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Geometry of surface deformations caused by induced shocks in the area of underground copper exploitation

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Introduction

Induced seismicity is a dynamic phenomenon that can be triggered off during increased anthropogenic activity in the rock mass and can appear in aseismic areas. It is connected with mining of solid minerals, extraction of conventional and unconventional hydrocarbons, underground storage of liquids and gases, production of geothermal energy and construction of retention reservoirs as these engineering operations change the natural stress distribution in the rock mass. Mining-induced tremors cause faster movement of the rock mass and accelerated compaction of above lying rock formations in these areas. Due to the unpredictable nature and strength of induced seismic events, their occurrence pose a threat to mining operations, technical infrastructures on the ground and also may affect human safety The aim of this research has been first to calculate surface deformations caused by a number of seismic events induced by underground mining and then to analyse statistically the principal geometrical parameters of the resulting deformation areas in relation to the magnitude of the seismic events.

Study area

The Rudna mine is located in the south west part of Poland in the Lower Silesia region (voivodeship) and is one of several underground copper mines operated by the KGHM Polish Copper S.A. company in the area. The spatial extent of the Rudna mining ground is limited by the following geographical coordinates: $51^0$34'15"N, $51^0$28'15"S and $16^0$02'10"W, $16^0$14'30"E and covers an area of approx. 77.8 km^2.

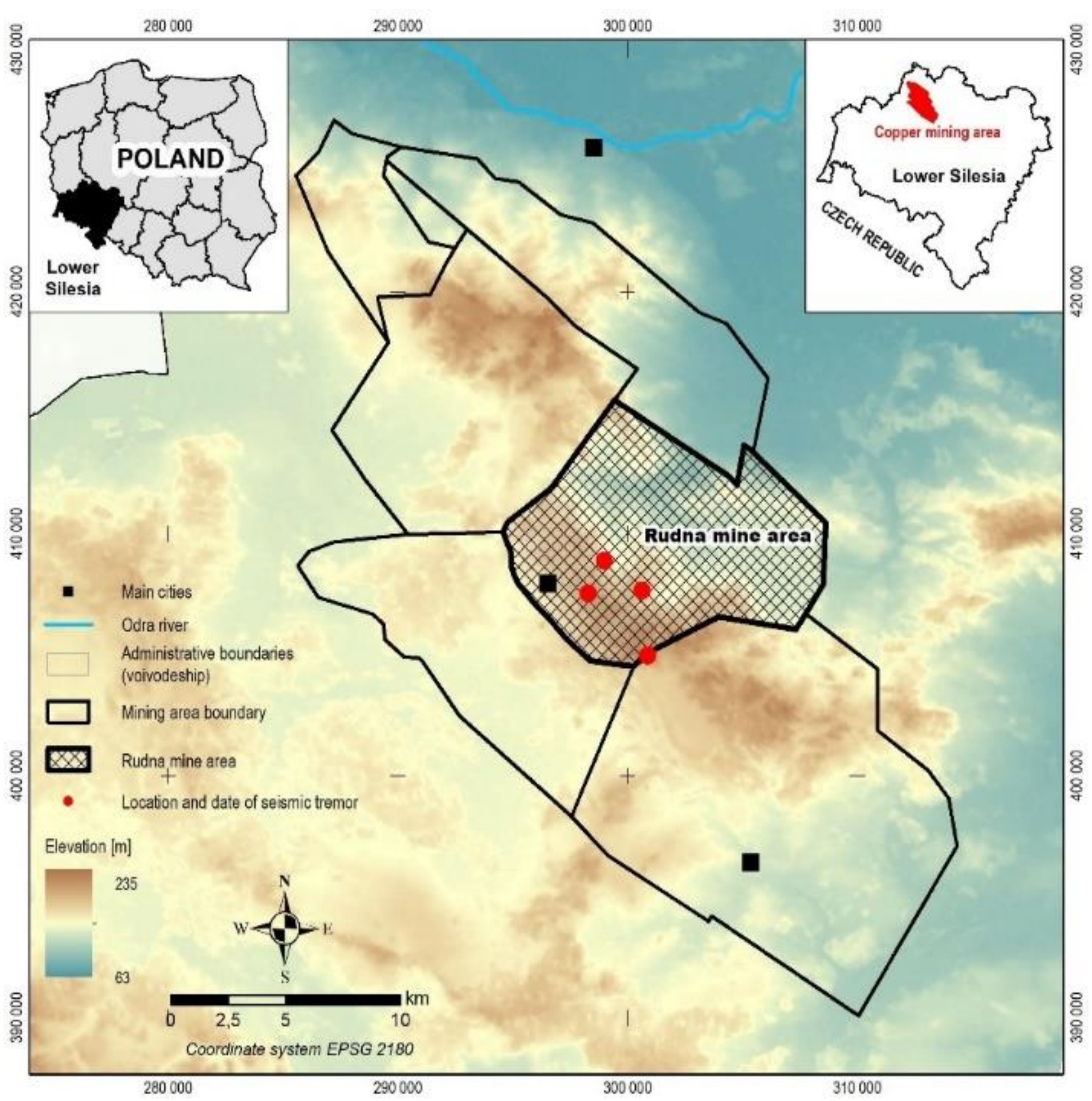

Figure 1. Location of the analysed seismic events in relation to Rudna mining ground boundaries

Data and methods

The analysed seismic events occurred between 16 December 2016 and 15 September 2018. Locations of these events (X, Y coordinates) were obtained from the Rudna copper mine seismic monitoring network. The deformations were calculated using differential satellite radar interferometry and 64 SLC images acquired by the ESA's Copernicus program Sentinel-1A/B missions. Several sets of image pairs, one acquired before and the second after particular event and for temporal bases ranging from 6 to 24 days were processed. The differential satellite radar interferometry (DInSAR) method was used to determine Line of Sight (LOS) displacements between two satellite images (master and slave). Finally, LOS displacement was converted to vertical displacements .The calculations were done in the GMTSAR version 5.4.5 software.

Results

The statistics, maximum, minimum, mean values of maximum subsidence and extent in N-S and W-E directions for each seismic event have been presented in Table 1 (results for pairs of descending and ascending imagery), and graphs in figures 2. The "-" sign in Table 1 indicates subsidence. Mean coherence values for pixels within the deformation areas ranged from 0.29 to 0.40.

Date of seismic event	16/12/2016	07/12/2017	26/12/2017	15/09/2018
Magnitude	4.5	4.7	4.8	4.6
min. displacement [mm]	-70	-59	-91	-66
max. displacement [mm]	-70	-101	-96	-81
mean displacement [mm]	-70	-83	-94	-77
min. W-E extent [km]	1.5	1.4	1.8	1.6
max. W-E extent [km]	1.5	2.0	2.1	2.0
mean W-E extent [km]	1.5	1.8	1.9	1.8
min. N-S extent [km]	1.8	1.9	1.7	1.8
max. N-S extent [km]	1.8	2.1	2.2	2.1
mean N-S extent [km]	1.8	2.0	2.1	1.9

** "-"indicates subsidence*

Table 1. Statistics describing geometry of deformation areas caused by the four analysed seismic events

A linear relation (with R^2 value of 0.977) was determined between magnitude of seismic event and mean maximum registered displacement (blue dashed line) (Fig. 2). In case of the extent of the deformation areas a similar linear relation with magnitude was obtained (blue solid line) (Fig. 2). A better fit was obtained for the N-S component (R^2 equal to 0.978) than for the W-E one (R^2 equal to 0.894) (blue dashed lines).

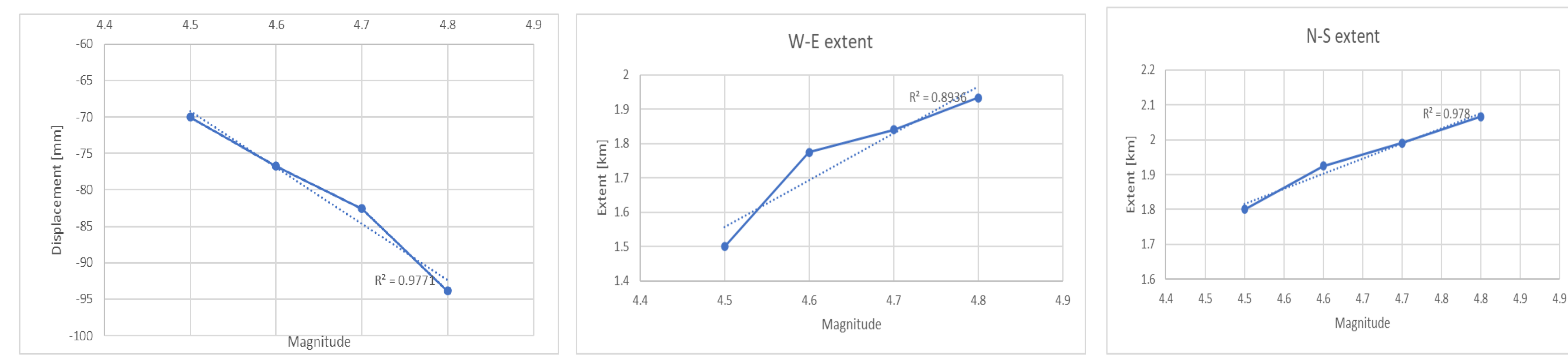

Figure 2. . Graphs: mean maximum vertical displacement vs magnitude, mean extent of deformation areas in W-E vs magnitude, mean extent of deformation areas in N-S vs magnitude.

Graphical representations (maps) of generalised deformation areas for each seismic events have been presented in figures 3 to 6. The negative value of displacement indicates subsidence. GIS spline interpolation function for optimised parameters of the method have been used to generate displacement maps for the four induced shocks: 16 December 2016 (Fig. 3), 7 December 2017 (Fig. 4), 26 December 2017 (Fig. 5) and 15 September 2018 (Fig. 6). The spatial extent of the subsidence zone was determined as the area of displacement greater than the value of -10 mm.

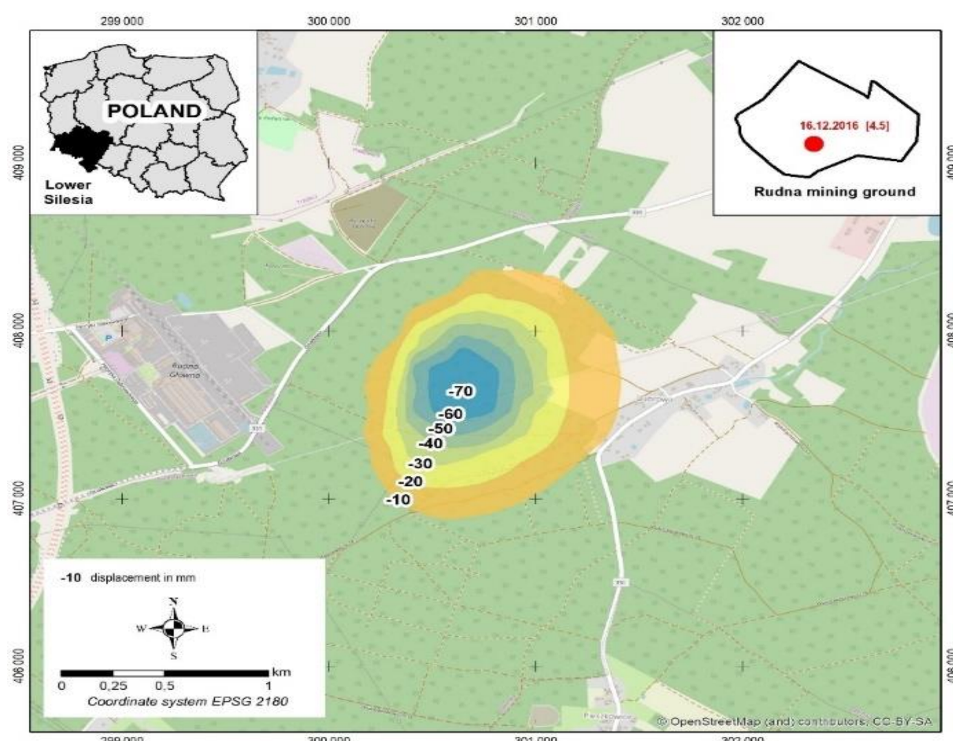

Figure 3. Map of the deformation resulting from the seismic event of 16 December 2016

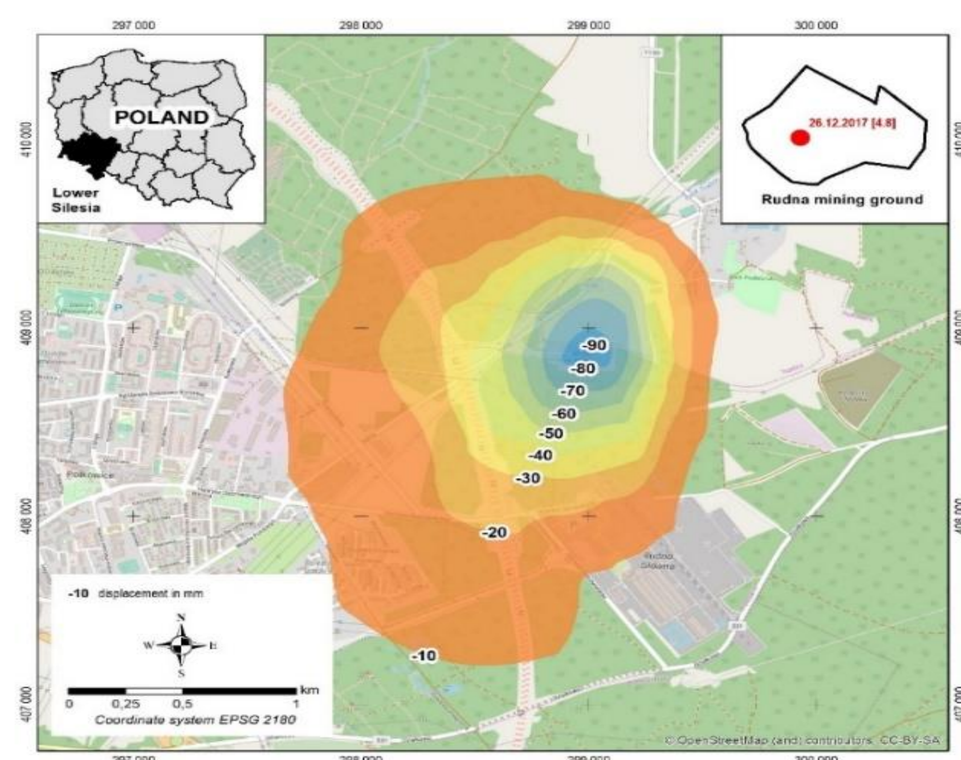

Figure 5. Map of the deformation resulting from the seismic event of 26 December 2017

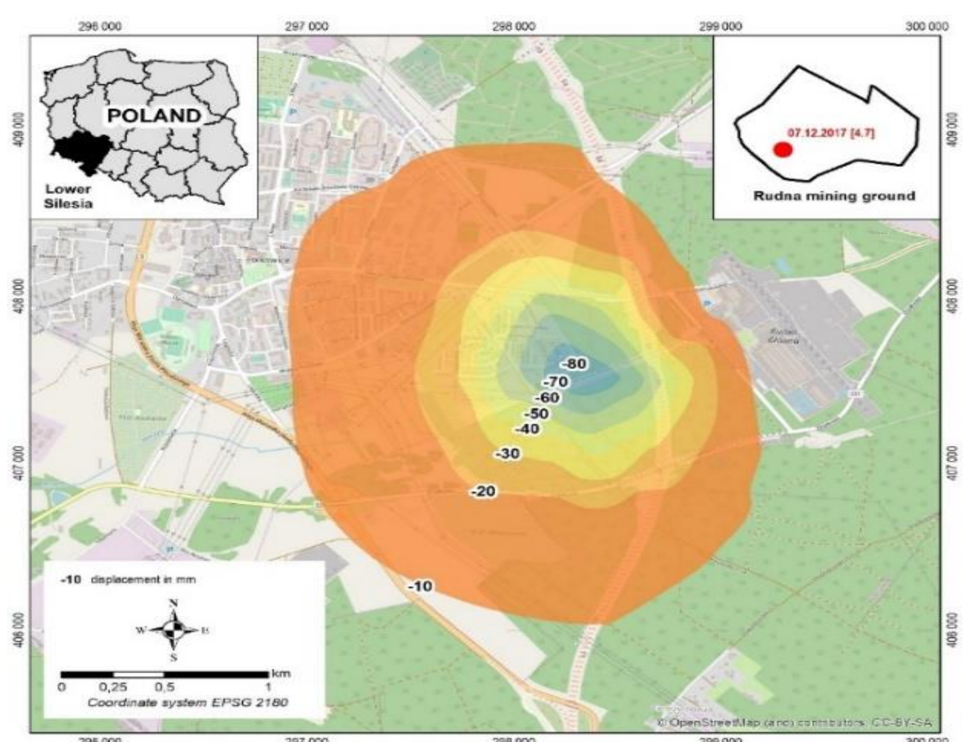

Figure 4. Map of the deformation resulting from the seismic event of 7 December 2017

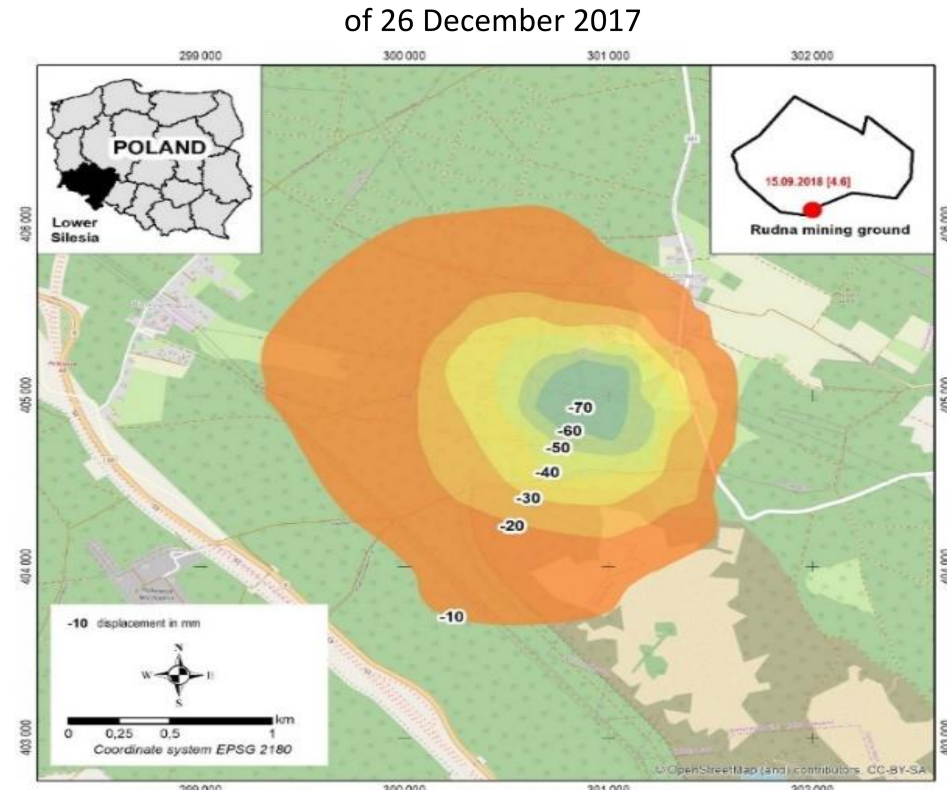

Figure 6. Map of the deformation resulting from the seismic event of 15 September 2018

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