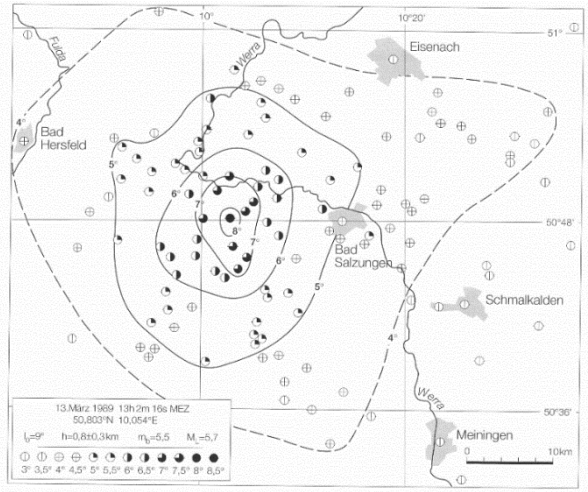
Relationship between magnitude, macroseismic intensity and distance for induced earthquakes in Germany

Diethelm Kaiser



EGU General Assembly, Vienna (Austria), 7–12 April 2019

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

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- Felt or damaging induced earthquakes are of public concern and of legal significance.

- Develop models describing relation between intensity, magnitude and distance (“intensity prediction equations, IPE”) for induced earthquakes in Germany

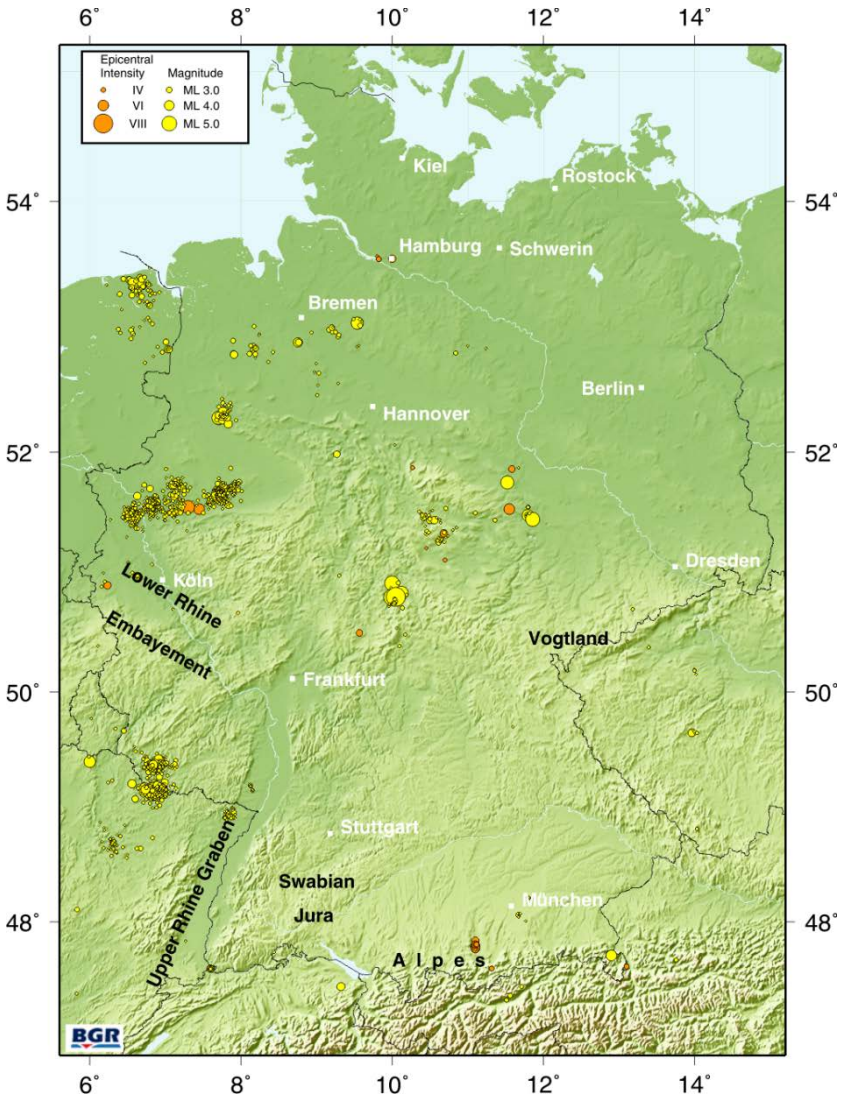
Data

- Earthquake database for Germany GERSEIS
- 5350 induced earthquakes
- 182 induced earthquakes with intensity and magnitude (*ML*) (1940-2015)
- 47 induced earthquakes with mean isoseismal radii and *ML*

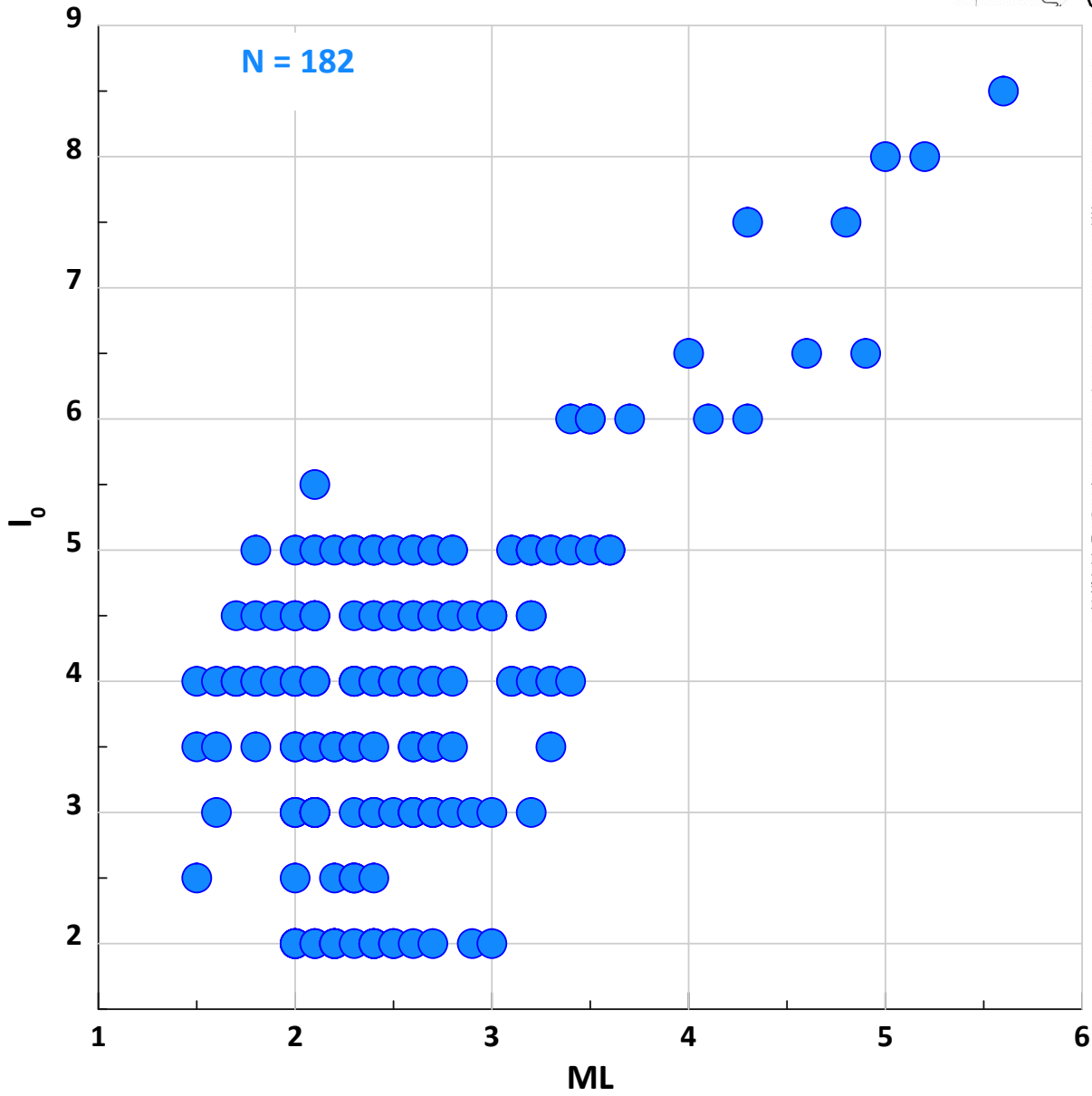
- 17 macroseismic maps of seismic events in mining areas in Germany

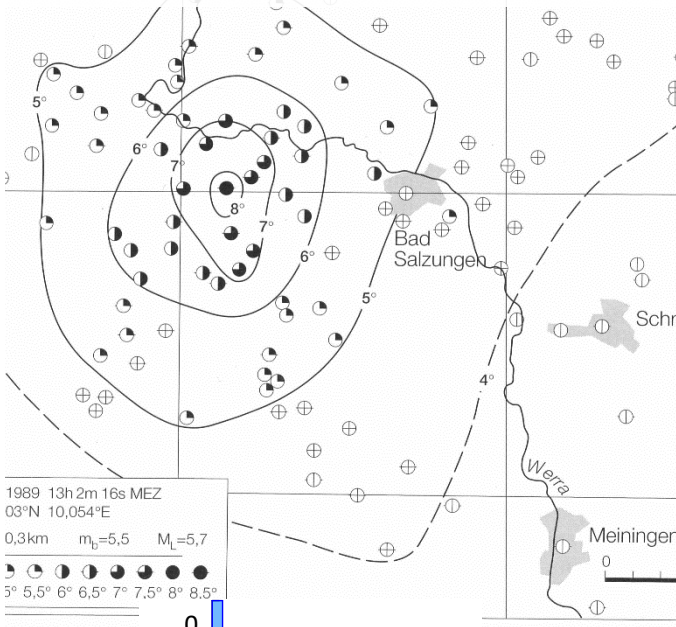
Data

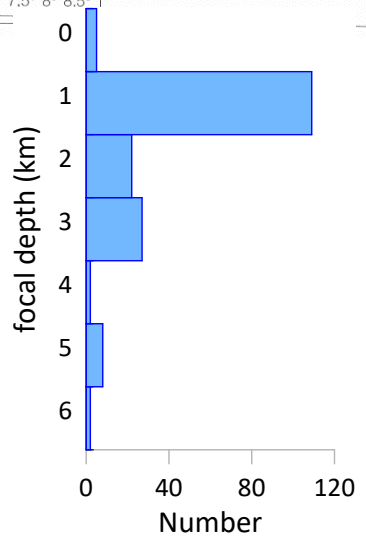
- Mining induced seismic events with moderate to severe building damage (intensity 7 and 8) have so far only occurred in potash and salt mining.
- Slight building damage (intensity 6) has also been caused by seismic events in coal mining.
- Over the past 20 years, the frequency of felt earthquakes has increased in regions with natural gas production and in recent years also in regions of deep geothermal energy production.



Völkershausen 1989, rockburst in potash mining
Leydecker, Grünthal, Ahorner (1998)







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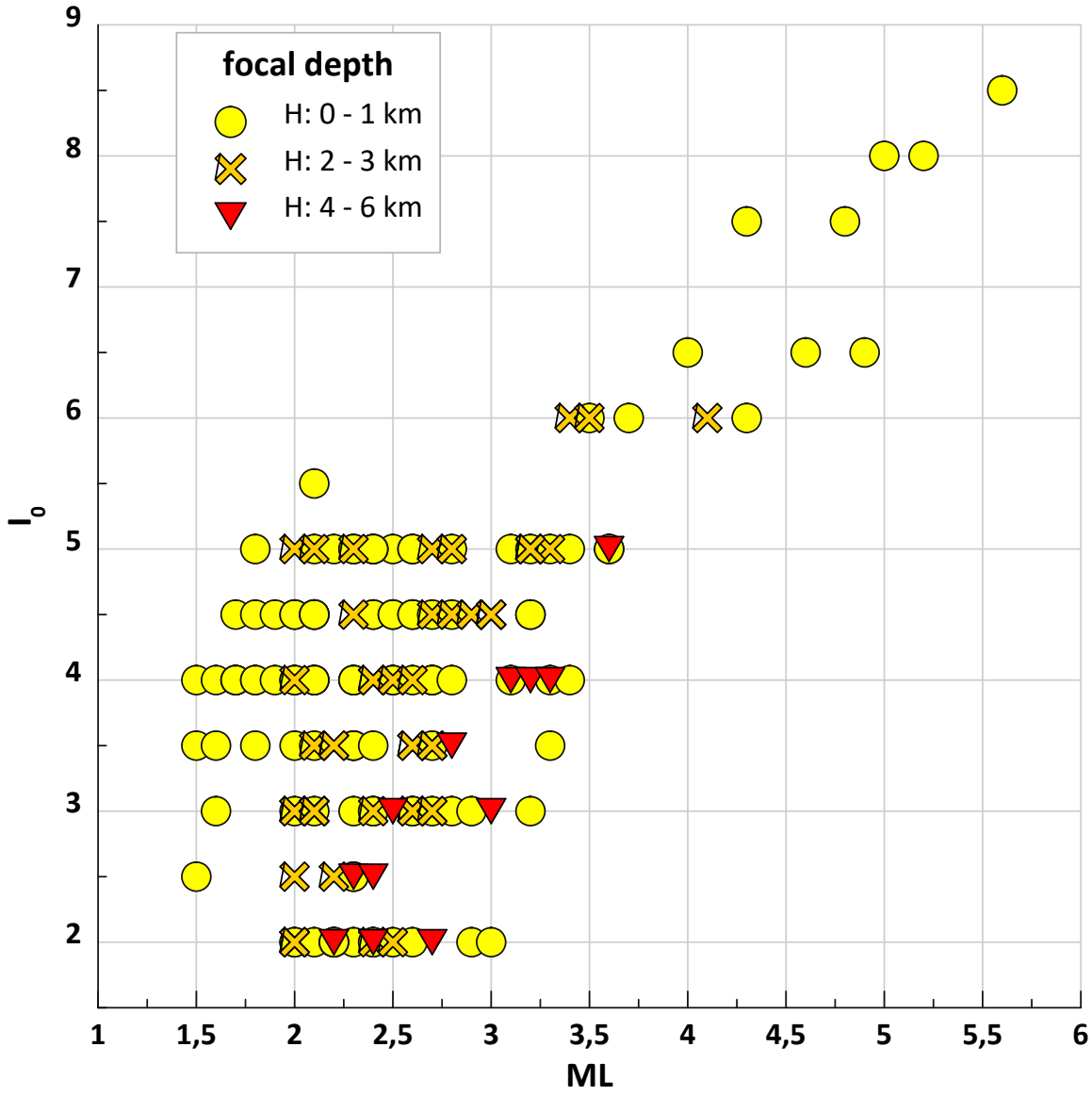

focal depth
H: 0 - 1 km
H: 2 - 3 km
H: 4 - 6 km
I_0
ML
9
8
7
6
5
4
3
2
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6

IPE

$$I = a + b\,M + c\,\log R + d\,R$$

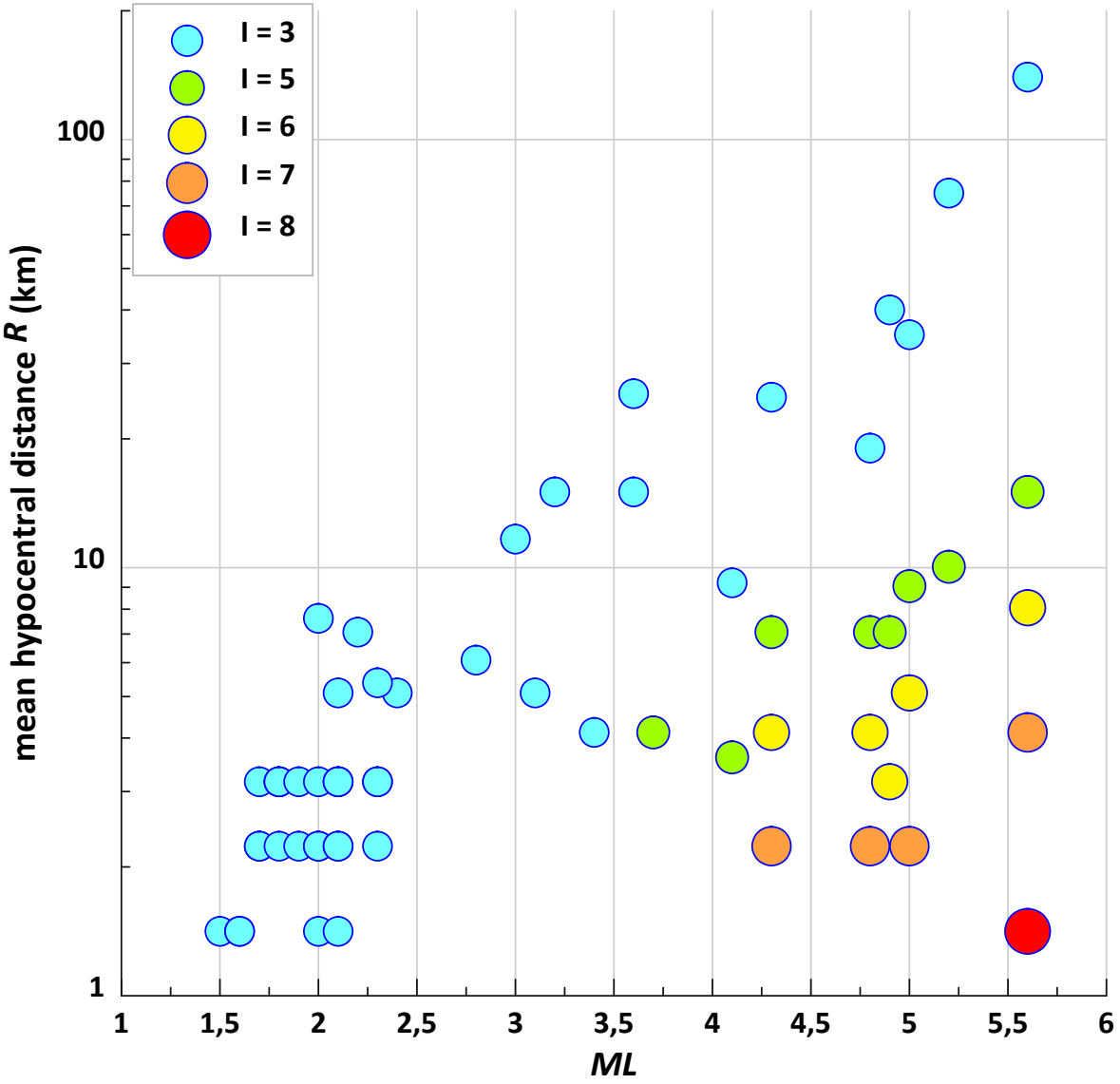
I : intensity
M : magnitude
R : hypocentral distance

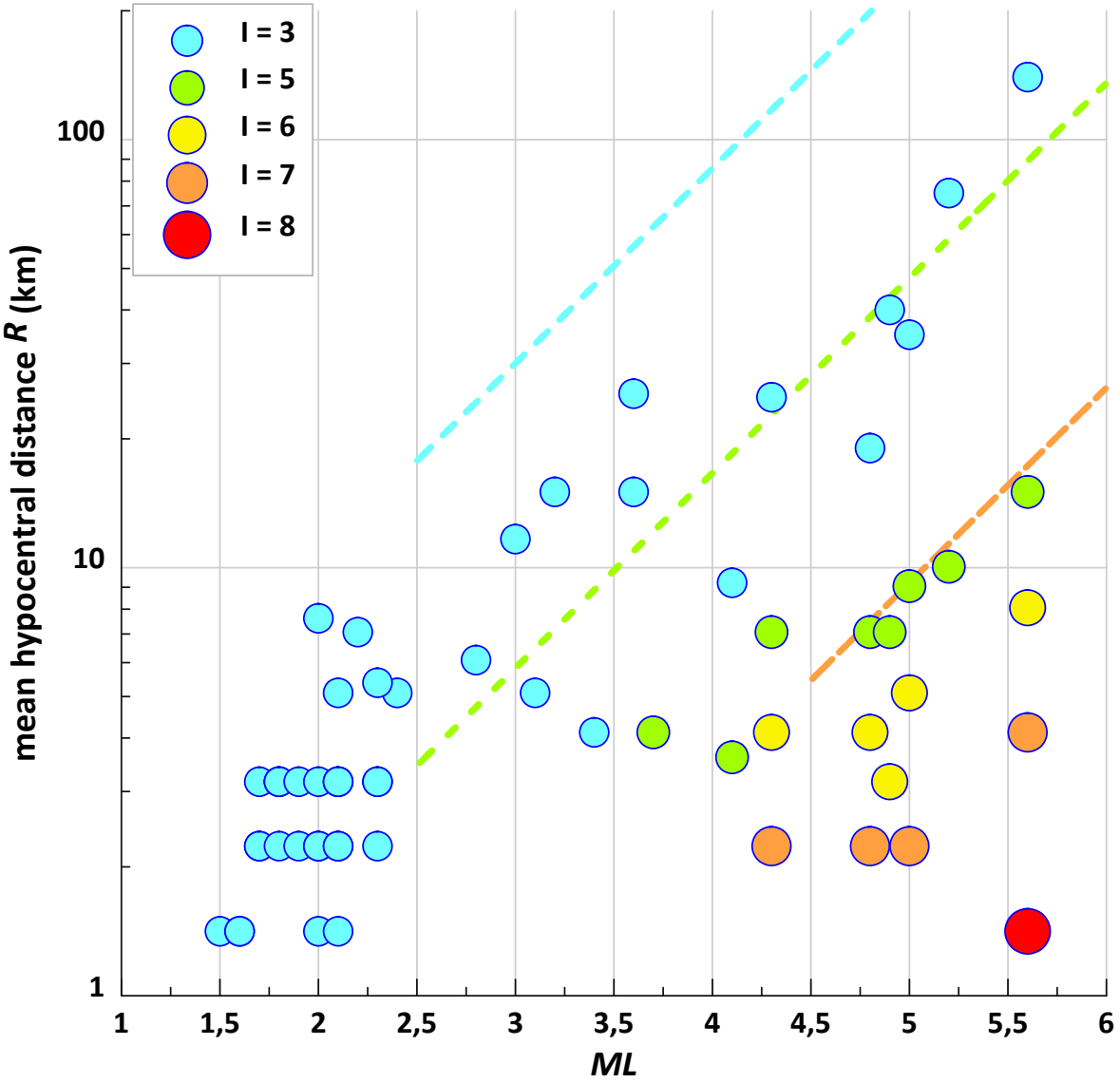
constants
a : scaling
b : energy release
c : geometrical spreading
d : anelastic attenuation

mean isoseismal radius R_{epi} (*I*)

$$R = (R_{epi}^2 + h^2)^{-1/2} \; ; \; h = \text{focal depth}$$

47 induced earthquakes with R_{epi}(I = 3, 5, 6, 7, 8), *h,* and *ML*


I = 3
I = 5
I = 6
I = 7
I = 8
mean hypocentral distance R (km)
100
10
1
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
ML



Musson (2005): $I = 3.31 + 1.28ML - 1.22 \ln R$

R in (km)

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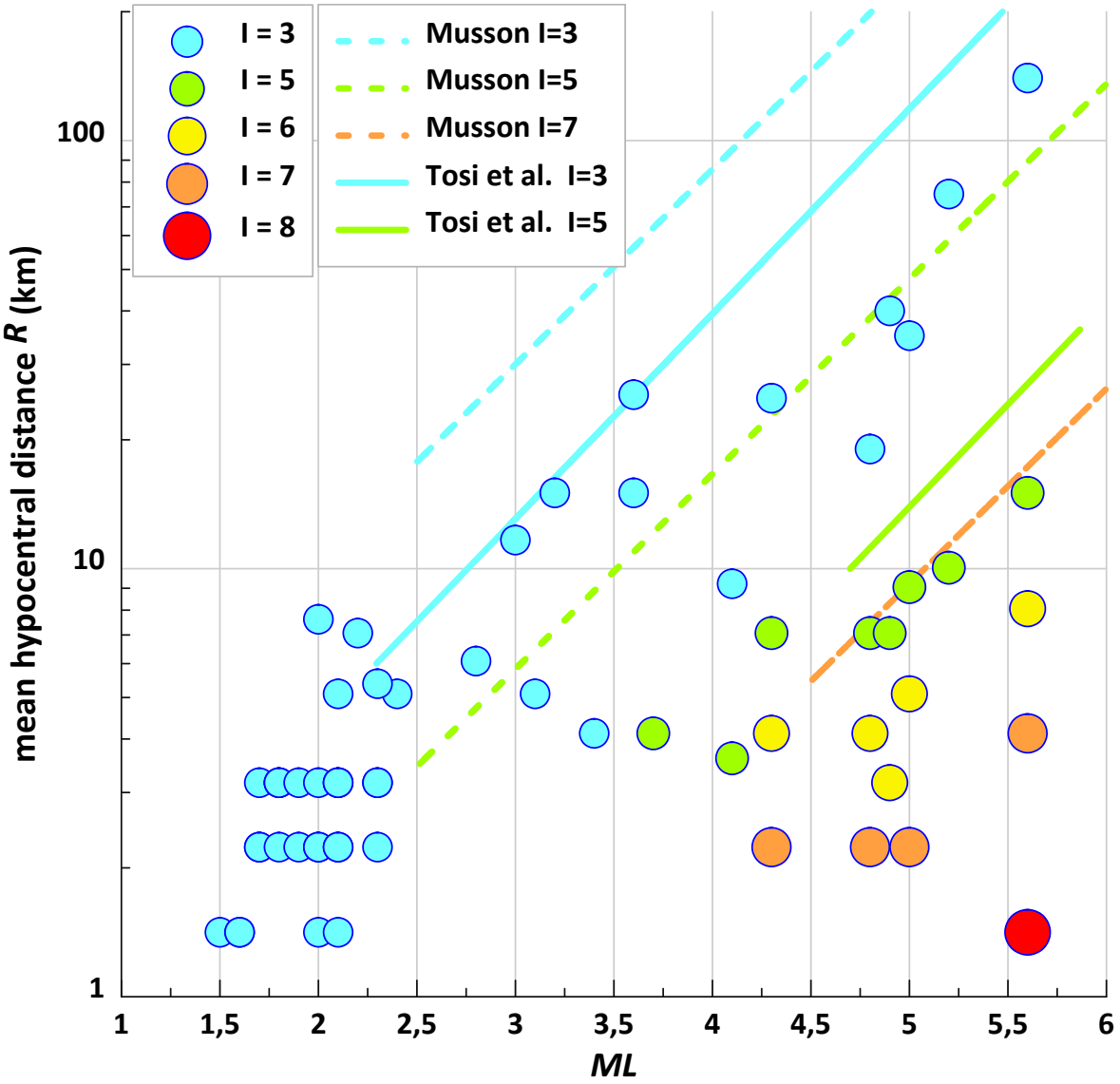

Musson (2005): $I = 3.31 + 1.28ML - 1.22 \ln R$

Tosi et al. (2015): $I = 2.31 + 1.03ML - 2.15 \log R$

R in (km)

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2016: Revision of Federal Mining Act "*Bundesberggesetz*"

- Damages within the "affected area" ("*Einwirkungsbereich*") of an induced seismic event shall be presumed to be caused by the mining operation, and compensation shall be paid by the mining company.

- The "affected area" shall be defined by the mining authority.

- Thresholds to define the "affected area":
  peak ground velocity PGV: 5 mm/s
  macroseismic intensity: 5 EMS

For damaging induced seismic events in the mining regions of Germany:

- Few PGV measurements
- Extensive macroseismic observations

Goal

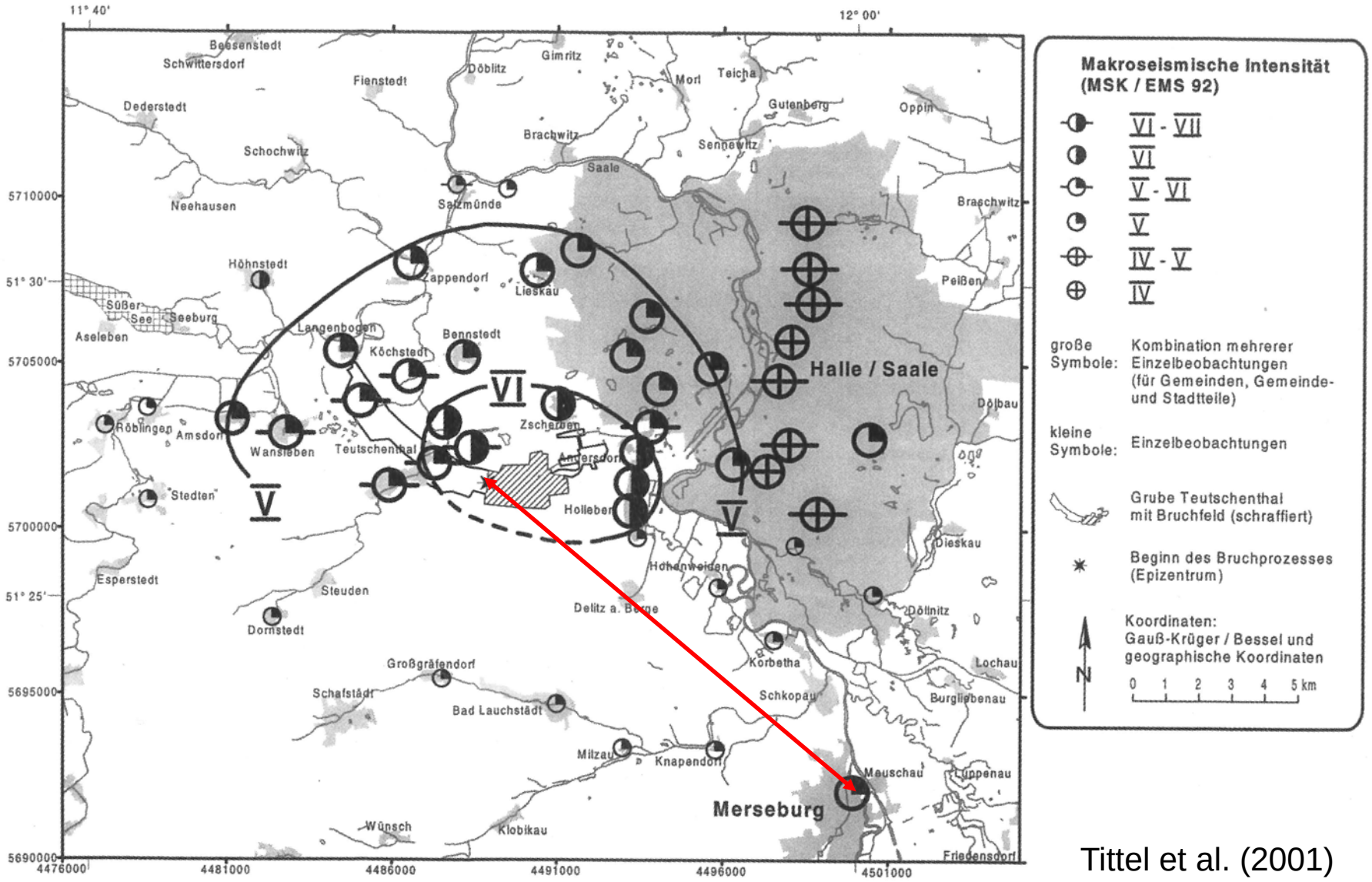
- **Find a conservative and simple relationship to estimate the „affected area“ from *ML*, epicentral coordinates and focal depth**

Data and Method

- **Analyze published macroseismic maps of seismic events in mining areas in Germany (N=17)**
- **Observed maximum hypocentral distances to intensity 5**

Example 1

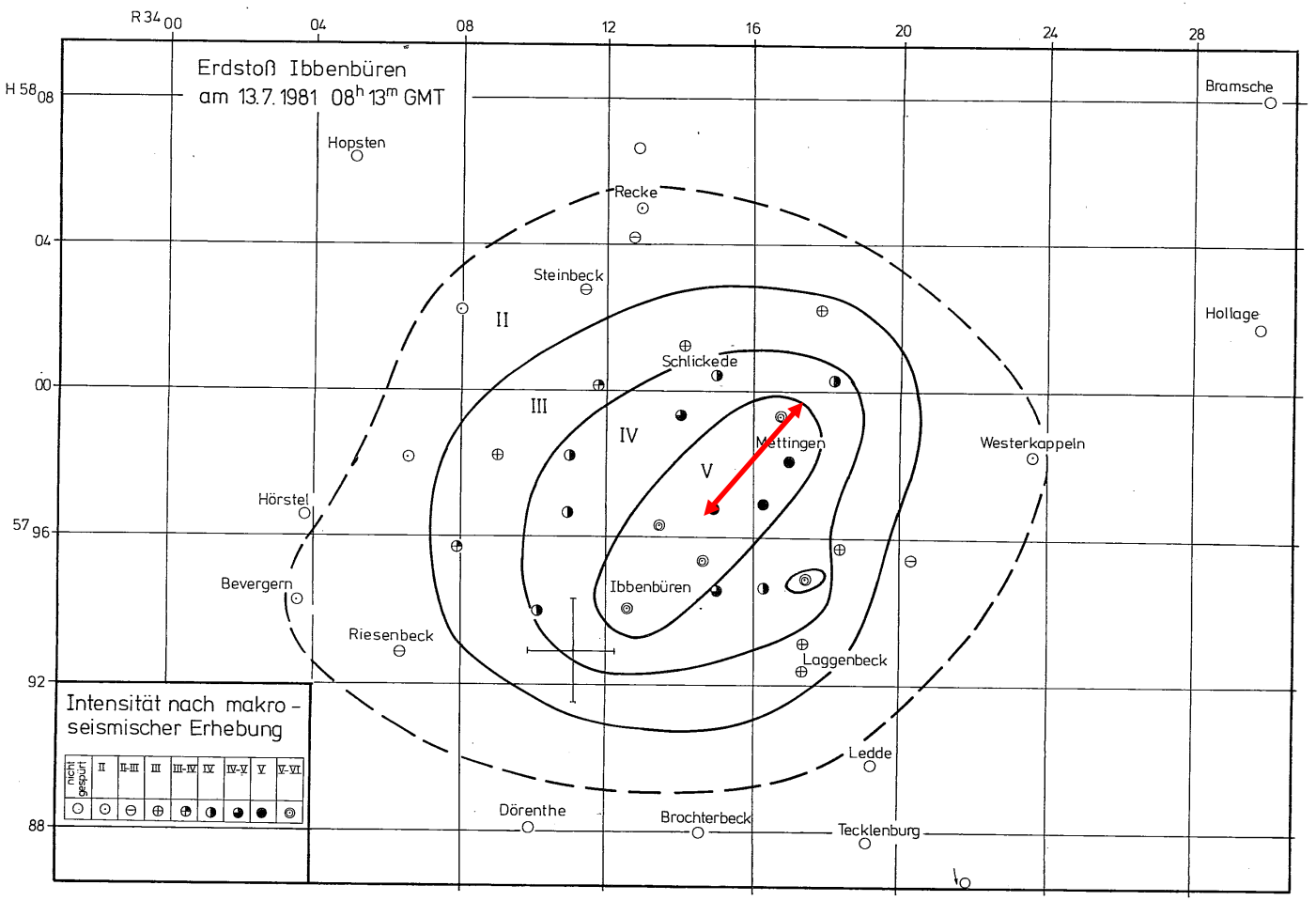
11.09.1996 Teutschenthal, potash mining, *ML* = 4.9



Tittel et al. (2001)

Example 2

13.07.1981 Ibbenbüren, coal mining, *ML* = 4.1



Harjes et al. (1983)

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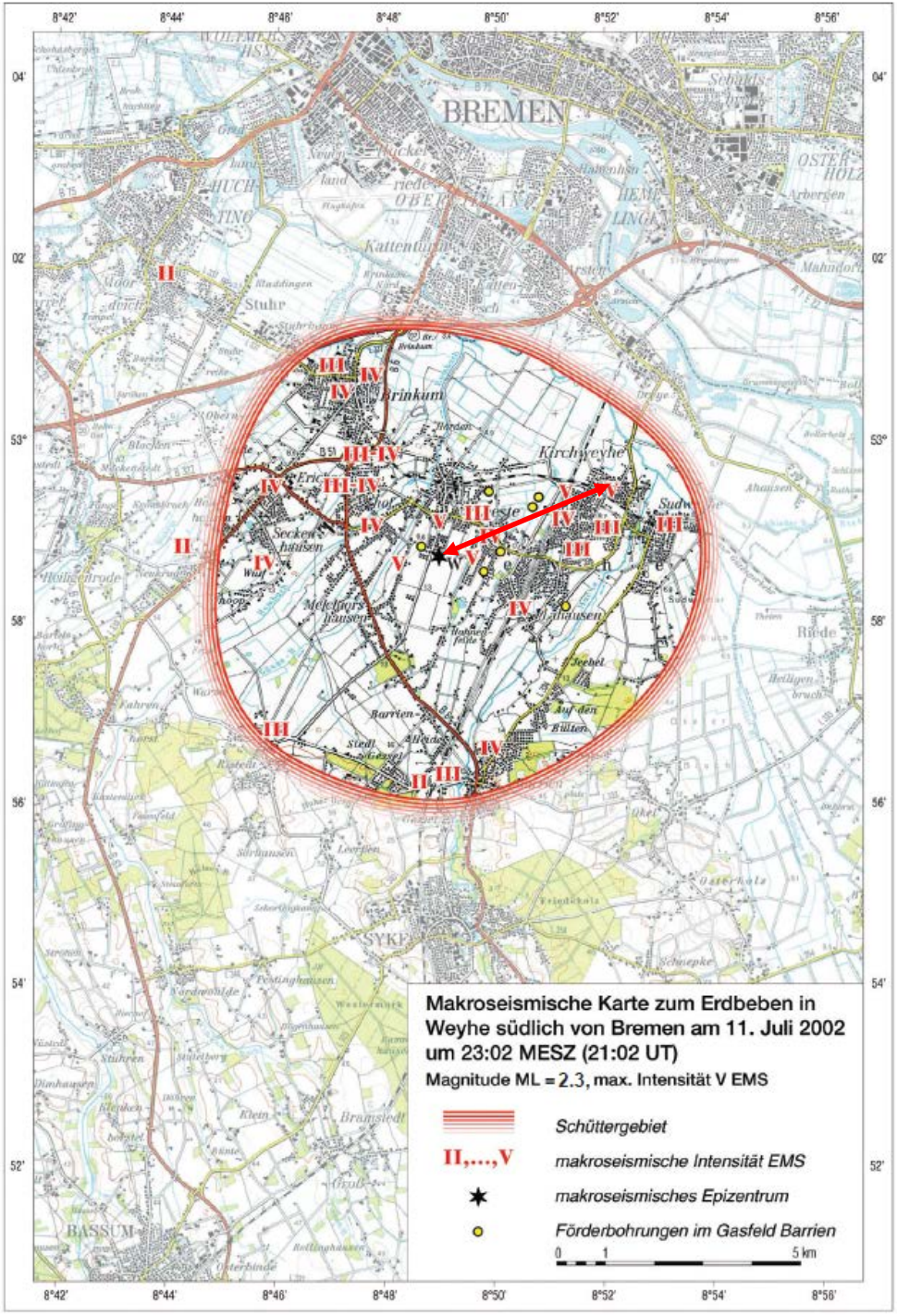


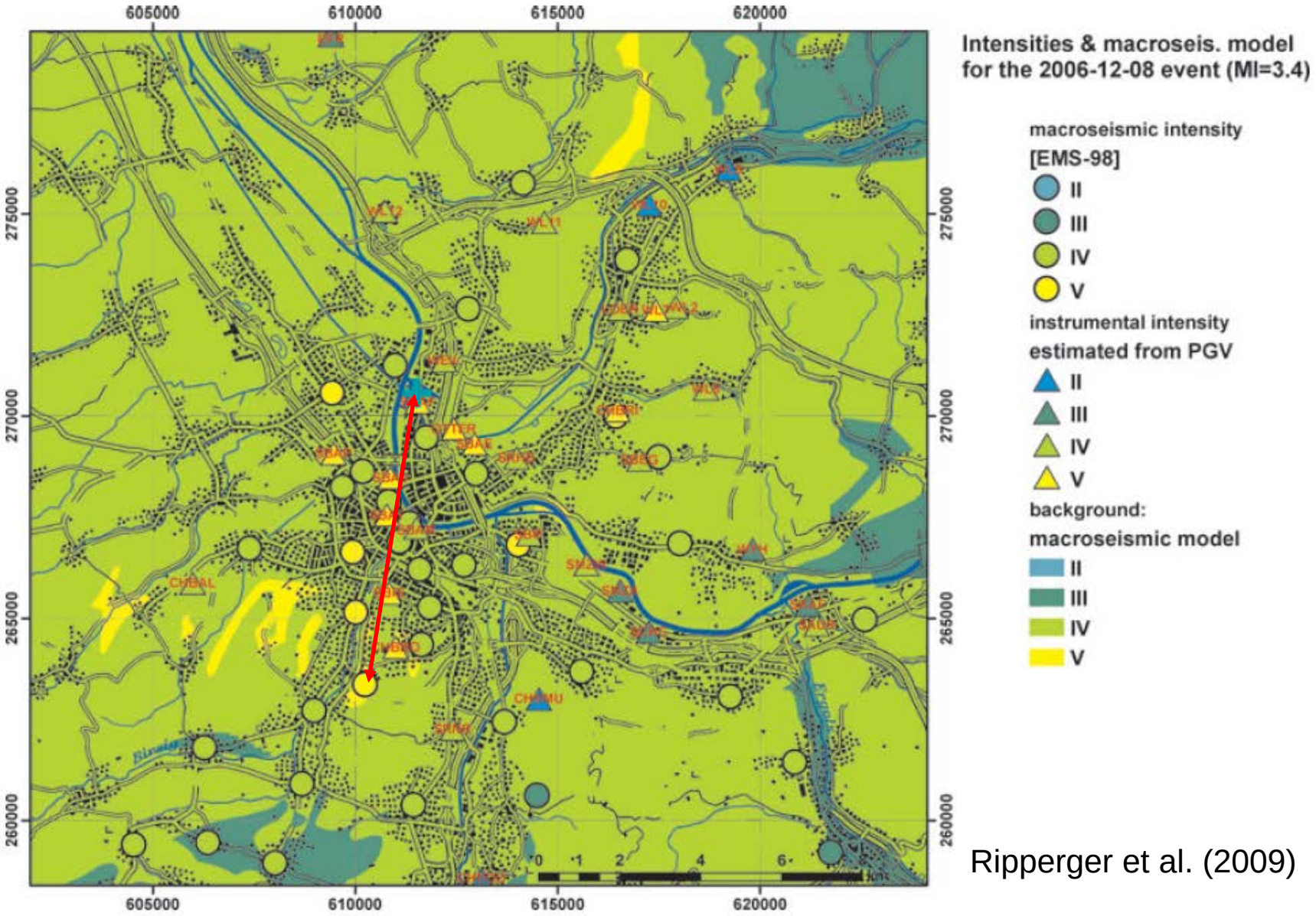
Example 3

11.07.2002 Weyhe, gas extraction, *ML* = 2.3

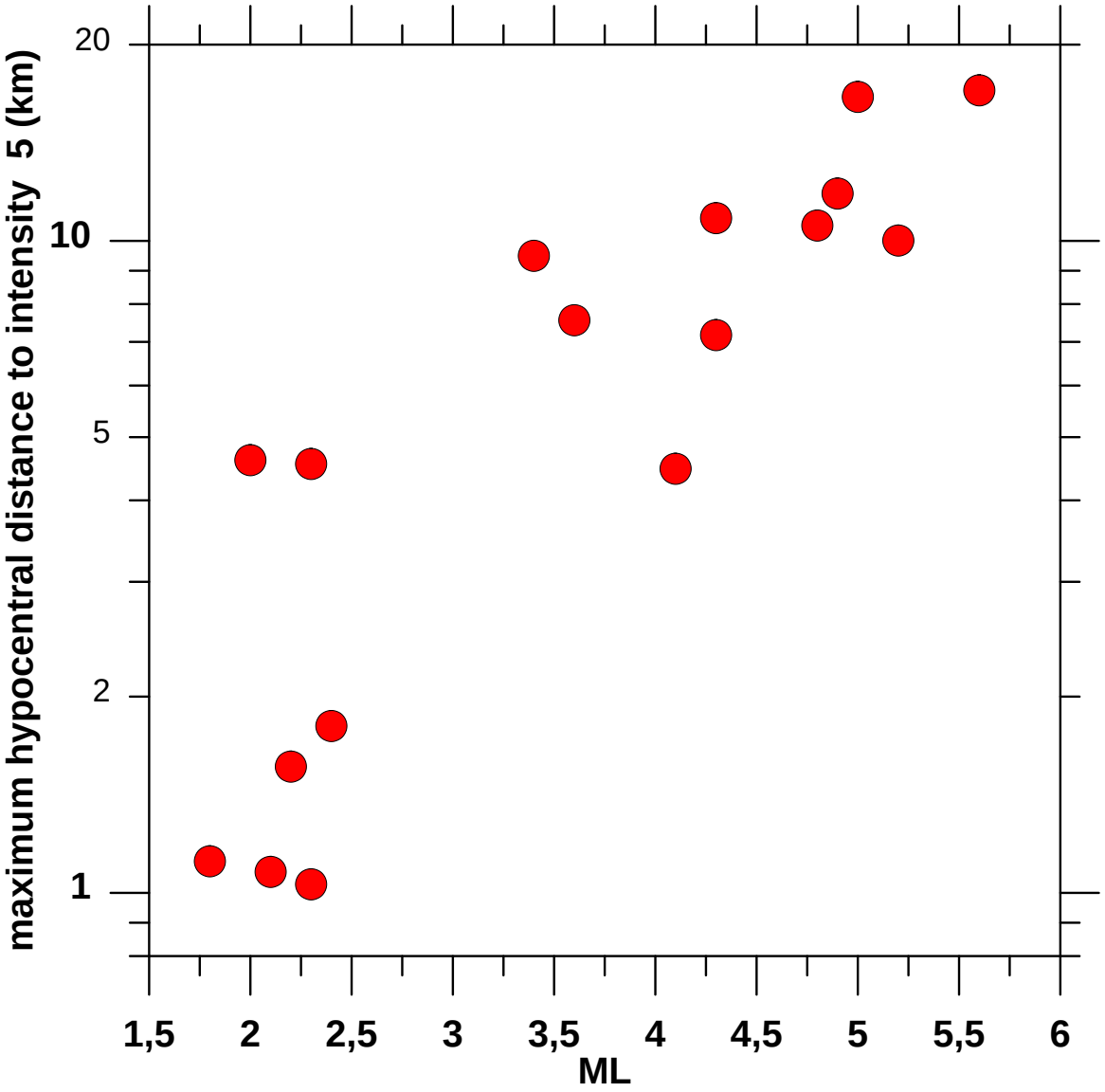
Leydecker (2003)

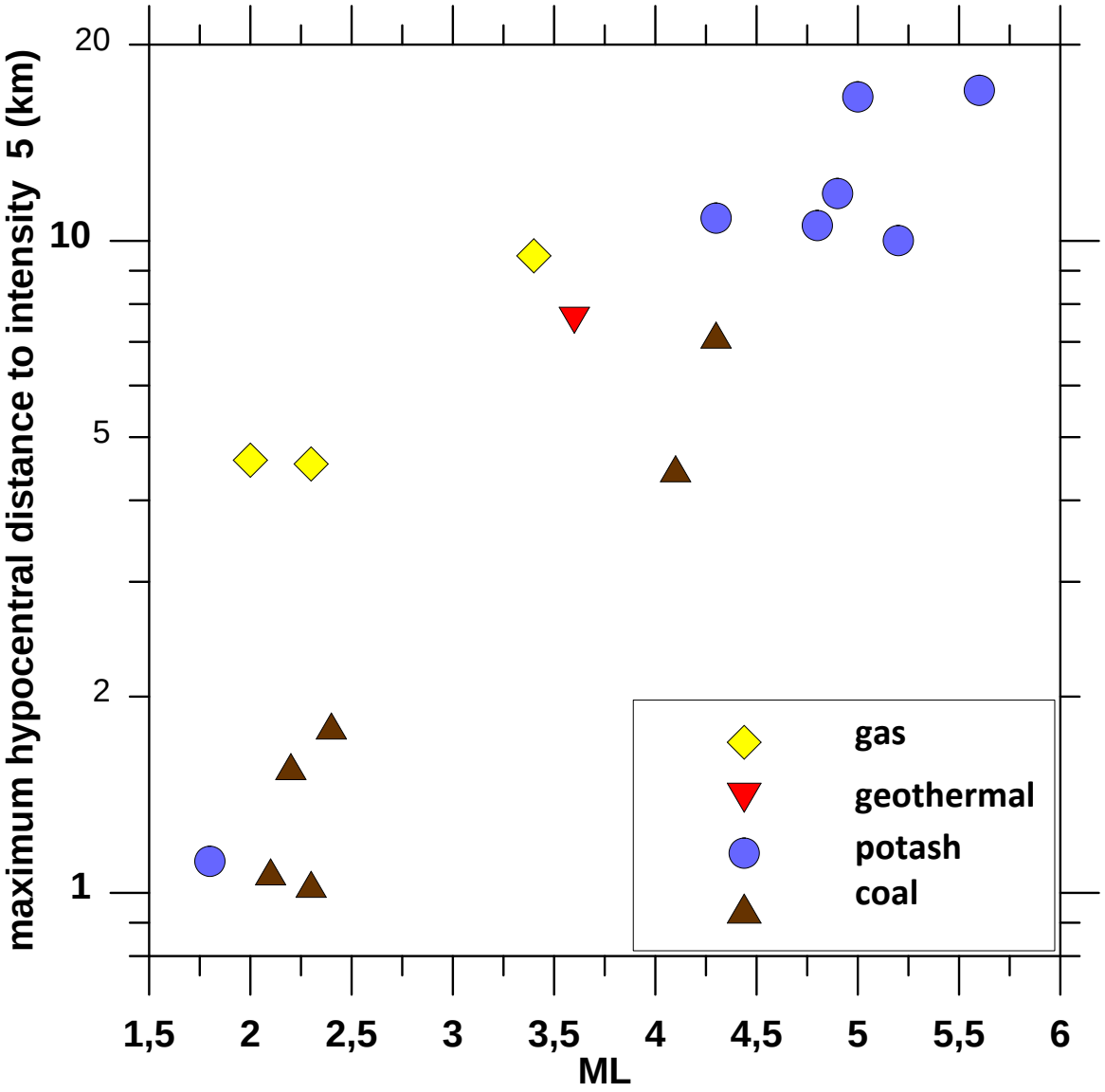
Example 4

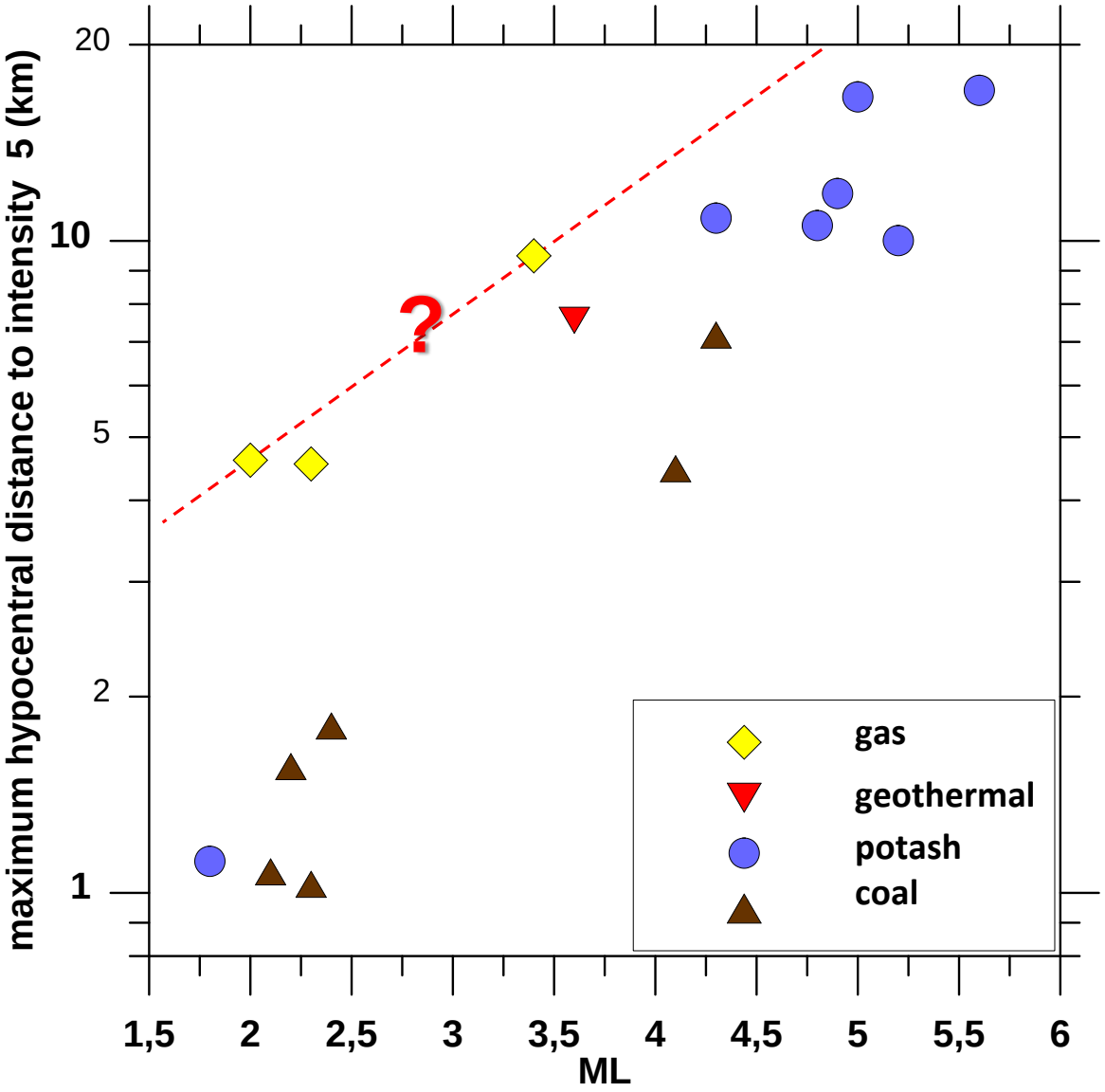
08.12.2006 Basel, geothermal stimulation, *ML* = 3.6



Ripperger et al. (2009)


maximum hypocentral distance to intensity 5 (km)
20
10
5
2
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
ML


maximum hypocentral distance to intensity 5 (km)
20
10
5
2
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
ML
gas
geothermal
potash
coal


maximum hypocentral distance to intensity 5 (km)
20
10
5
2
1
?
gas
geothermal
potash
coal
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
ML

Relationship between magnitude, macroseismic intensity and distance for induced earthquakes in Germany – Conclusions

1. Focal depths show a large influence on the relationship between *M* and *I*. Intensity 5 has been observed for shallow (~1 km depth) events with magnitudes as small as *ML*=1.8.

2. Simple models of the form $I = a + b\,M + c \log R$, with *R* = hypocentral distance, can be fitted to the observations. Models for tectonic earthquakes do not fit for induced earthquakes; for induced seismic events *I* is smaller for a given *M* and *R*.

3. Major differences were found between different mining areas: In gas production areas intensity 5 effects were always observed at greater hypocentral distances for a given magnitude, compared to coal and potash mining areas.

Relationship between magnitude, macroseismic intensity and distance for induced earthquakes in Germany – Next steps…

1. Extend database

2. Analyze differences between different mining areas.
   Different attenuation properties?

3. International comparison

4. Analyze PGV

5. Since macroseismic data (especially intensity data points) in Germany are available almost exclusively in analog form and are often difficult to access, it is necessary to establish a database for induced earthquakes including macroseismic data.