On a possibility of acquiring <u>strong motion</u> rotation from rockburst induced seismic effects

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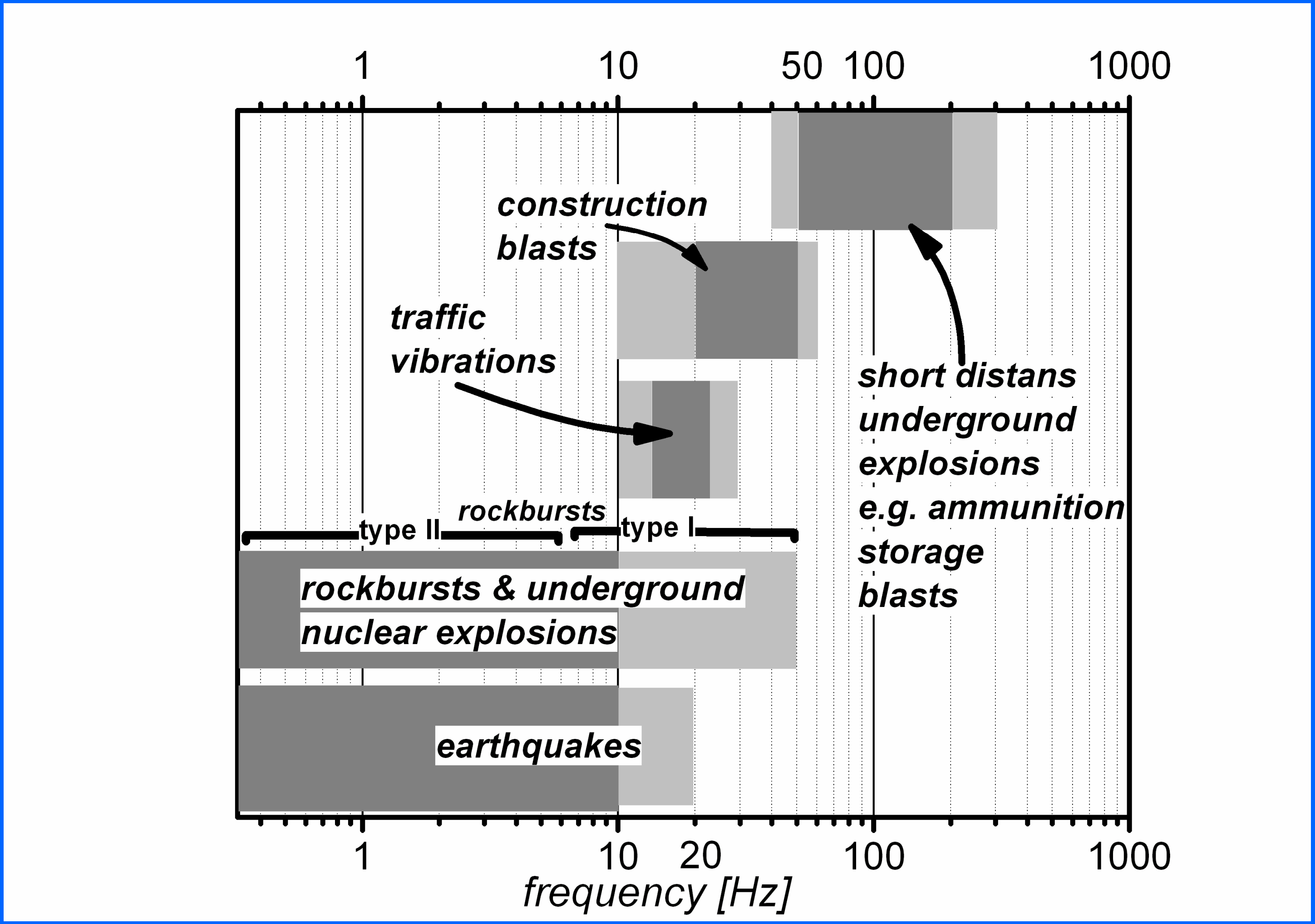
Semi-natural & artificial seismic excitations

- rockkbursts (from deep mining or reservoir seismicity)
- nuclear underground explosions
- distant conventional explosions (e.g. from quarries)
- close (to structure) explosions of underground ammunition storages
- pile hammering
- traffic ground motion etc.

Dominating frequency bands in various seismic effects



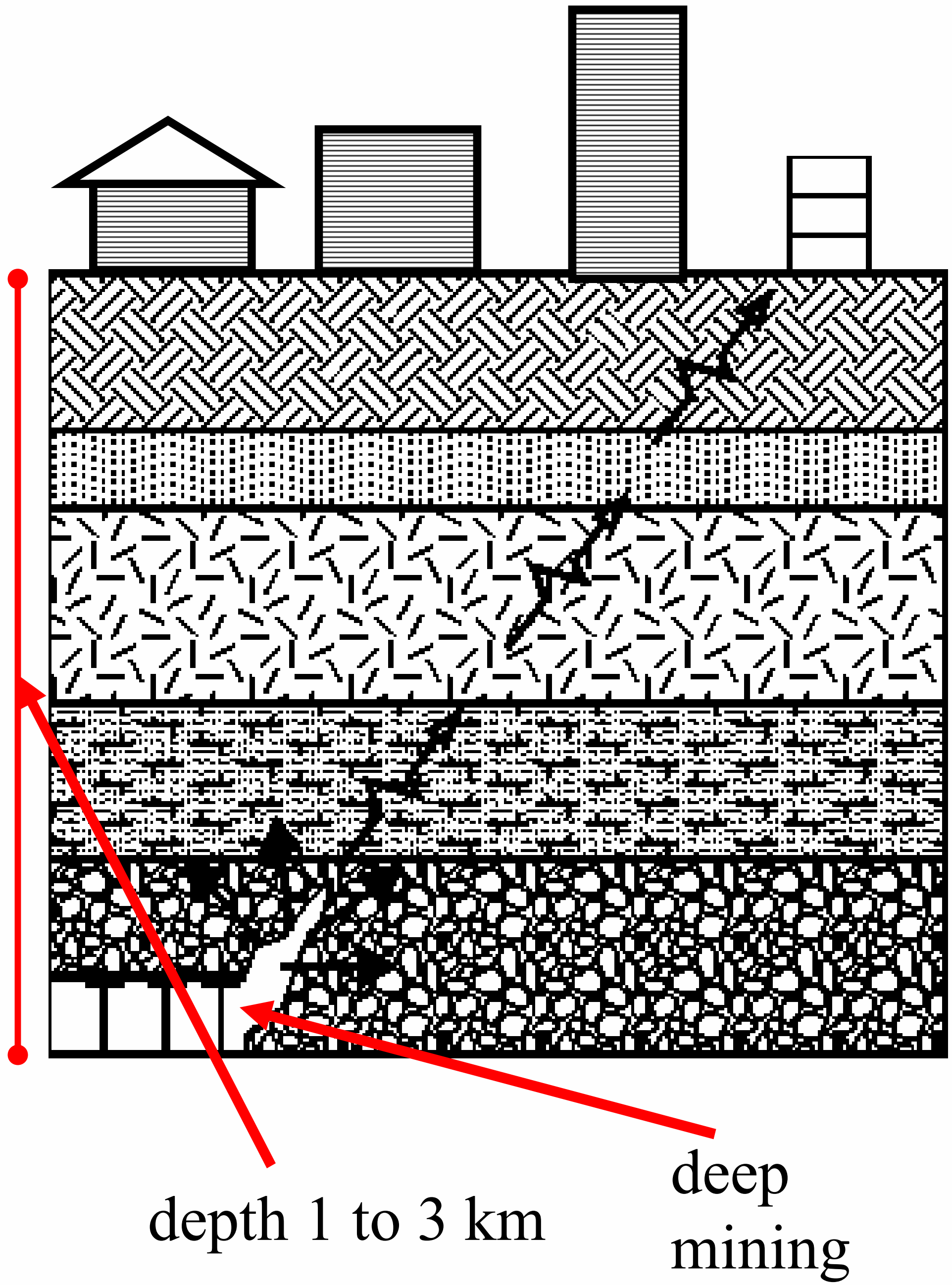
Rockburst induced ground effects

- chain reaction of <u>pillar bursts</u>
- <u>slipage</u> on preexisting tectonic fault
- <u>earthquake triggered</u> on a nearby fault
- etc...

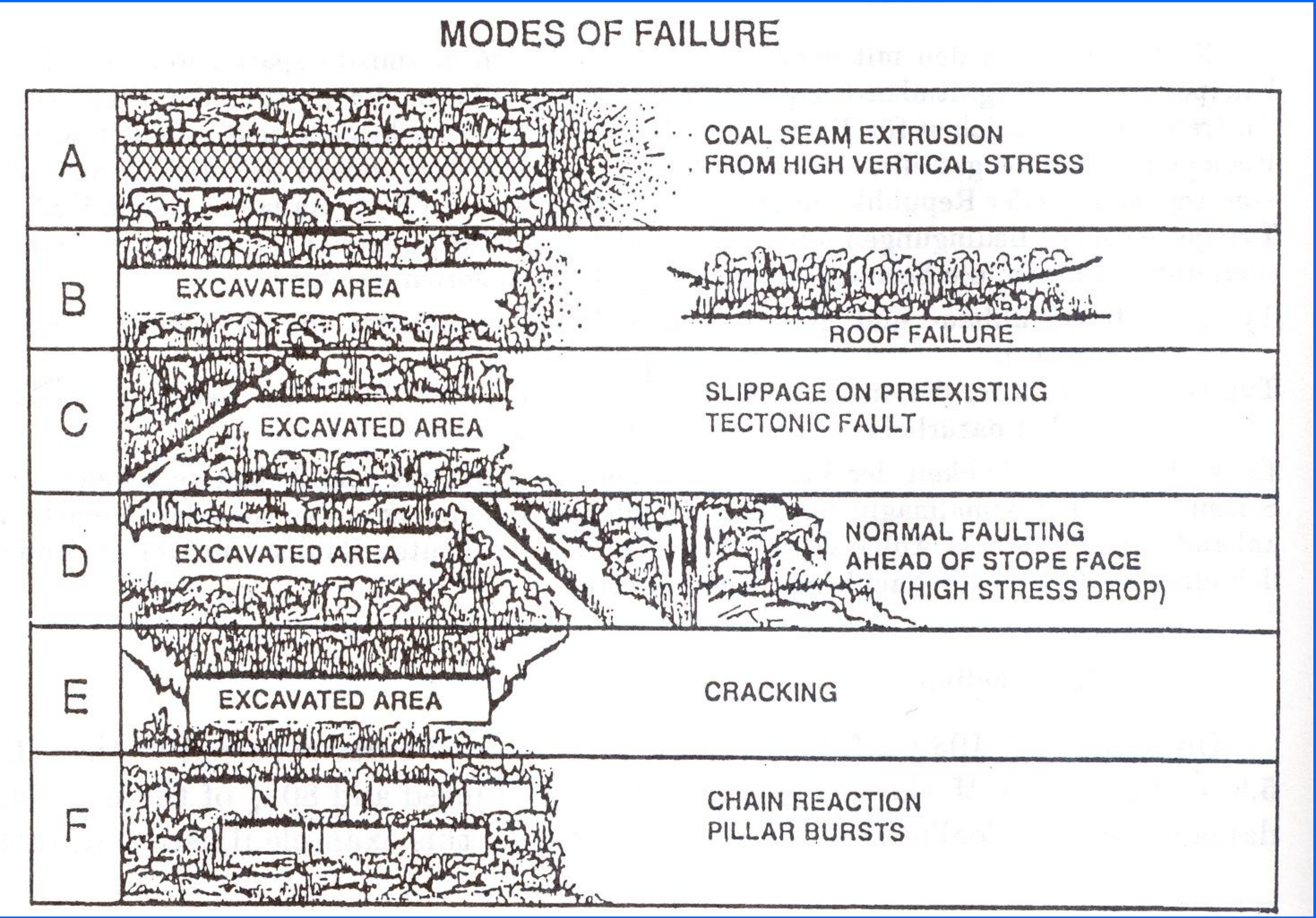
See e.g. Johnston, Rockbursts from a global perspective, in: *Induced Seismicity*, edited by Knoll, Balkema 1992

Some of them are <u>triggered directly</u> by underground explosions, but <u>the strongest occur randomly</u>

may exceed $M_L=5$
with hipocentral distance 1-3km
energy released may reach 10^10J



Modes of ground failure during rockbursts



How strong and how intensive can be a rockburst?

Polkowice, Poland February 20th 2002
Energy $E=1.5\times10^{9}$ J, Richtera magnitud $M_L \approx 4.0$, MSK64=VI+

Polkowice May 21st 2006
Energy $E=1.9\times10^9$ J, Richtera Magnitud $M_L \approx 4.3$ MSK64=VI+

Kalgoorlie, Western Australia 21 IV 2010 –Richtera Magnitud M_L =5.0

The Golden Eagle Hotel lies damaged after the earthquake in Kalgoorlie-Boulder, WA. Picture : Andrew Whitton
Source: The Australian

Stilfontain, South Africa, March 9th 2005
Richter Magnitud M_L =5.3 MSK64=VIII

Couertesy of Dr Artur Cichowicz

From the Council for Geoscience South Africa)

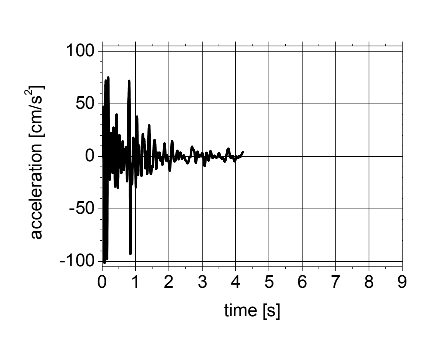
Seismological clasification of rockbursts (Johnstone 1991)
a) type I – frequent, less intensive, similar to strong blasts,
b) type II – rare, more intensive (similar to shallow earthquakes, magnitude similar to strong, underground nuclear explosions)

Table 1. Characteristics of Rockbursts

type I	type II
Generally, rate is a function of mining activity	Not enough data to determine relationship with mining rates.
Location is generally within 100 m of mining face or on some preexisting zone of weakness or geological discontinuity near the mine.	Location is on some preexisting fault surface that may be up to 3 km from the mine.
Intact rock can be broken in the rupture when mining induced stresses exceed the shear strength of the material. Orientations of rupture planes can vary.	All occur in preexisting, possibly prestressed tectonic faults. Mining may simply "trigger" these events on faults of preferred orientations.
Often high stress drops observed.	Stress drops more similar to natural earthquakes.
Low to medium magnitudes.	Potential for high magnitudes.

Clasification of of rockbursts based on surface ground motion records

after ZEMBATY Z., Rockburst induced ground motion - a comparative study, *Soil Dynamics & Earthquake Engineering*, vol.24, no.1, January 2004, pp. 11-23.



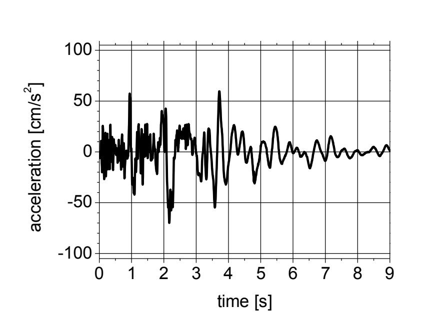
1. **Type 1 (similar to blast effects)**

   Quite frequent (return period 1-3 months), short duration 1-2s, Rather high horizontal peak accelerations PGA=200-300cm/s^2 low velocities PGV<2cm/s), very low displacements PGD=1-2mm

   almost no structural damages

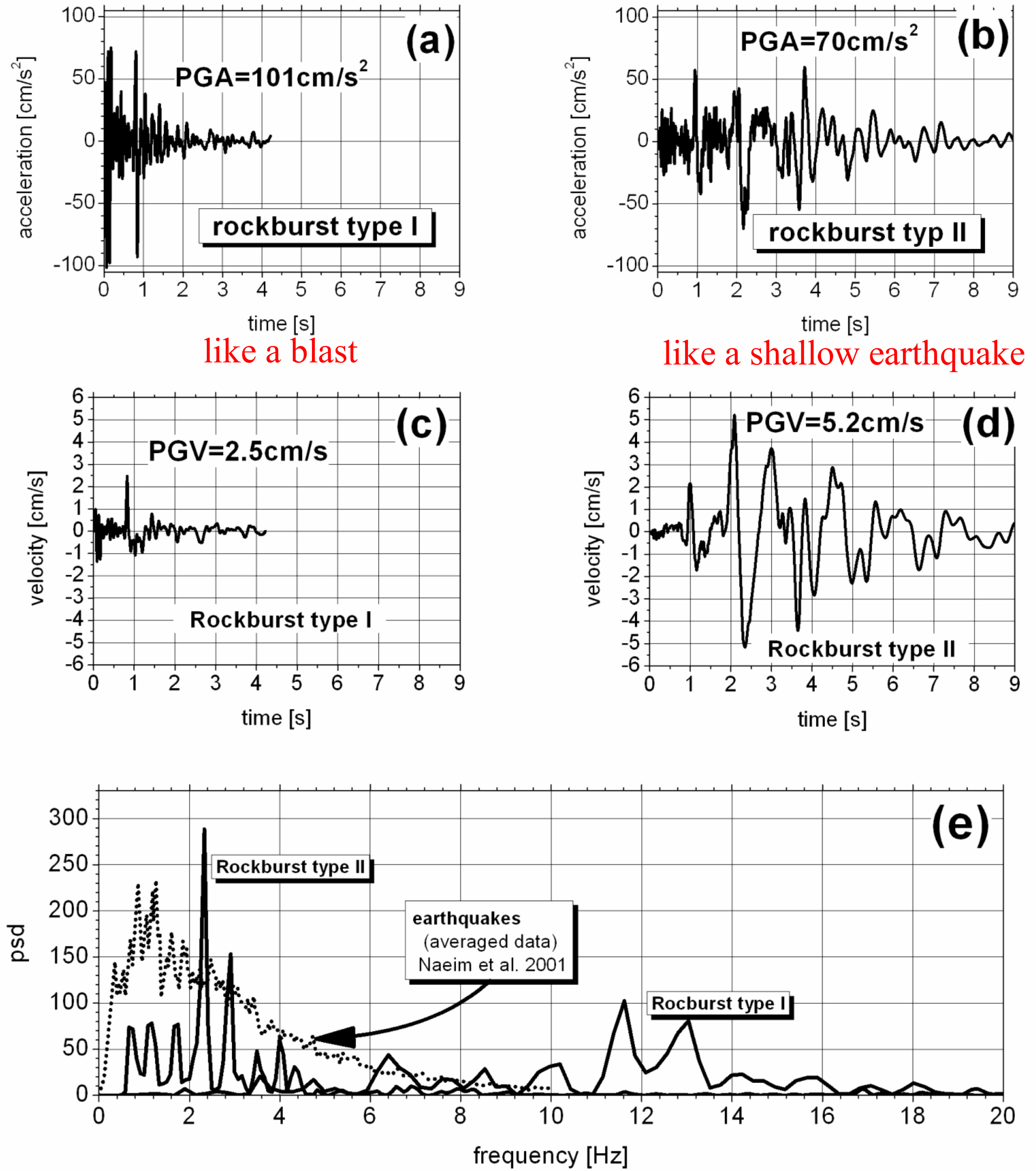
2. **Type 2 (similar to shallow earthquakes)**

   Not too frequent (return period 1-2 years), longer duration 4-5s,
   Moderate PGA= 50-150 cm/s^2
   Higher peak ground velocites PGV=10-20cm/s
   Higher peak ground displacements PGD=1cm

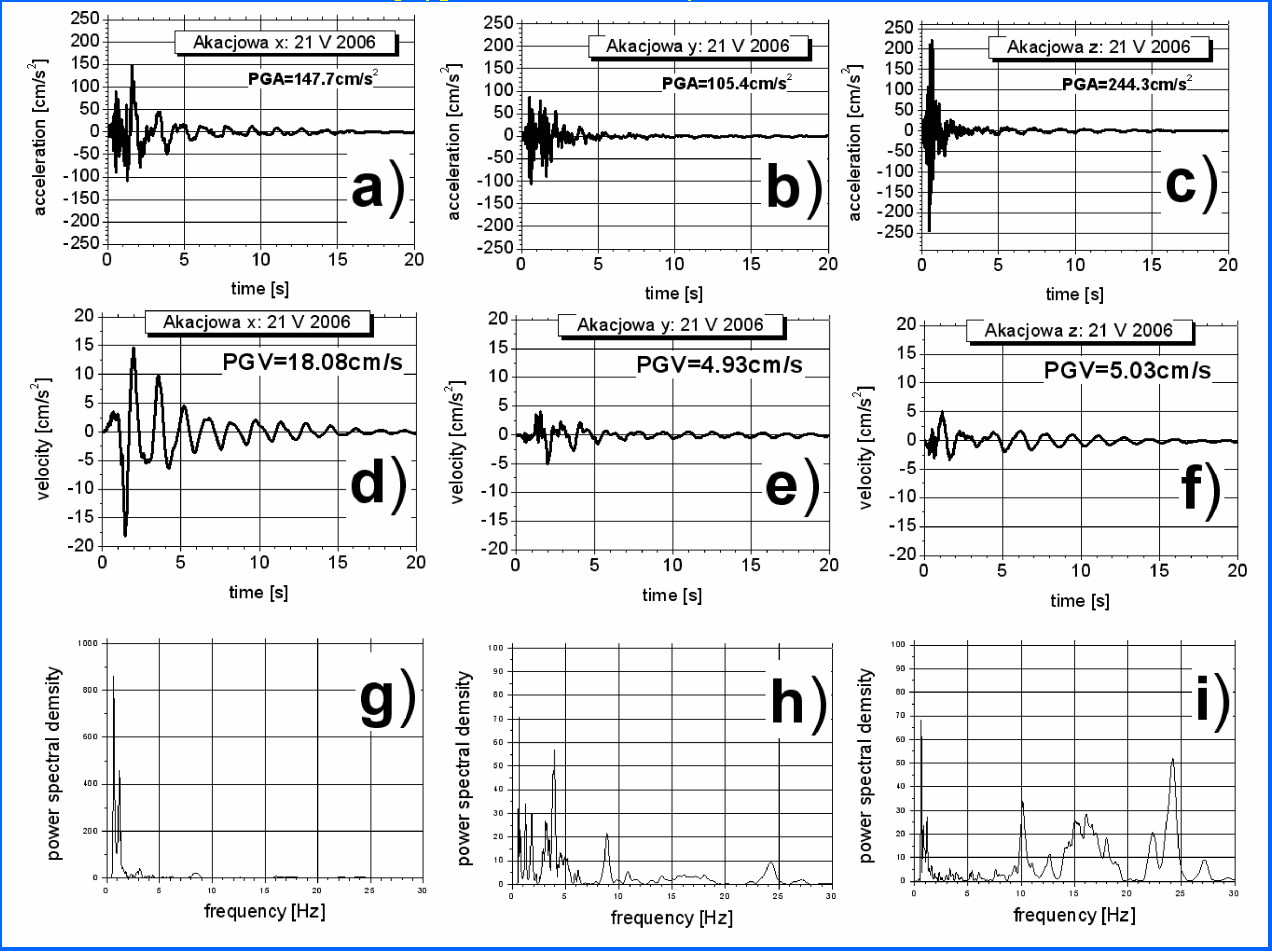


Peak Ground Velocities can serve as measures of rockburst surface intensity for both types of rockbursts while accelerations are often misleading

Comparison of rockbursts type I and II



Record of the strong type II rockburst May 21st 2006, Polkowice, Poland



Conclusion:

1. Surface mine effects are monitored and forecasted

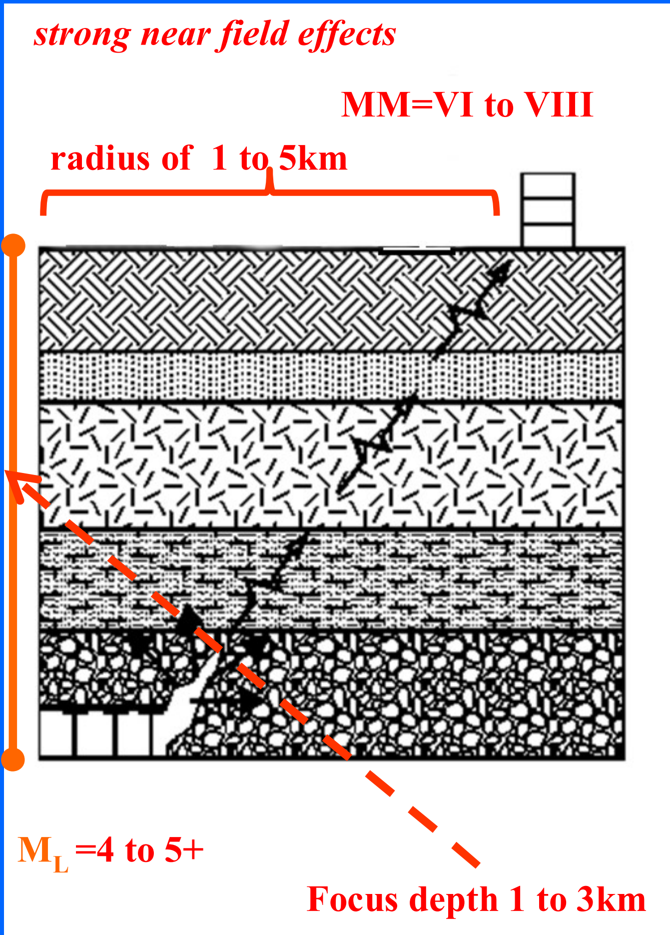
2. With the return period of 1-2 years one can expectrockbursts with high intensities

   MM=VI (in LGOM basin Poland)

   MM=VII to VIII in South Africa

3. One can easily record **strong** (!) **rotations** of MM VI to VII using just well located 3-4 instruments in the areas of radii 5-10km during 2-3 years

4. Strong rockburst areas are good test fields to acquire strong rtations



List of rockbursts:

Table 2. Mine or Mining District Characteristics

Mine	Country	Ore	Geology	Depth of mine	Mining operation area	Period of coverage
Esterhazy Cory	Canada Saskatchewan	potash	soft, most competent layer composed of carbonate	7100 m	continuous (no blasting)	mostly Canadian regional network since 1960
Springhill	East Canada	coal	not available	less than 1 km	R & P above 2000 ft longwall below	no information
Quirke	Elliot Lake, Canada	uranium	dipping, strong brittle quartz, high horizontal stress σ_h:σ_v = 2.1	500 m	1100 × 600 m room & pillar	Sep 84 to April 85
INCO Metal	Sudbury, Ontario, Canada	nickel	low grade disseminated norite		3 mines	instrumented in 1940's
Kirkland	Southern Ontario, Canada		hard rock			no information
General	China	coal	not available	200 - 700 m	32 coal mines in districts	sinc 1949
Chengzi	China	coal	not available		coal pillar recovery	no information
Horonai	Japan	coal	not available	1000 m	mostly longwall	10 years
Ruhr area	Germany	coal	not available	average 700 m	longwall	17 geophone network for 4 months
GDR	Germany	potash	not available			not available
Lubin Copper Basin	Poland	copper		600-1000 m		1975-1983

Table 2. (continued)

Mine	Magnitude frequency relationship	Rate of events	Maximum size of events	Precursory phenomena	Source	Reference
Esterhazy Cory			2.3 to 3.1 magnitude MMI up to V	prior to 1970, no seismicity		Hasegawa 87, Herget & Macintosh 87, Gendzwill 84
Springhill				monitoring rise in level of 'foreshocks'		Hasegawa 87
Quirke		150 pillar burst type. Previously in 1982, a large series of events	assume pillar burst – Type I			Udd & Hedley 87
INCO Metal				prior to burst, frequency content of activity increased		Pakainis 84, Cummins & Given 73
Kirkland						Hasegawa 87
General		2000 per 50 years	2.5 to 3.8, assume Type I	using acoustic monitorins		Mei & Lu 87
Chengzi			3.4 intensity VII			Hua 87
Horonai				investigate use of strain energy index to predict potential		Ishijima, Fuji & Sato 87
Ruhr area		10 000 events per 4 months	all Type I	rate increased with approach of longwall		Will 80
GDR			5.4 m_b (Type II)			Stiller et al.
Lubin Copper Basin	many relationships derived (see text)	at least 361 events in 10 years	4.0 to 5.0, larger magnitudes possible, Type II	changes in b-value	radii from 70 to 502 mm, found M_L to be a direct measurement of seismic moment	Gibowicz 85

List of rockbursts continued :

Table 2. (continued)

Mine	Country	Ore	Geology	Depth of mine	Mining operation area	Period of coverage
Upper Silesia Coal Basin (Karvina)	Poland, Czecho-slovakia	coal	2 formations: 1. large number of coal seams, reduced thickness, fine grained sed-iments. 2. Coarse grained continental sediments (high strength conglome-rates)	600-1000 m	very high rate of production	since 1982
Witwaters-rand	South Africa	gold	hard quart zite	3 km		various arrays
Klerksdorp District	South Africa	Gold	extensional, normal faulted hard rock, ar-gillaceous to siliccous quartzites with subor-dinate conglomerates & shale horizons	average 2.3 km	4 large mines aver-age area = 200 km^2	digital network in-stalled 1986
Carleton-ville	South Africa	gold	unfaulted, intact rock, hard rock	2-4 km		digital network in-stalled 1986
East Rand Proprietary Mine	South Africa	gold	high strength rock	2-3 km	300 m longwall & strike pillars	various arrays
Blyvoor-uitzicht	South Africa	gold	quartzites, strength 250 MPa	2-3 km	4 mines longwall	various arrays since 1978
Granges-berg	Sweden	Iron	dipping slab orebody, surrounded by lepite & granite	500 m		1984 network in-stalled after large event, $M_L = 3.2$

Table 2. (continued)

Magnitude frequency relationship	Rate of events	Maximum size of events	Precursory phenomena	Source	Reference
since 1982, 12 rockbursts and 62 'tre-mors' rec-orded	at least one Type II event		events occur-ring on dis-continuities	Konecny et al. 87	
Linear		4-5	arrest of tilt displacement	m_b - M_L similar to nu-clear explosions	Cook 76
	most smaller than 3.0 mag. More than 6000 events from mag. 0.2 to 5.4 in ten years	5.2 (Type II) (source radius 84 m. stress-drop = 23 b)		stress drops similar to earthquakes. Source dimensions larger than Carletonville & ground motion time history more extended	McGarr et al. 87, Gay et al. 84
	May to Oct. 1986, 22 mag > 3.5	4.0 upper limit (0.045 G, 376b)		high stress drops, smaller source dimen-sions, less extended ground motion time histories	McGarr et al. 87
b = 0.6	$M_L \geq 2.0$, expected every 12 days	2.8 (Type I), 3.8 (Type II, rockbursts occur in pillars & ir-regular geometry)			McGarr 82
b = 0.65 to 0.97				source radii from 25-65 m, stress drop 0.5 to 5 MPa for mag. 1.0-2.0, FPS showed strike parallel to face, pure shear	McGarr 82, Spottiswoode 84
in between swarms & af-tershocks. For $1.1 \leq M_L < 3.2$, log N = 3.04-1.08 M_L. b here is larger than for natural crustal earth-quakes (b = 0.85)	1000 events in less than 4 years rec-orded after main shock	$M_L = 3.2$		focal mechanism for large event showed shear failure not cavity collapse	Bath 84

List of rockbursts continued:

Table 2. (continued)

Mine	Country	Ore	Geology	Depth of mine	Mining operation area	Period of coverage	Magnitude frequency relationship	Rate of events	Maximum size of events	Precursory phenomena	Source	Reference
Sunnyside coal mining district	Eastern Utah, USA	coal	4 m thick coal seam, underlain by thick-strong, thick bedded sandstone 24-40 in. thick. Overlain by weak 45 m thick shale & sandstone	events cluster at 1 km ranged from 1 to 3 km depth	room & pillar	microearthquake study undertaken		from 1967 through 1970: 50 000, 20 000, 27 000 and 1500 seismic events per year. 1700 > 1.5 magnitude	range from -1.0 to 2.8 mag unit. The larger magnitude occurred away from immediate mine on pre-existing faults		composite fault plane solution shows thrusting. Corner frequencies from 10 to 14 Hz. Strike of FPS agrees with tectonic stress field	Smith et al. 74, Wong 85
Book Cliffs, E. Wasatch Plateau	Utah, USA	coal	numerous and complex joints and faults			regional network		very high natural induced (Type I) seismicity. Densest clusters of activity where mining exceeds 50 000 tons	M_L 4.0		Type II's occurring on deep faults, FPA agree with horizontal tectonic stressfield studies	Wong 85
Coeur-d'Alene mining district (general)	Northern Idaho, USA	metals	intensely faulted sheared structural knot. Precambrian rockranges from fine-grained argillites & sites to coarse ground quartzites			no information on seismic arrays						Wallace & Morris 86
Star	Northern Idaho, USA	lead, zinc, silver	see 'Coeur-d'Alene', above. Hard brittle rock, high horizontal stress	7900 ft	horizontal timbered cut and fill method. Produce 1000 tons of ore per day. Complicated geometry	24 geophone net work installed 1975					activity associated with quartzite band that traverses center of main vein ore body at sharp angle	Langstaff 80
Central Pennsylvania	USA	coal	not available	600 ft	longwall blasting	geophone array		micro activity strongly proportional to daily mining schedule. Activity remains high for 5 min. after blast	Type I		depth of event within 100 ft of coal seam	Hardy & Mowry 76
Sydney Basin, Bowen Basin	N.S.W., Queensland, Australia	coal	not available	500 m		some monitoring equipment for micro-tremors installed			mostly outbursts are of concern	inconclusive		McKavanaugh & Enever 80, Grezi et al. 84
Staffordshire	Great Britain	coal	mudstone and shale with intervening coal seams & non-continuous lenticular sandstone bodies	1 km	longwall	seismicity network since 1970's	a & b parameters affected by position of advancing face (See text. See 4.11)	Type I only	M_L 3.0-3.5, Type I.I Largest events occur when advancing face under pillars	largest events occurred during smallest a and b values		Wong 85, Kusznir et al. 84