hat{m}_{\max}}\left[\hat{F}_m^{\,a}(m)\right]^n dm$$





INSTITUTE OF GEOPHYSICS
POLISH ACADEMY OF SCIENCES

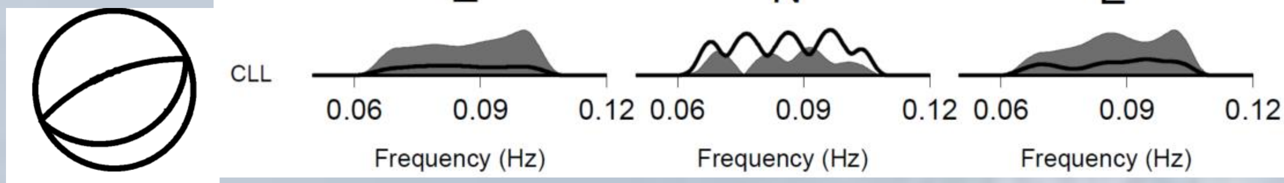
Ksiecia Janusza 64, 01-452 Warsaw, Poland, www.igf.edu.pl e-mail:office@igf.edu.pl
SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR, LITHOSPHERE RESEARCH, GEOMAGNETISM, PHYSICS OF ATMOSHERE
HYDROLOGY AND HYDRODYNAMICS, POLAR RESEARCH, CENTRAL GEOPHYSICAL OBSERVATORY AT BELSK

MIS Events have often extended sources with significant non-DC components (*the feature of all kinds of AS*)

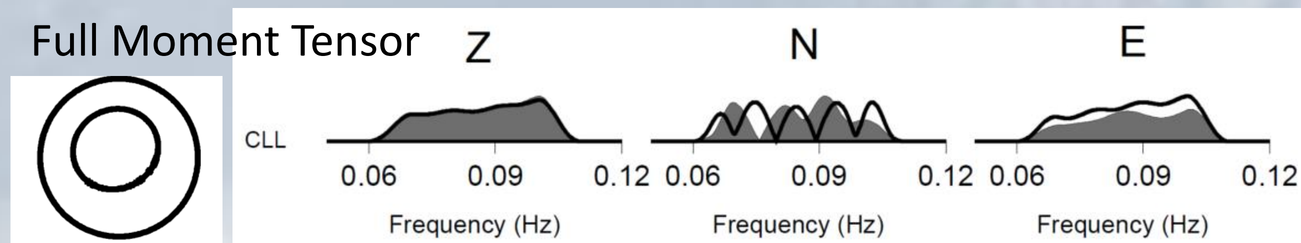
Mw3.8 19/03/2013
19 miners stacked

(*Rudziński et al, 2015*)

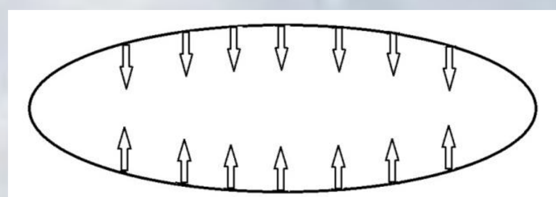
Double-Couple

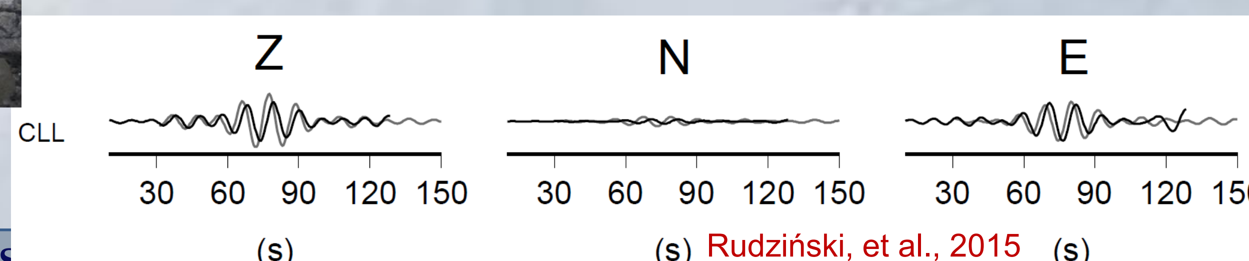


Full Moment Tensor



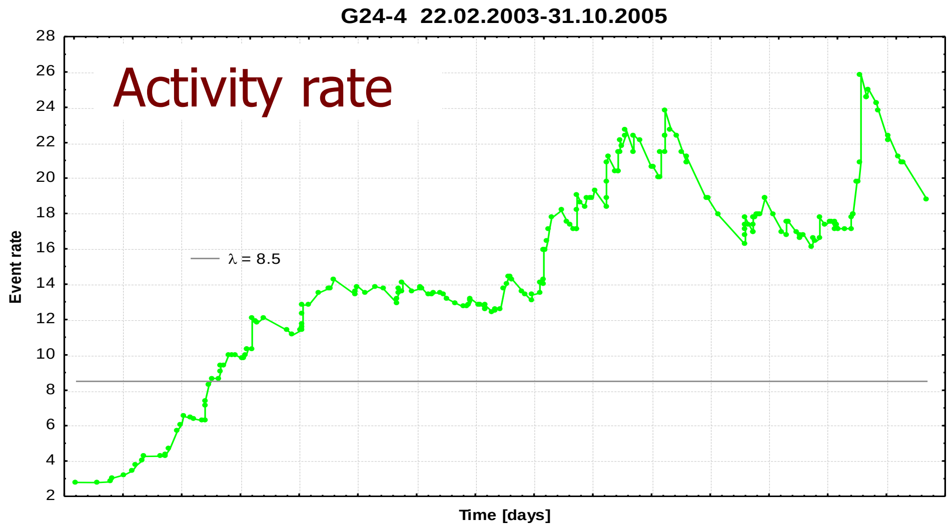
Tabular Cavity collapse model

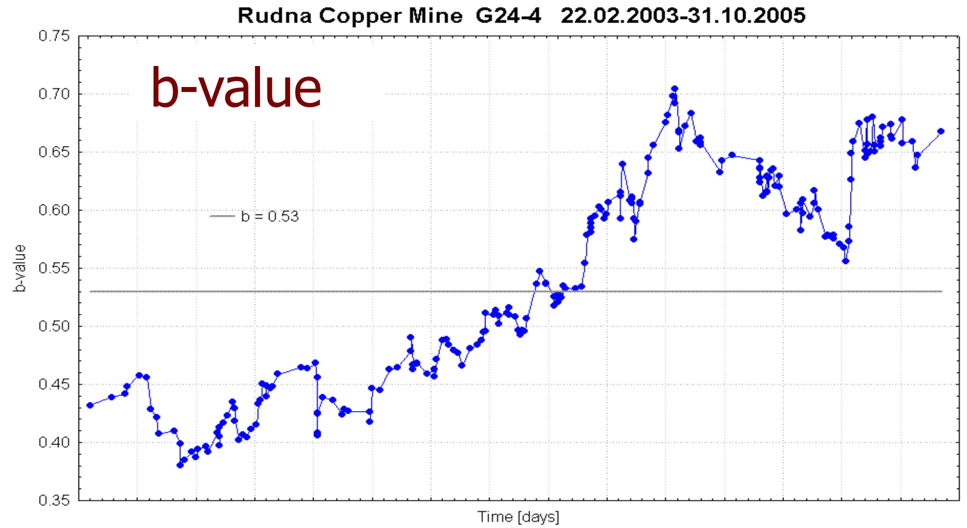


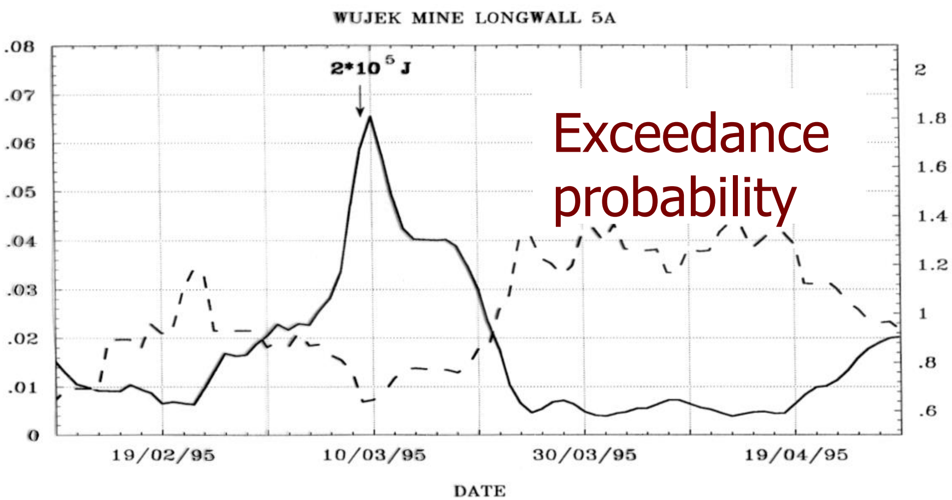


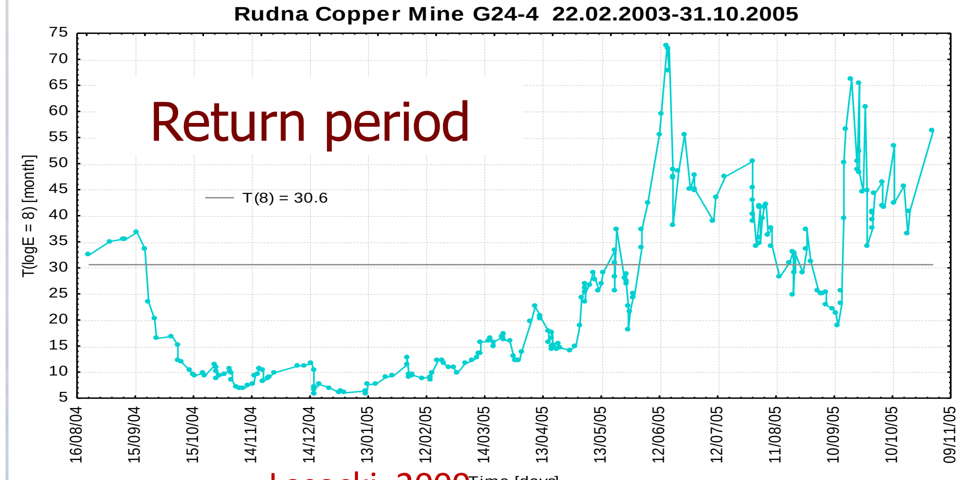
MIS is controlled primarily by time varying mining works

⇒ Within individual active zones the activity rate and the event size distribution change in time









Lasocki, 2009

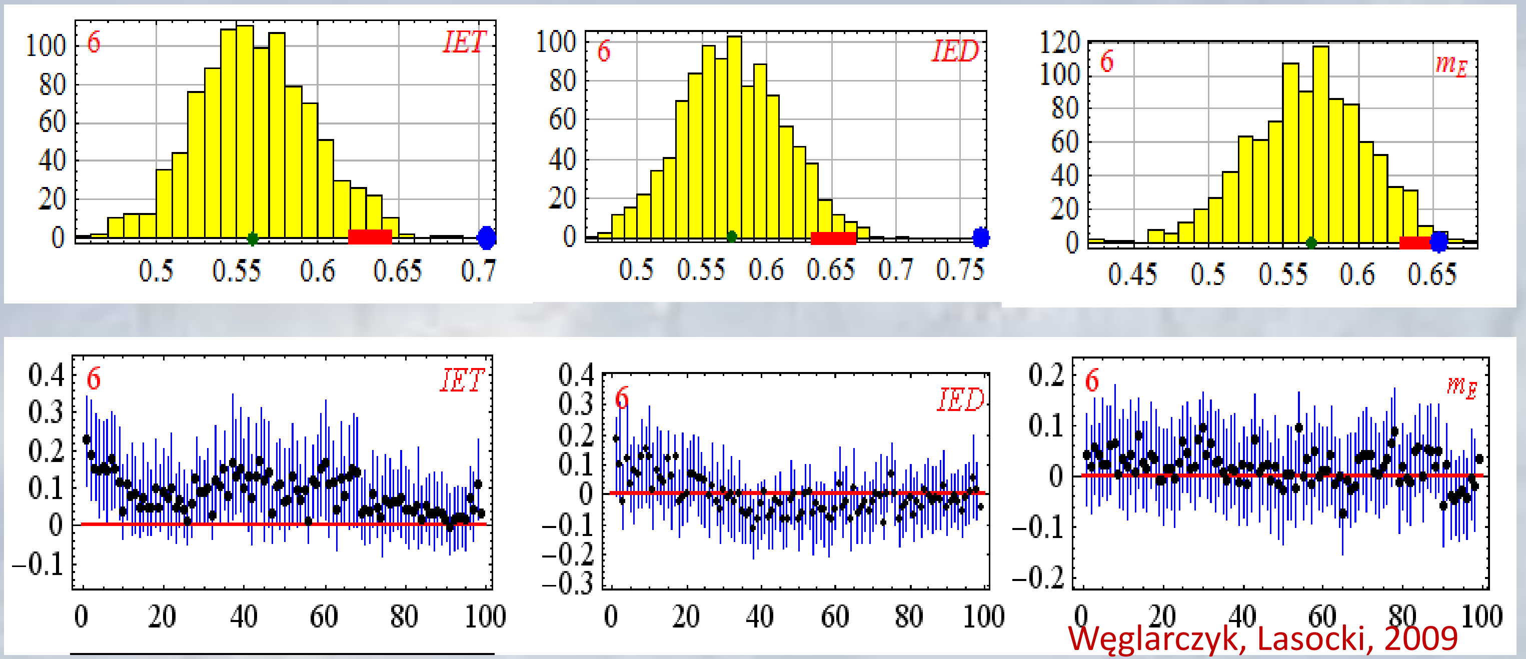
INSTITUTE OF GEOPHYSICS
POLISH ACADEMY OF SCIENCES
Ksiecia Janusza 64, 01-452 Warsaw, Poland, www.igf.edu.pl e-mail:office@igf.edu.pl
SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR, LITHOSPHERE RESEARCH, GEOMAGNETISM, PHYSICS OF ATMOSHERE
HYDROLOGY AND HYDRODYNAMICS, POLAR RESEARCH, CENTRAL GEOPHYSICAL OBSERVATORY AT BELSK

Events are interrelated in a short as well as in a long time scale.

Interevent Time | Interevent Distance | Magnitude

Long Memory: Hurst R/S Analysis

Short Memory: ACC Analysis

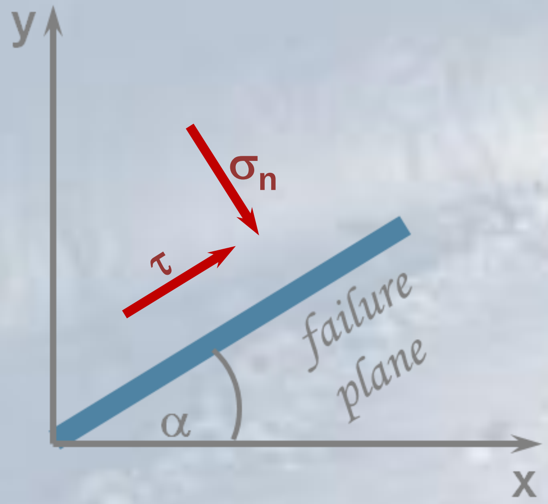


Węglarczyk, Lasocki, 2009

Static stress change due to coseismic displacement plays an important role for subsequent event generation

(*the feature of all kinds of AS*)

Coulomb Failure Criterion:



$$\Delta CFF = \Delta\sigma_f = \Delta\tau - \mu(\Delta\sigma_n - p)$$

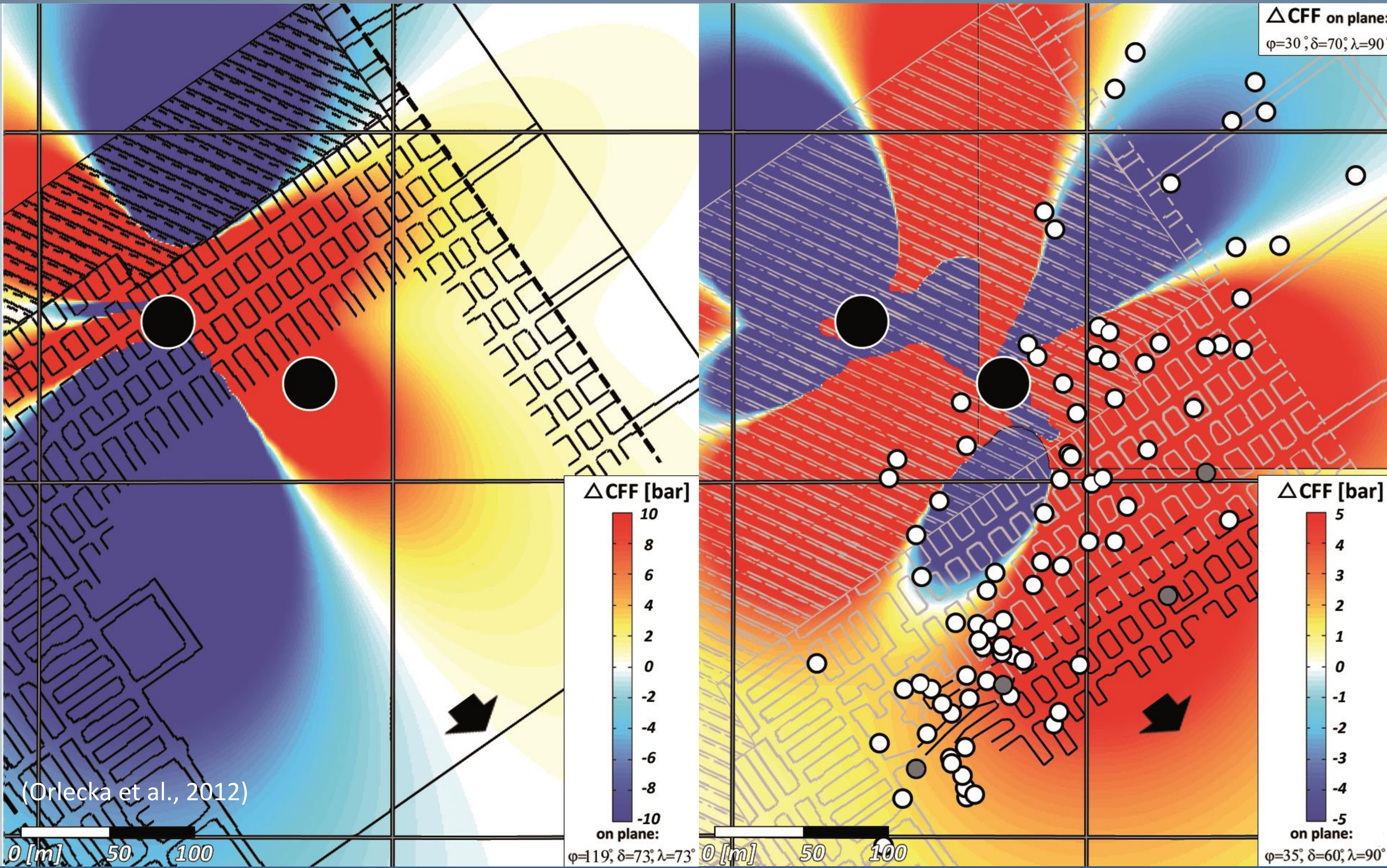
$\Delta\tau$ - the shear stress on failure plane

$\Delta\sigma_n$ - the normal stress

p - the pore fluid pressure

μ - the coefficient of friction

G-11/8 section



INSTITUTE OF GEOPHYSICS
POLISH ACADEMY OF SCIENCES

Ksiecia Janusza 64, 01-452 Warsaw, Poland, www.igf.edu.pl e-mail:office@igf.edu.pl
SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR, LITHOSPHERE RESEARCH, GEOMAGNETISM, PHYSICS OF ATMOSHERE
HYDROLOGY AND HYDRODYNAMICS, POLAR RESEARCH, CENTRAL GEOPHYSICAL OBSERVATORY AT BELSK

CONCLUSIONS ON ASSESSMENT OF SEISMIC HAZARD

- *Due to specific features of MIS the seismic hazard analysis must undergo substantial modifications to be applicable to MIS problems.*

- *One has to take into account complexity of source mechanisms, transient and time-varying character of the seismic process, complexity of magnitude distribution, interrelations among events.*

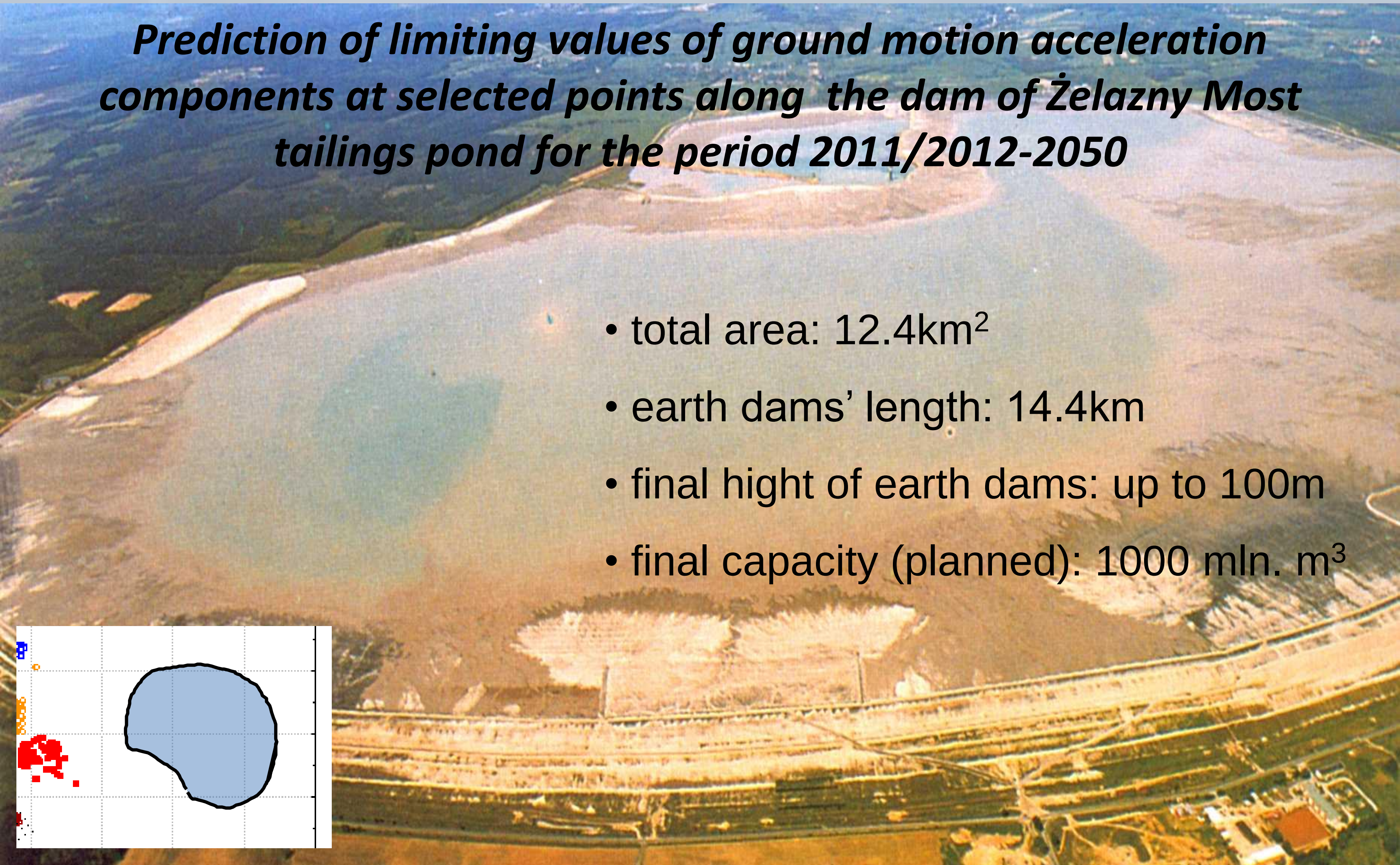
- *The seismic hazard cannot be reliably assessed without considering technological factors conditioning the seismic process.*

- *Due to the dependence of the seismic process on technological activity the results of hazard analysis are predictions related to a prescribed time period.*

- *The above conclusions extend onto all kinds of anthropogenic seismicity*

A CASE STUDY OF ASSESSEMENT AND MANAGEMENT OF THE SEISMIC HAZARD DUE TO MIS

(Lasocki et al. 2011; 2012)



Prediction of limiting values of ground motion acceleration components at selected points along the dam of Żelazny Most tailings pond for the period 2011/2012-2050

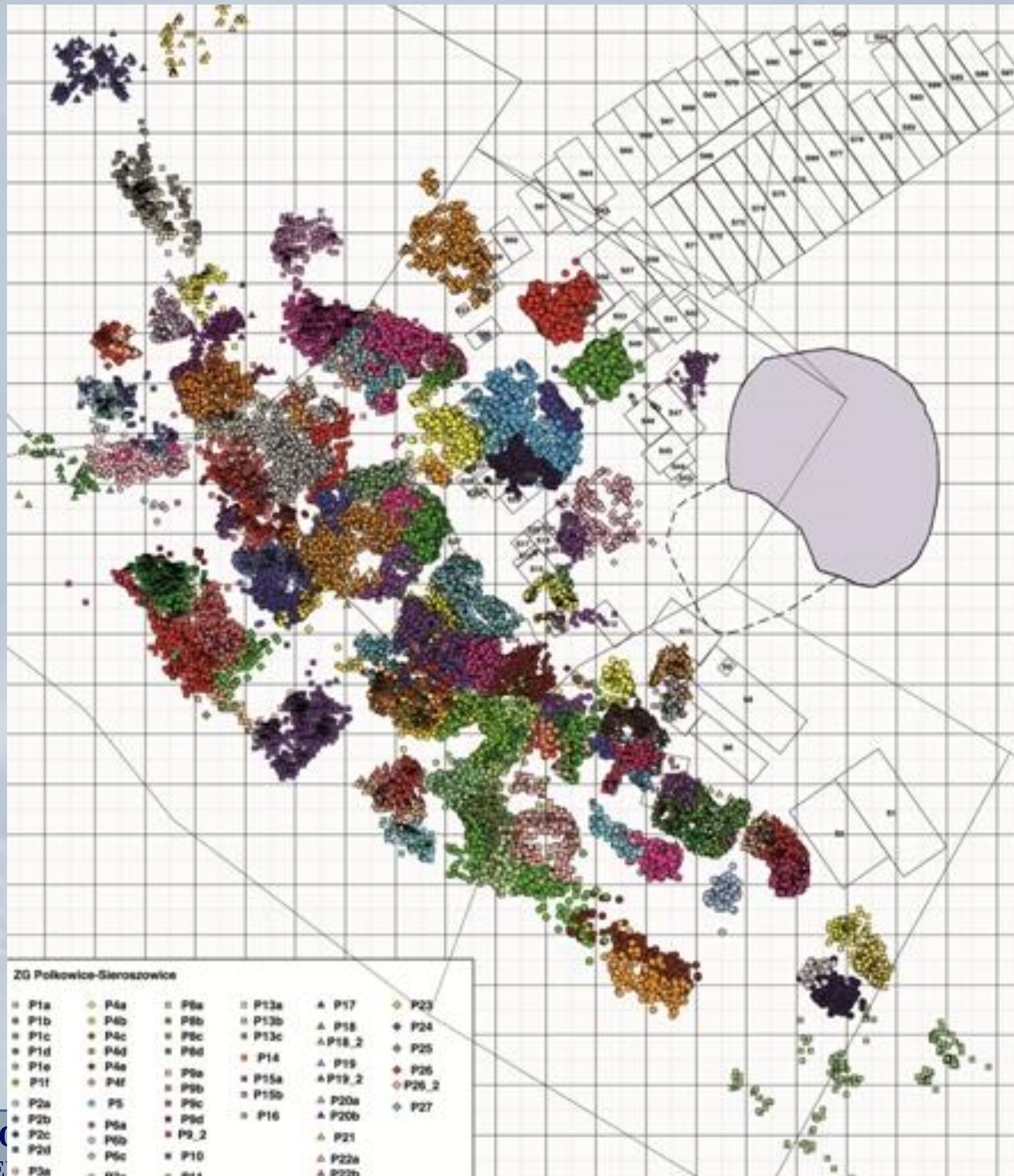
- total area: 12.4km^2
- earth dams' length: 14.4km
- final hight of earth dams: up to 100m
- final capacity (planned): 1000 mln. m^3

A CASE STUDY OF ASSESSEMENT AND MANAGEMENT OF THE SEISMIC HAZARD DUE TO MIS

Prediction of limiting values of ground motion acceleration components at selected points along the dam of Żelazny Most tailings pond for the period 2011/2012-2050

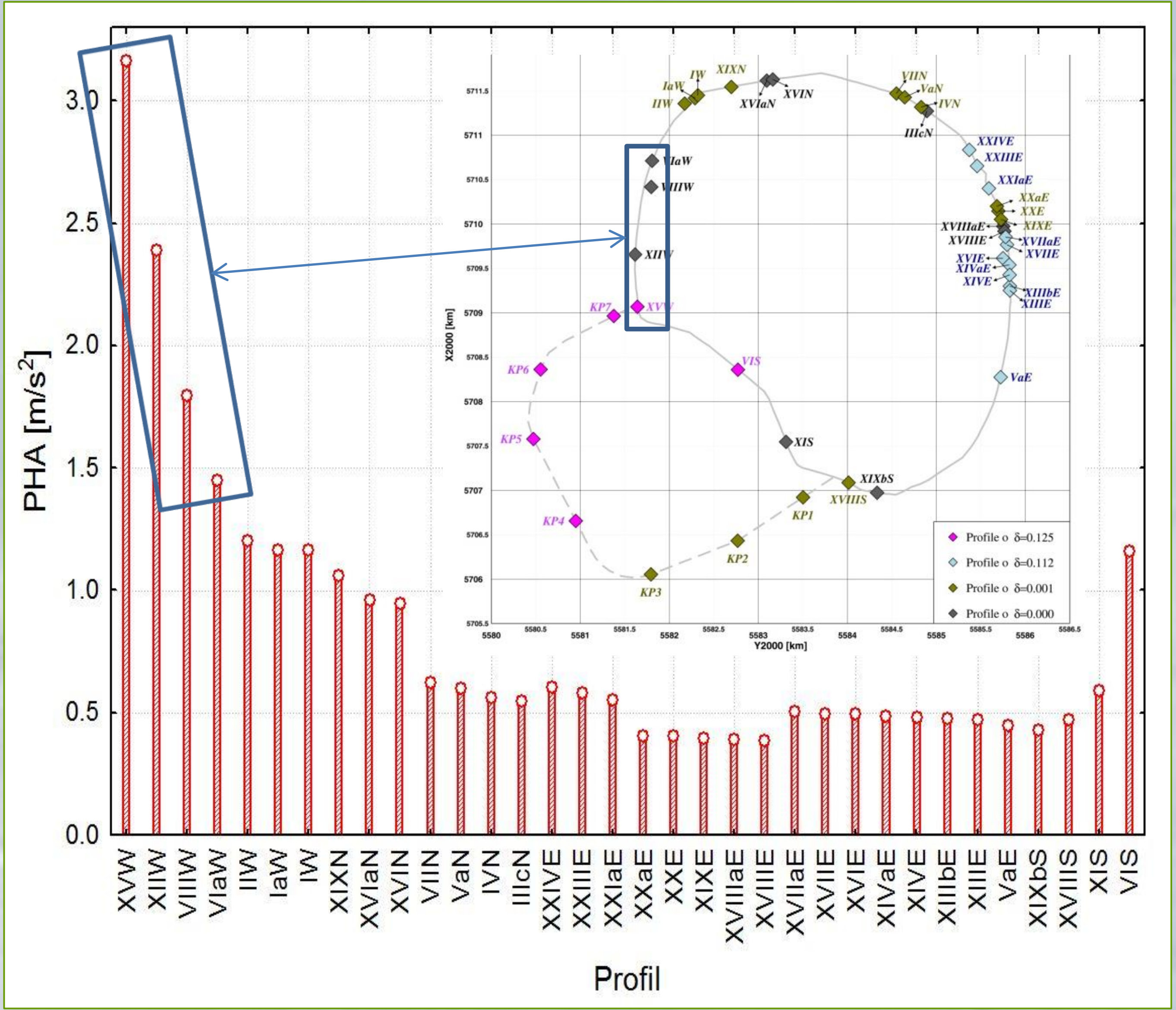
Assumptions:

- The limiting value = PGA of exceedance probability 5%.
- The analysis takes into account impacts of mining works planned for the years 2011-2050 within a 5 km wide zone around the protecting pillar of the pond. (84 mining panels).


ZG Polkowice-Sieroszowice
P1a
P1b
P1c
P1d
P1e
P1f
P2a
P2b
P2c
P2d
P3a
P4a
P4b
P4c
P4d
P4e
P4f
P5
P6a
P6b
P6c
P7a
P8a
P8b
P8c
P8d
P9a
P9b
P9c
P9d
P9_2
P10
P11
P13a
P13b
P13c
P14
P15a
P15b
P16
P17
P18
P18_2
P19
P19_2
P20a
P20b
P21
P22a
P22b
P23
P24
P25
P26
P26_2
P27

Limiting PHA predicted for 2011-2050. Exceedance probability = 0.05

PROFIL	X 2000	Y 2000	PHA [m/s²]
XVW	5709066	5581643	3.17
XIIW	5709658	5581614	2.39
VIIIW	5710416	5581643	1.79
VIaW	5710712	5581808	1.45
IIW	5711356	5582173	1.20
IaW	5711418	5582290	1.17
IW	5711452	5582322	1.16
XIXN	5711545	5582697	1.06
XVIaN	5711617	5583095	0.96
XVIN	5711627	5583162	0.94
VIIN	5711469	5584553	0.62
VaN	5711428	5584645	0.60
IVN	5711316	5584830	0.56
IIIcN	5711272	5584895	0.55
XXIVE	5710834	5585370	0.60
XXIIIE	5710655	5585460	0.58
XXIaE	5710400	5585590	0.55
XXaE	5710200	5585680	0.41
XXE	5710145	5585698	0.40
XIXE	5710053	5585728	0.40
XVIIIaE	5709973	5585754	0.39
XVIIIE	5709919	5585766	0.39
XVIIaE	5709854	5585779	0.50
XVIIE	5709766	5585796	0.50
XVIE	5709614	5585748	0.49
XIVaE	5709540	5585820	0.49
XIVE	5709426	5585823	0.48
XIIIbE	5709301	5585826	0.47
XIIIE	5709253	5585828	0.47
VaE	5708275	5585722	0.45
XIXbS	5706974	5584335	0.43
XVIIIS	5707088	5584015	0.47
XIS	5707545	5583312	0.59
VIS	5708360	5582770	1.16

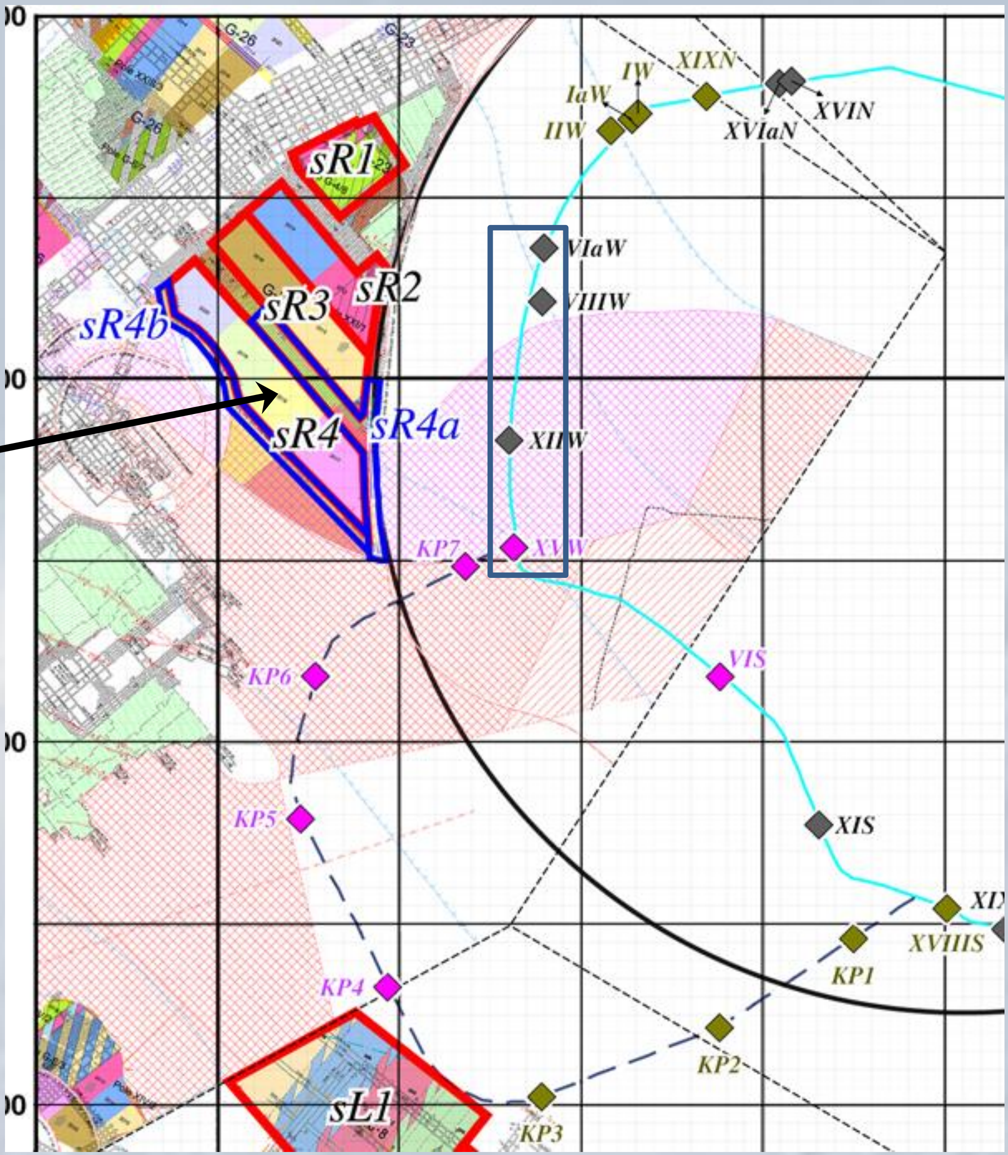


Recomendations For The Company Management

In order to decrease seismic hazard to an acceptable level:

1. Exploitation in panels described as sR4 zones should be suspended

2. Exploitation within zones sR1-sR3 should be directed from the border of protecting pillar outwards (towards NW)



References

Central Mining Institute, Poland (2014) Personal communication.

Durrheim, R.J. (2010) Mitigating the risk of rockbursts in the deep hard rock mines of South Africa: 100 years of research. In: Extracting the Science: a century of mining research, J. Brune (editor), Society for Mining, Metallurgy, and Exploration, Inc., pp. 156-171.

Hasegawa H.S., Wettmiller R.J., Gendzwill P.J. (1989) Induced seismicity in mines in Canada - an overview. Pure Appl Geophys 129, 423-453

Johnston J.C., Einstein H.H. (1990) A survey of mining associated rockbursts. In: Proc. 2nd Int. Symp. on Rockburst and Seismicity in Mines, Minneapolis, USA, A.A Balkema, Rotterdam, pp. 121-128

Kijko A., Lasocki S., Graham G. (2001) Nonparametric seismic hazard analysis in mines. Pure Appl. Geophys. 158, 1655-1676

Lasocki S. (2001) Quantitative evidences of complexity of magnitude distribution in mining-induced seismicity: Implications for hazard evaluation. Rockbursts and Seismicity in Mine: Dynamic rock mass response to mining (van Aswegen, G., Durrheim, R.J., Ortlepp, W.D. eds.) SAIMM S 27, Johannesburg, 543-550.

Lasocki, S. (2008) Some unique statistical properties of the seismic process in mines, Proc. 1st Southern Hemisphere International Rock Mechanics Symposium SHIRMS 2008, Perth, 16-19 September 2008, (Potvin, Y., Carter, J., Dyskin, A., Jeffrey, R., eds.), Australian Centre for Geomechanics, pp. 667-678

Lasocki S., Orlecka-Sikora B. (2008) Seismic hazard assessment under complex source size distribution of mining-induced seismicity. Tectonophysics 456, 28-37, doi: 10.1016/j.tecto.2006.08.013

Lasocki S., et al. (2011) Updated prediction of the influence of seismicity in mines of KGHM "Polska Miedź" S.A. on the Żelazny Most repository for the period of mining activities. Report. KGHM Polska Miedź S.A., Hydrotechnical Division, Rudna.

Lasocki S., et al. (2012) Detailed prediction of impacts of tremors and surface deformations induced by mining, on OUOW „Żelazny Most" with an account for OUOW extension and program of copper ore excavation till 2042. Report. KGHM Polska Miedź S.A., Hydrotechnical Division, Rudna.

Lizurek G., Rudziński Ł., Plesiewicz B., (2015) Mining induced seismic event on an inactive fault, Acta Geophysica 63, 176-200, DOI: 10.2478/s11600-014-0249-y

Orlecka-Sikora B., Lasocki S., Lizurek G., Rudziński Ł. (2012) Response of seismic activity in mines to the stress changes due to mining induced strong seismic events, International Journal of Rock Mechanics and Mining Sciences, 53, 151-158, DOI: 10.1016/j.ijrmms.2012.05.010

Ortlepp, W.D. (1997) Rock Fracture and Rockbursts. South African Institute of Mining and Metallurgy, Johannesburg.

Rudziński Ł., Cesca S., Lizurek G. (2015) Complex rupture process of the March 19, 2013, Rudna mine (Poland) induced seismic event and collapse in the light of local and regional moment tensor inversion, Seismological Research Letters (submitted)

Urban P., Lasocki S., Blascheck P., do Nascimento A.F., Nguyen Van Giang, Kwiatek, G. (2015) Violations of Gutenberg-Richter relation in anthropogenic seismicity. J Geophys. Res (submitted)

Węglarczyk S., Lasocki S. (2009) Studies of short and long memory in mining-induced seismic processes. Acta Geophysica 57, 696-715, doi: 10.2478/s11600-009-0021-x

Thank you for attention

INSTITUTE OF GEOPHYSICS
POLISH ACADEMY OF SCIENCES
Ksiecia Janusza 64, 01-452 Warsaw, Poland, www.igf.edu.pl e-mail:office@igf.edu.pl
SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR, LITHOSPHERE RESEARCH, GEOMAGNETISM, PHYSICS OF ATMOSHERE
HYDROLOGY AND HYDRODYNAMICS, POLAR RESEARCH, CENTRAL GEOPHYSICAL OBSERVATORY AT BELSK