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Note

Monitoring and modelling of mining related land deformation with open data and data driven approaches

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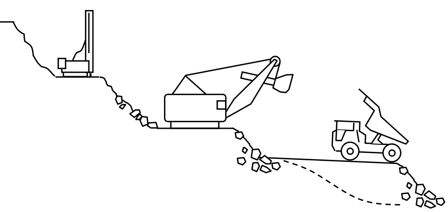
Study of the potential of GIS based data driven analytical methods and open data for modelling land deformations in mining areas is the topic of a sabbatical research at the NTNU IGP within the Polish NAWA Bekker programme.



1. INTRODUCTION

Mining of minerals from deposits inherently causes changes to the land. In case of surface mining the transformations include pits and quarries, larger open pits and strip mining, as well as the associated overburden or waste rock dumps that result in large scale transformation of the terrain. Underground mining techniques are used to extract minerals from deeper deposits and include longwall (continuous) mining used e.g. for hard coal, room and pillar mining used e.g. for laterally extensive copper ores, cut and fill mining used primarily for high valued ores and sub-level stoping or sub-level caving used e.g. for steep iron ore deposits. There are also methods dedicated to other types of deposits such as solution mining (e.g. brine solution mining), hydraulic fracturing (e.g. to extract gas or crude oil).

Mining related ground deformations are caused by the movement of the overlying rocks into the voids left by extraction of mineral and waste rock from the deposits that migrate towards the surface at various rates depending on the geological and mining conditions. Generally, land deformations can be classified into continuous and discontinuous (Fig. 1). The former in the shape of subsidence basins and throughs and the latter producing forms such as sinkholes, cracks or fissures. The other effects associated with mining include mine drainage causing cone of ground water table depression (in order to access underground or near surface deposit) and the resulting movements due to the compaction of the ground, waterlogging of subsided areas (especially in post-mining areas due to restoration of former ground water levels over subsided land) and subsidence from seismicity induced by mining causing faster migration of the rock mass deformation to the surface (Milczarek et al, 2021). Post-mining deformations occur even decades after the end of the underground extraction of minerals (Vervoort and Declercq, 2017) and manifest in the form of residual subsidence, uplift (caused by change of rock mass conditions due to saturation of the previously drained formations), as well as discontinuous deformations due to destruction or deterioration of old, especially shallow, voids left underground.

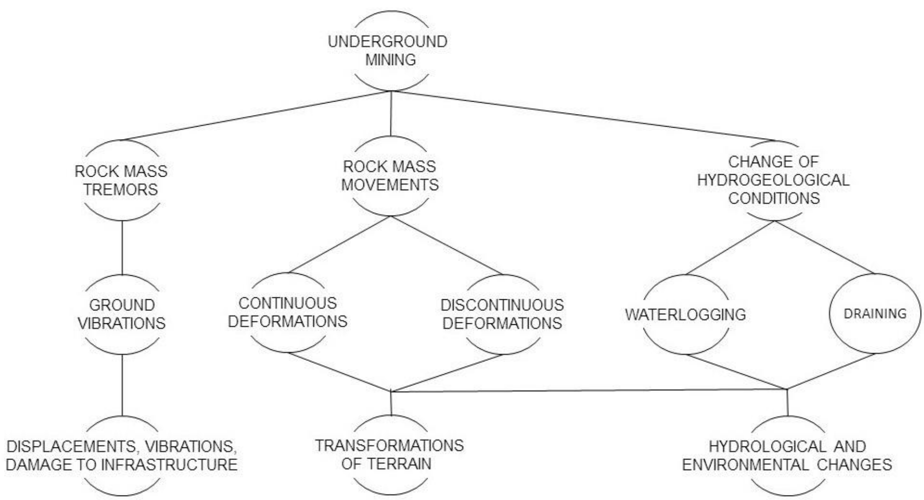


Figure. 1. The cause and effect aspects of transformations caused by underground mining (based on Kwiatek, 1997).

Due to these effects, it is necessary to monitor active and post-mining areas to obtain information that is accurate, current and interpreted by mine surveyor/engineer for proper assessment of the condition of the land above and in the vicinity of mining operations.

Traditionally land deformations on mining grounds, such as subsidence, have been observed with surveying techniques such as levelling, GNSS levelling, Total Station measurements and their indices calculated using various methods predominately based on an empirical approach, influence functions or more recently deterministic numerical methods (Knothe 1953, Kratzsch 1983, Chrzanowski and Szostak-Chrzanowski 1986, Whittaker and Reddish 1989, Chudek 2002, Strzalkowski 2015). Both the observations and calculations have been usually conducted in 2D lines and profiles (along and/or across land above the mined orebody).

2. METHODOLOGICAL APPROACH

To describe precisely and subsequently predict land deformations resulting from mining, especially operations conducted in complex and composite conditions it is necessary to understand and define the relationships between geological and mining conditions (e.g. geometrical parameters of deposit and mining project) and the resulting changes on the land surface such as subsidence and/or uplift, groundwater level changes, and land use and land cover changes (due to subsidence and relative movement of groundwater table).

The spatial complexity and dimension of the problem associated with mining less accessible deposits, critical for the European economies, the above-mentioned and presently used approaches have become insufficient as a reliable descriptor and predictor of mining impacts including the post-mining phase. In addition, these methods do not allow for modelling of land use or cover changes, a significant effect of mining on the surroundings.

Proliferation of remotely sensed satellite and airborne data and data driven processing methods open new ways to observe and model land deformations on mining grounds. For example, the European Copernicus programme Sentinel missions, are able to register ground movements, land use changes, vegetation and soil conditions with sufficient spatial resolution (e.g. 10 - 30m) and frequency (6 - 12 days) to provide more and more open data available for spatio-temporal analysis of land transformation on mining grounds. Moreover, the vast archive of satellite imagery allows for backward analysis, useful for example for studies of deformations, which result from induced seismicity, as well as historical studies. In addition, emerging national web services such as the German Ground Motion Service (https://bodenbewegungsdienst.bgr.de) or the Norwegian InSAR Norge (https://insar.ngu.no) provide nationwide, freely accessible view and download capabilities for InSAR data based on the Copernicus Sentinel-1 data processed by means of the Persistent Scatterer Interferometry procedure (PSInSAR) (Fig. 2). Optional, additional evaluations for selected regions based on higher spatial resolution SAR data acquired by TerraSAR-X or Radarsat-2 are also available.

Figure 2. National services for InSAR data (left - Norway, right – Germany).

Whereas, accurate digital elevation models (DEM) are available openly or upon request from authorities such as the Polish Central Office of Geodesy and Cartography (https://mapy.geoportal.gov.pl) albeit at larger time intervals spanning several to dozen years. The processed models offer horizontal accuracy of 1m (e.g. in the LAS format) with density of no less than 4 points per m sq and vertical accuracy of single decimetres. Undoubtedly, the number and acquisition frequency of these data will improve in the coming years. The concept of multi -source and -resolution approach to monitoring mining related deformation has been shown in Fig. 3

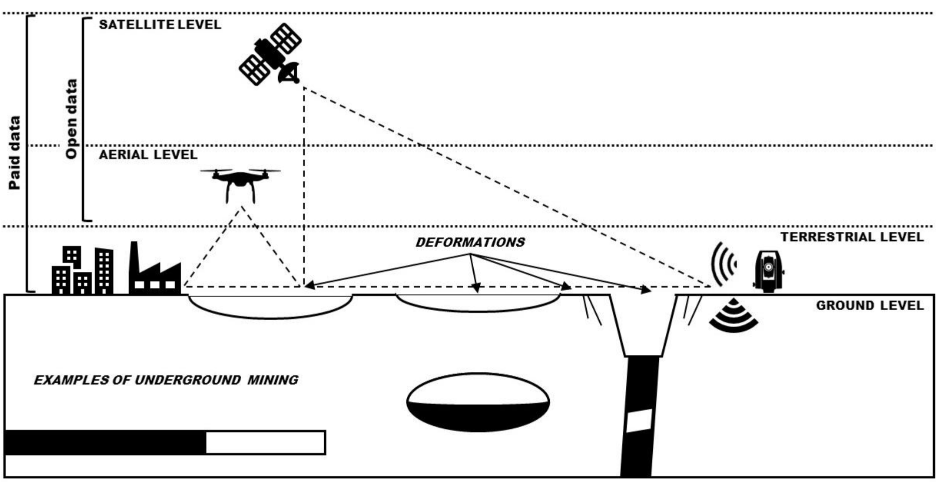


Figure 3. Multi source and multi resolution approach to monitoring mining related land deformation.

Availability of these data together with mine project design information have attracted data driven modelling methods such as multifactor weighted spatial regression (Charlton and Fotheringham 2009) or machine learning based random forest regression (Breiman 2001) techniques to develop models and overcome the limitations of the traditional empirical or deterministic calculations of mine effects (deformations) on the surrounding environment.

Thus, the proposed research methodology incorporates two pillars,

- the first being multi -source and -resolution spatial data from satellite and aerial remote sensing,
- the second utilises a geographic information system (GIS) based spatially weighted multifactor regression and data-driven machine learning algorithms.

Within the project conducted at the NTNU the potential of the first pillar to provide reliable, accurate and timely data for monitoring land deformations in a mining area will be tested. The potential limitations such as seasonal conditions, topography and geometry of observations will be assessed. In the second phase, weighted multifactor spatial regression and random forest regression methods will be applied to develop and test models linking the observed changes (land deformation and land cover changes) and the potential causative factors (mining, geological and topographic conditions). For this purpose a grid of uniform reference units with attribute values assigned will be used. The attributes will represent dependent (observed changes) variable and the independent (causative factors) variables. Different spatial resolutions will be tested. The performance of the regression models will be assessed statistically and the identified driving factors behind the observed land deformations and/or land cover changes will allow to study future trends (including periods when due to seasonal conditions remotely sensed data are not available), as well as could be applied to other areas (e.g. where mining project is planned but not yet started).

The study aims to perform an analysis on a case of one of the mines in Scandinavia using the sub-level caving system (Fig. 4). The following, but not limited to, set of variables is considered: dip of the deposit, thickness of the deposit, depth below ground level, distance to underground operation, depth and thickness of the caved zone, distance to the caved zone, distance to the fractured zone and derivatives of the DEM such as slope and curvature.

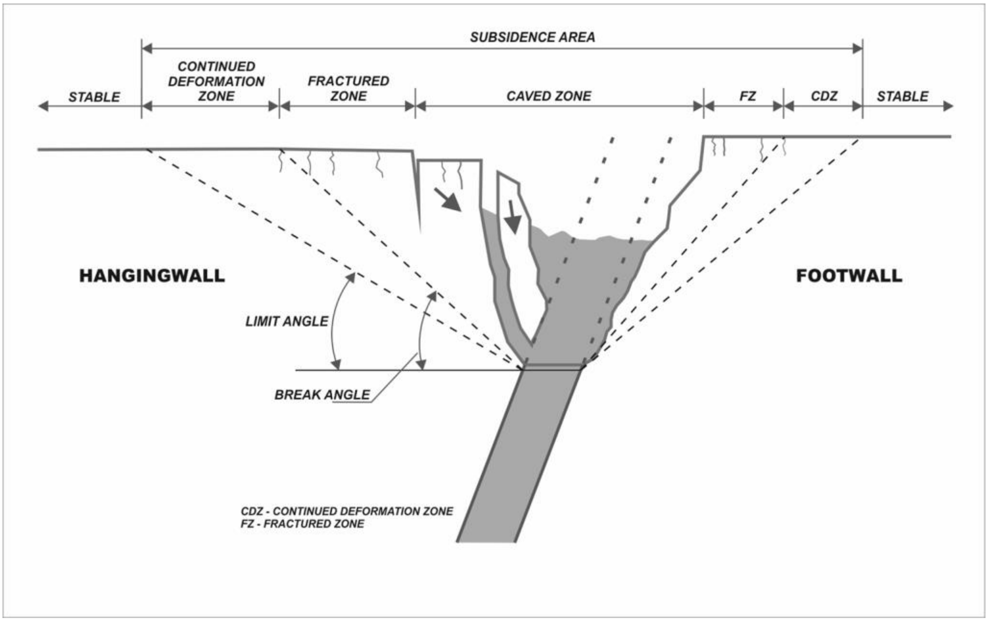


Figure 4. Rock mass deformation in the sublevel caving (SLC) mining system (source Blachowski & Ellefmo, 2012).

3. CONCLUSIONS AND OUTLOOK

The project will allow to obtain in depth knowledge and expertise in data-driven methods for analysis and prediction of land deformations based on open data sources and applied to complex geological and mining conditions. The expected results will provide means to propose a cost-effective augmentation or alternative to ground motion measurements and predictions for mining areas, as well as act as a first stage of a monitoring system and indication to implement high-precision geodetic observations if significant changes are detected.

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