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MORPHOLOGICAL VARIATIONS IN SUBSIDENCE BASIN AND IMPORTANCE FOR LAND USE PLANNING: UNDERMINED KARVINA REGION (CZECH REPUBLIC)

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Abstract: The study area has been greatly affected by mining activities and other anthropogenic activities since it falls within the so-called Ostrava-Karvina Coal District. Morphological variations in time by temporal variations in subsidence basins by underground mining activities in the Moravia-Silesian Region in the north-east of the Czech Republic was investigated in this article. Subsidence was observed in the four time intervals of 1983-1990, 1983-1995, 1983-2000, and 1983-2005. Relationships between estimated subsidence during time period of 2003-2010 and municipality land use plans were identified by overlay analyses. There is a clear impact on the land use plans caused by varying thoroughness of the urban planners. As the result of the observations in these periods, underground mining activities considerably had a negative impact on the current built-up area. Despite this, the built-up area erected on the most affected subsidence interval of "500-1200 cm" during the last time period of 1983-2005 is only 1%. According to the Land Use Plan Categorization, development planned for the most impacted subsidence interval of "500-1200 cm" is in the U_V_0 category of Unspecified Production Zone and also in the U_DL_2 zone of mining interest. This development area covers 1.54% of the overall planned development. Analyses related with slope deformation in the study area imply that there are three active areal shaped slide areas, one so-called other areal shaped slide area (55.6 ha) and three active very small slide areas. A possible risk is posed by the active areal shaped slide areas which have an overall surface area of 12.05 ha. As the main results of this study; it was found that the subsidence distribution implies trends which confirm that the area unaffected by subsidence impacts decreased over time due to the expansion of the subsidence basin, and thus a re-distribution of impacts occurred in the study area. These impacts were caused by black coal mining in the Karvina Mine, the CSA Plant and in allotments of Karvina-Doly I, Doubrava and Darkov. As another result; the analyses showed that impacts of subsidence in the area had not properly considered in the planning of future development.

Key words: Subsidence basins; morphologic changes; land use planning; underground mining; landslide.

1. INTRODUCTION

The objective of this study is to stress the necessity to consider morphological variations over time due to temporal variations in subsidence basins connected with increased mining activities. This is an important requirement for land use planning and other purposes such as educational, geomorphological, environmental and engineering-geological research and surveys.

When the extraction of coal, oil, shale and other minerals or geological materials by surface mining is impossible, underground mining methods are used. In underground mining, geological materials completely enclose the working environment. Underground mining is one of the most important mining activities in the world and there has been found very large terrestrial areas in different parts of the world. Underground mining (soft rock) refers to a group of underground mining techniques used to extract coal, oil shale and other minerals or geological materials from rocks, and this technique also differs greatly from surface mining techniques. Removal of the material by underground mining can create environmental problems and safety hazards (Altun et al., 2010).

The presentation is based on a case study in the Karvina, Doubrava locality on map sheet 15 44 03. This locality is an important active mining region in the north-east of the Czech Republic, and it has prominent manifestations of undermining caused by black coal mining in geological conditions as specified in the following chapter. In this article, mines influencing the localities were described by various overlay analyses based on field measurements and Geographic Information Systems (GIS).

Four time periods of subsidence variations have been evaluated and characterized by isocatabases, which are isolines with identical subsidence values in centimetres. This was related to the overall study area and the current built-up area. Future development is represented in the individual land use plans vectorized and integrated for the purpose, since they were compiled in different municipalities with the so-called extended scope of activities required in land use plan preparation. In addition to an evaluation of ground subsidence variations, a distribution assessment was conducted concerning engineering-geological zones which comprise the most important representatives of the engineering-geological conditions in this locality. It is stressed that variations in subsidence have different impacts on different geological environments. It is therefore apparent that less suitable foundation conditions will be enhanced by variations in morphology in undermined areas, particularly when the area is situated on slopes. Therefore, a distribution of slope movements was included in this research, and this was also a subject of overlay analysis. However various authors including Onargan et al., (2009); Dong & Ninomiya, (2009); Castaneda et al., (2009); Cooper, (2008); Harnischmacher, (2007); Macklin et al., (2006); Lecce & Pavlowsky, (2001) and James, (1999) researched underground mining and variations in ground morphology, the essential core of this topic has been covered only marginally.

2. CHARACTERISTICS OF THE STUDY AREA, MINES AND ALLOTMENTS

The study area is located in the Moravia-Silesian Region in the north-east of the Czech Republic (Fig. 1a) and its total area is approximately 73 km^2. This area has been greatly affected by mining activities and other anthropogenic activities since it falls within the so-called Ostrava-Karvina Coal District. Mining is the main causative factor forming the face of the landscape in mine workings and underground mining. The study area is contained on map sheet 15 44 03 (Czech reference number of topographic map sheet) in a 1:10,000 scale, and in territorial zoning it forms the part of the cadastral territory of the municipalities of Detmarovice, Doubrava, Karvina, Petrovice u Karvine. In geomorphologic classification, it is a part of the Ostrava Coal Basin complex, and it falls within the districts of Ostrava Bottomland, Karvina, Havirov and Orlova Plateau (Demek, 1987).

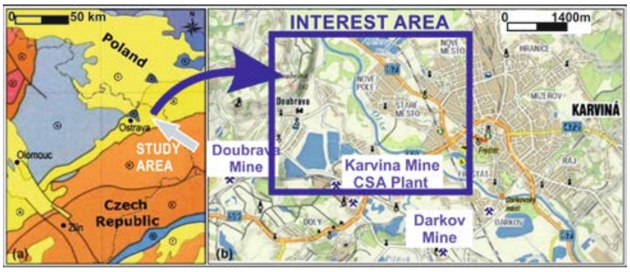

Figure 1. a. Location map of the study area and, **b.** localization of mines in the study area (1:70 000). Notes:1 – Karvina Mine –CSA Plant,– Darkov Mine (modified from Mapy.cz)

The *Ostrava Bottomland* is located in the eastern and southern part of the *Ostrava Coal Basin* and it is a complex of Quaternary fluvial sediments composed predominantly of a sandy-loamy layer of recent sediments and slope gravel-sand. Frequent dumps and embankments of anthropogenic origin are the characteristic of the lower level of recently formed valley flats.

The *Karvina Plateau* has the characteristics of a flat upland and it is situated in the north-eastern part of the *Ostrava Coal Basin*. It is composed of a complex of gravels and sands of glaciofluvial and fluvial origin topped by a layer of loess loam. This plateau was formed by various accumulated erosion movements, particularly glaciofluvial, fluvial and eolian. It has apparent modelling of a periglacial and humid character with asymmetric valleys, landslides and gullies.

The *Orlova Plateau* is located in the central part of the *Ostrava Coal Basin* and it represents a flat upland with varying thick strata of gravels, sands and glacigenous loams in the roof of the coal-bearing Carboniferous**,** which is covered by a layer of loess loam. It has also an apparent accumulation of material of glacigenous and eolian origin, articulated by the processes of periglacial and humid destruction. There are also remnants of accumulation plateaus, moraine lines, landslides, gullies and asymmetrical valleys. The anthropogenic impacts include dumps, embankments and subsidence basins (Demek, 1987).

The study area forms the part of the *Upper-Silesian Coal Basin*, which enters the territory of the Czech Republic from Poland and forms a sedimentary area triangular in shape. Paleo-geographically, it belongs to the foredeep and adjacent section of the Variscan mountain foreland. The coal basin's basement is composed of Brunovistulicum and Devonian and Low-Carboniferous deposits. The oldest rocks are as deep as 1000 to 4000 m and belong to the pre-Paleozoic Cadomian crystalline complex, while the basin is filled with clastic Upper-Carboniferous sediments with black-coal seams. The Upper-Silesian Coal Basin is the largest black-coal basin in the Czech Republic, and here significant black-coal reserves are buried to a several-hundred-metre depth which increases from the south to the east. The northern section of the Upper-Silesian Coal Basin is the Ostrava-Karvina portion, the Ostrava-Karvina Coal District, and the southern section is the Podbeskydi. The division into the more westerly and more mobile foredeep of the Variscan Mountains and the more easterly platform section are most important geologically. The intensity of tectonic failure falls gradually from the west to the east (Chlupac et al., 2002, Curda et al., 1998, Kachlík, 2003).

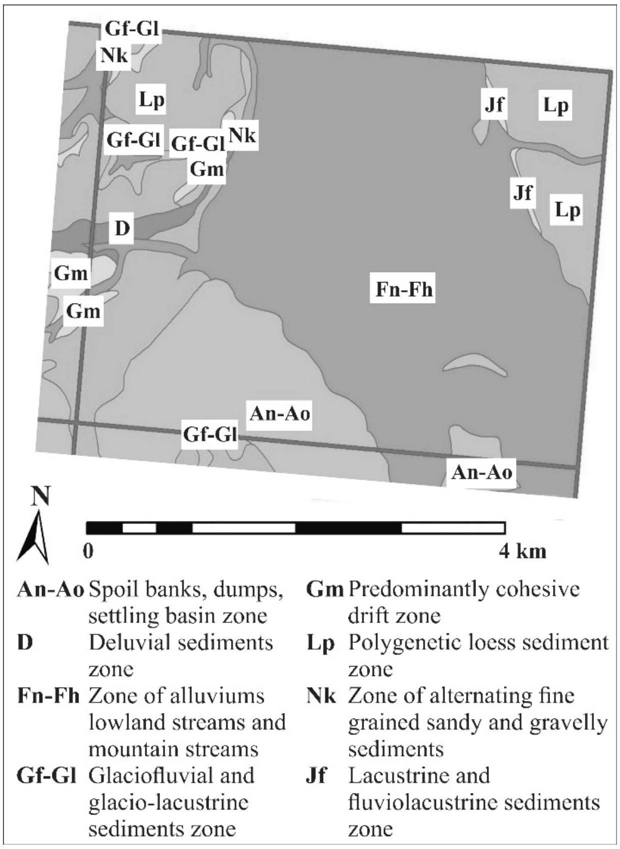

Figure 2. The map of engineering-geological zones (prepared according to UUG, 1997)

Based on the engineering-geological zoning map, the interest zone is characteristic of spoil banks, dumps and settling basins zone (An-Ao), the predominantly cohesive drift zone (Gm), the Deluvial sediments zone (D), the Zone of polygenetic loess sediments (Lp), the Zone of alluviums lowland streams and mountain streams (Fn-Fh), the Zone of alternating fine-grained sandy and gravelly sediments (Nk), the Glaciofluvial and glaciolacustrine sediments zone (Gf-Gl) and the Lacustrine and Fluviolacustrine sediments zone (Jf) (Fig. 2).

The map given in figure 1.b depicts the principal mine workings in this territory as described below. These are mines whose activities left prominent traces in the study area and whose impacts are the subject of this study evaluation. The following allotments are (DP): Karvina-Doly I, Karvina-Doly II, and Doubrava.

The Karvina Mine was established by merging the former CSA Mine and Lazy Mine on the 1st April 2008 and it is situated 25 km north-east of Ostrava. The organizational structure of the Karvina Mine incorporates two mining plants: the Lazy Plant and CSA Plant. The CSA Plant is *situated* in the allotment of A Karvina-Doly I and A Doubrava near Orlova.

3. EVALUATION OF SUBSIDENCE

This chapter of the article covers the evaluation of specific geofactors, such as subsidence caused by underground mining activities, the expansion of slope deformations and engineering-geological zones for map sheet 15 44 03. It also describes the mutual relationships between these geofactors.

Some authors such as; Forrester & Whittaker, (1976); Wagner & Schumann (1991); Jones, et al., (1991); Mattson & Magers, (1995); Mattson et al., (1998); Cain, (1998); Booth et al., (1999); Marschalko et al., (2008.a); Blachowski et al., (2009); Szczerbowski, (2009); Trckova, (2009); Marschalko & Treslin (2009); Jirina & Jan (2010); Li et al., (2010) and Ren et al., (2010) dealt with mutual relationships of subsidence and underground mining, but their work contained no connection with variations over time and land use planning.

The study area is the largest area is in the municipality of Karvina. Its next largest areas are in the municipalities of Doubrava and Detmarovice, and in the north-eastern edge is Petrovice u Karvine. The allotments on this map sheet; Karvina-Doly I, Doubrava and Karvina-Doly II were arranged according to spatial representation. Subsidence sizes caused by mining activities were then evaluated with respect to time throughout the study area, the overlay analyses of subsidence and current built-up area were carried out and evaluated, the subsidence was estimated with respect to the land use plan, slope activities were assessed and the estimated subsidence was compared with a map of engineering-geological zones.

3.1. Overall evaluation of subsidence in the study area

In this territory, subsidence sizes caused by black coal mining in the Karvina Mine, CSA Plant, owned by the OKD Company, were evaluated. Subsidence was observed in the four time intervals of 1983-1990, 1983-1995, 1983-2000, 1983-2005 (Fig. 3 and 4). The choice of these intervals with identical initial year was not made randomly. This methodology allows the monitoring of increases in subsidence over time in connection with mining progress, whereas the selection of evaluations considering only individual time periods would not produce a distinct comparison of such increases.

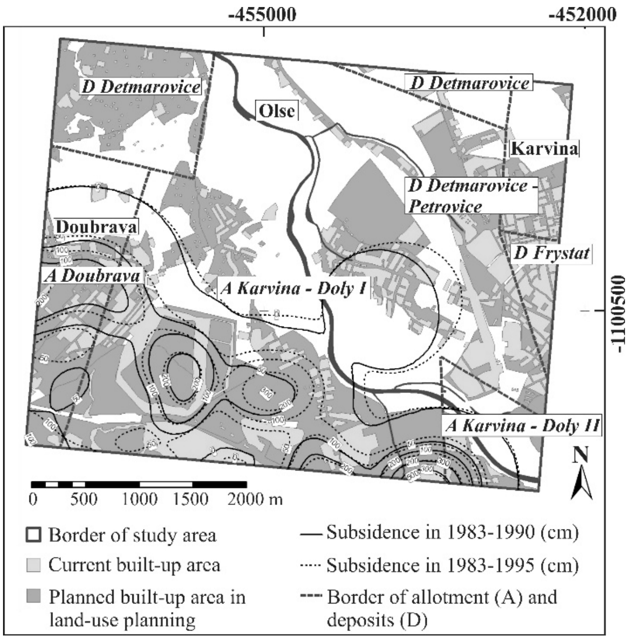

Figure 3. Subsidence caused by black coal mining in 1983-1990 and 1983-1995with marked current and future development (subsidence data by OKD).

This study also includes an evaluation of the estimated subsidence by 2010 (2003-2010), which is not stated in the subchapter as it was not assessed in a manner compatible with the four above mentioned time periods. For adequate comparison of the results of the subsidence values, the following seven intervals were selected;

a. “land without subsidence”,
b. “subsidence up to 50 cm”,
c. “50-100 cm”,
d. “100-200 cm”,
e. “200-300 cm”,
f. “300-500 cm”
g. “500-1200 cm”.

The above stated intervals were assigned with all relevant partial values. The source of subsidence is the actual identified subsidence in cm provided by the OKD mining company and these values were vectorized in GIS environ by using software package of ArcGIS 9.1 (2005).

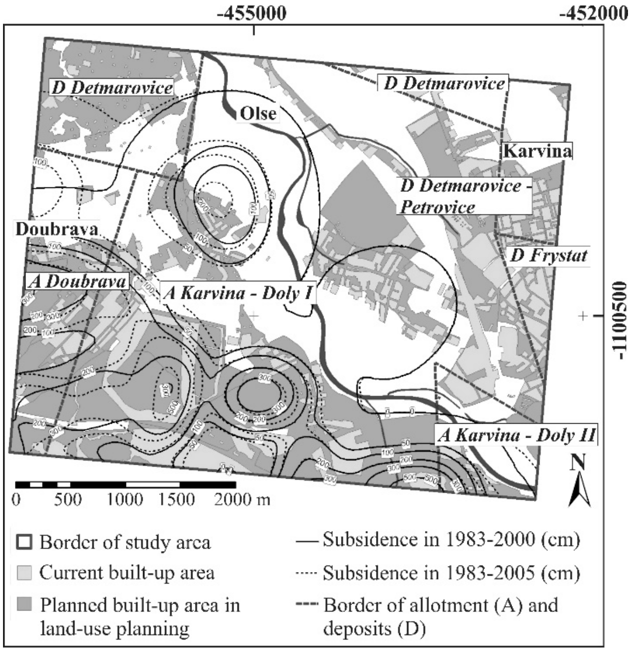

Figure 4. Subsidence caused by black coal mining in 1983-2000 and 1983-2005 with marked current and future development (subsidence data by OKD)

The selected study area offers a unique educational opportunity to compare land without underground mining impacts, which forms a vast area without subsidence, with land having clear manifestations of undermining with gradual changes from small to more prominent subsidence. The land “without subsidence” is situated in the northern half of the map sheet.

During the course of the observed periods, the area of land unaffected by subsidence decreased from the original 60.5% (11.04 km^2) to 37.5% (6.86 km^2) (Fig. 5). The second most frequent group was that with subsidence interval values “up to 50 cm” and here the subsidence covers more than a fifth of the overall area Gradations in the observed time periods were 26.8%, 21.4%, 30.5% and 29.7%. A much smaller area is taken up by subsidence in the “50-100 cm” interval, where values ranged from 7.5% (1.37 km^2) to 7.9% (1.44 km^2) and eventually to 6.9% (1.26 km^2). A characteristic development of the subsidence basin is depicted by the graphic representation of subsidence in the “100-200 cm” range and this trend can also be observed in the following intervals. There is a sharp rise in values over time from 4.2% (0.77 km^2) to a final value of 12% (2.19 km^2). A similar course, though with lower values, was registered in “200-300 cm” interval (0.9%, 2.2%, 6.7% and 6.4%). A sharper increase in values is observed in the “300-500 cm” interval, with a clear increase in subsidence extent from 0.2% (0.04 km^2) to 6.7% (1.23 km^2), which corresponds to an increase of 3.35%. The last evaluated interval of “500-1200 cm” was more balanced and it contains the lowest values in the monitored set, ranging from 0% to 0.7% (0.13 km^2).

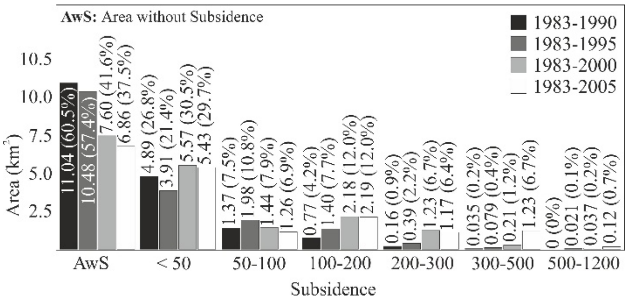

Figure 5. Variations in subsidence in the study area in the individual time sections

3.2. Evaluation of subsidence in relation to the current built-up area

Gutierrez et al., (2002), Juany et al., (2004), Kies et al., (2006), Deguchi et al., (2007), Gao et al., (2007), Gourmelen et al., (2007), Cui et al., (2008), Gueguen et al,. (2009), Lesniak & Porzycka (2008), Bayer et al., (2009), Tripathi et al., (2009) examined subsidence basin conditions which formed in consequence to mining activities.

Figure 6 provides well-arranged results of overlay analyses between subsidence in the study area and a surface area of the current built-up area during the four observed periods of 1983-1990, 1983-1995, 1983-2000 and 1983-2005. The current built-up area represents an important evaluation criterion as this landscape element is among the most vulnerably impacted sites in territories affected by mining. This is due to the huge potential damage caused to engineering objects. Such identification with respect to subsidence is vital for property owners to claim possible damages due to underground mining, and also for mining organizations to respond to state organizations’ demands for compensation. Naturally, when the built-up area is not located directly at mining sites, the situation is less complicated for mining companies. The viewpoints of future developers, investors, designers, architects, engineering geologists and other users and expert workers are also significantly relevant. They must be able to incorporate basic information on mining impacts into their plans, and the optimal way this can be achieved is through implementation of this studied information into land use plans.

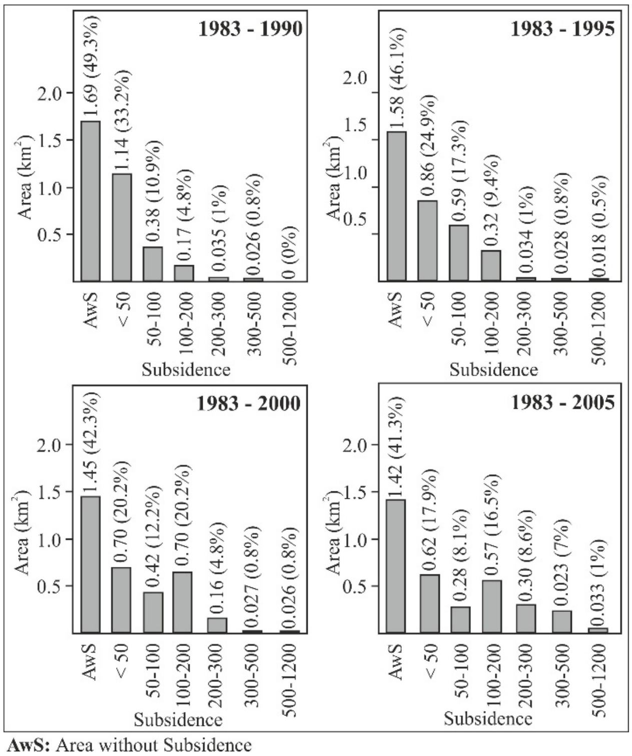

Figure 6. Relationships between current built-up area and subsidence in the study area

An important source of built-up area distribution for this study is the current built-up area identified by vectorization of registered topical aerial photos within geographic information systems. The size of the built-up area in land unaffected by underground mining did not change significantly in the course of the monitored periods. There was a decrease of 8%, from the original 49.3% (1.69 km^2) to the final 41.3% (1.42 km^2) (Fig. 6). A falling trend in subsidence expansion over time can also be observed in the second subsidence interval of “up to 50 cm”, where the built-up area was greatly reduced from 33.2% (1.14 km^2) to 20.3% (0.7 km^2) and ultimately to 17.9% (0.62 km^2) in the last examined time period. In the third interval of “50-100 cm”, an initial rise from 10.9% (0.37 km^2) to 17.3% (0.59 km^2) was observed with subsequent falls to 12.2% (0.42 km^2) and 8.1% (0.28 km^2). In the following intervals there is an increasing trend of sites with subsidence distribution over time. In the interval of “100-200 cm”, the values increased from 4.8% (0.17 km^2) to 16.5% (0.57 km^2). A much more pronounced increase in values is apparent in the interval of “200-300 cm”, where the built-up area increased from 1% (0.04 km^2) to 8.6% (0.3 km^2) during the observed period. There was a sharp rise in the size of the built-up area in the “300-500 cm” subsidence values, which approximated 840% compared to the first and the fourth time section, from an initial 0.8% (0.03 km^2) to 6.7% (0.23 km^2). Over the observed years, the built-up area situated on subsided land at “500-1200 cm” increased from zero to 1% (0.03 km^2) in the total built-up area.

3.3. Evaluation of subsidence in relation to land use plans

The following overlay analyses in the study area identified mutual relationships between the estimated subsidence for 2003-2010 and municipality land use plans. The applied digital land use plan for the analyses originated from vectorization of raster maps of the individual municipalities in GIS environ. These were obtained through cooperation with the Moravian-Silesian Regional Office. They depicted consequent complicated unification since the individual territories had been planned by different urban planners. Despite complying with identical regulations and recommendations, in certain cases these were interpreted with particular differences. There is a clear impact on the land use plans caused by varying thoroughness of the urban planners. This was mainly influenced by the different characteristics of individual areas which had varying numbers of functional sites of land use plans dependent on their purpose. These varied in different towns and villages because of differing historical traditions in individual territories, and because of their unique production capacities, their means and their environmental pressures. Following extensive effort, this time consuming work resulted in the unification of the land use plan so that it could be utilized in a compatible manner for subsequent overlay analyses in this study area.

The analyses imply that subsidence impacts in the area are only partly taken into consideration in the planning of future development (Fig. 7). The largest area of the planned development (57.8% - 3.85 km^2) is to be constructed on the most suitable land site without subsidence. In the following five intervals the distribution of the built-up area is quite balanced, ranging from 7.9% to 9.9%, and this is a disappointing discovery. On the subsidence interval “up to 50 cm”, 8.1% (0.57km^2) new development is planned and slightly less development (7.9% (0.55 km^2) is to be constructed on the subsidence interval of “50-100 cm”. The second largest built-up area according to the analyses (9.9% (0.69 km^2) will be constructed on the subsidence interval of “100-200 cm”. A slight decrease was observed in the following group of subsidence “200-300 cm”, where 8.2% (0.57 km^2) is planned, and for the interval of “300-500 cm” there is a slight rise to 9.7% (0.68 km^2). The smallest group was on subsided land of “500-1200 cm”, where only 1.5% development (0.11 km^2) is planned.

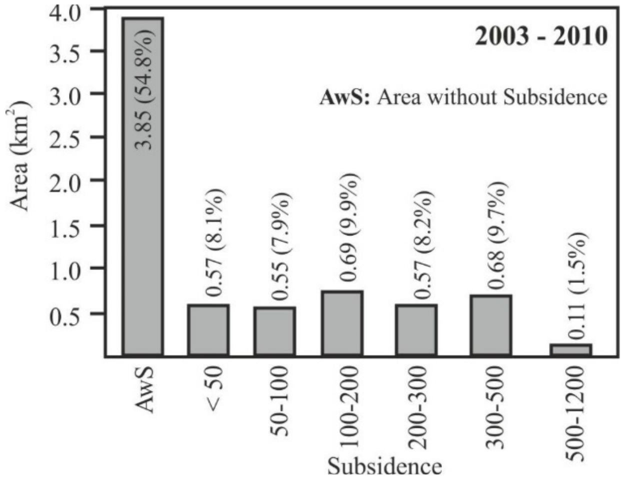

Figure 7. Relationships between planned development and subsidence (2003-2010) in the study area.

3.4. Estimated subsidence in relation to the engineering-geological zones

The necessity to consider engineering-geological conditions in land use planning has been reported in various connections by Dai et al., (1994); Pacheco & Oliveira, (1998); McCall, (1998); Kiersch (2001); Lee et al., (2006); Li & Liu, (2004); Marschalko et al., (2008.b, c); Reeves (2008); Marschalko et al., (2009); Marschalko & Treslin (2009).

In the assessment of conditions for future development in landscape affected by mining, it is interesting to note the relationships between engineering-geological zones in the range of particular land mining subsidence value impacts. The spatial distribution of the individual engineering-geological zones in relationship to selected subsidence value ranges is shown in figure 8. An example of this impact evaluation is the site with the highest subsidence values of “500-1200 cm”.

This site contains only zones of spoil banks, stock piles and dumps *An* and zones of settling basins and waste dumps *Ao*. The *An* zone is represented by carboniferous waste rock, slag and fly ash, and the *Ao* zone is composed of anthropogenic deposits such as rubble and solid municipal waste.

3.5. Slope deformations in the study area

In the evaluation of future development shown on land use plans in these mining affected territories, one of the most important geofactors noted is the existence of slope deformations which are compared with sites without mining impacts. To consider such impacts in this study area, overlay analyses were carried out in GIS with selected isocatabases of estimated subsidence with slope deformation, together with the current and planned built-up area according to the land use plan (Fig. 9).

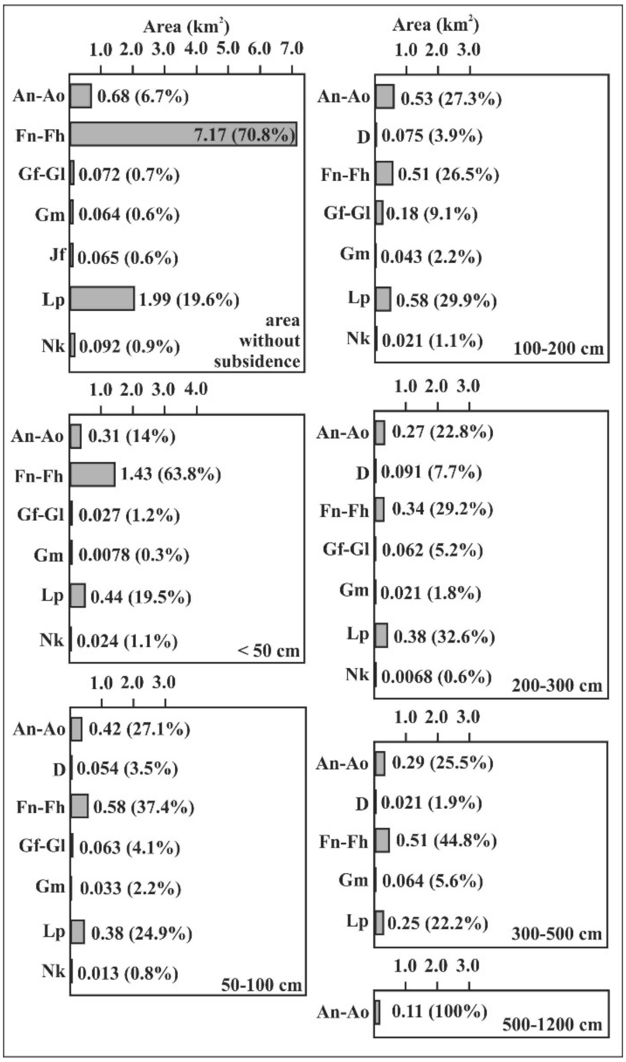

Figure 8. Relationships between area of major engineering-geological zones and subsidence (2003-2010).

There are many factors influencing slope deformation in mining areas. The most important of these are land surface sinking, changes in slope gradient and in height, difference between the affected ground surface and the surrounding ground characteristics. The existence and influence of increased tensile load in affected areas are very often underestimated, because even in places with minimum subsidence this can be decisive in the activation of slope deformation. Hence loosening of the inner structure, an increase in void content and a decrease in rock cohesion may occur (Marschalko et al., 2008a, b, c, d). Most importantly, changes in hydrogeological conditions can have a decisive influence on slope stability. Relationships between slope movements and mining have been previousy discussed in various connections by Culshaw et al., (2006), Erginal et al., (2008), Marschalko et al., (2008.d), etc.

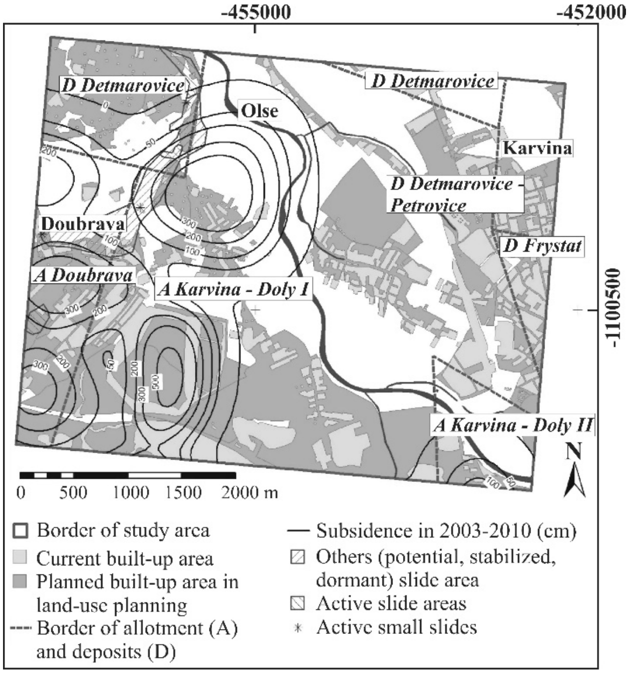

Figure 9. Subsidence due to mining in 2003-2010 with marked current and future development and slope deformations (subsidence data by OKD)

Identified slope deformations occurring in the study area were divided according to surface areas into areal shaped and point shaped ones, and according to their degree of activity, these categories were subdivided into active landslides and others such as potential, stabilized and buried.

In the *distribution of active areal shaped slide areas* there is a slide area situated on the subsidence intervals of “100-200 cm” (39.7%) to “300-500 cm” (6.2%), along the western margin of map sheet 15 44 03. This falls predominantly in the cohesive drift zone *Gm* (68.4%) and in the zone of polygenetic loess sediments *Lp* (17.4%). However, a very important finding is that despite an active slope deformation, development in the U_BI_2 category (Table 1), covering the zone of individual scattered residences, is planned on 91% of the landslide surface area there.

The following two slope deformations form part of the so-called “other slope” areas. The first is completely situated on the subsidence interval of “100-200 cm” in the zone of polygenetic loess sediments *Lp*. The second slide area is affected by subsidence in the entire interval of “100-200 cm”, but it is also found in the predominantly cohensionless glaciofluvial and glacial sediments zone *Gf-Gl* (59.5%) and in the zone of alternating fine-grained sandy and gravelly sediments *Nk* (29.4%).

Table 1. The land use plan categorization.

Functional zones	Codes
zone for land reclamation	U_F
zone of individual residences	
zone of continuous individual housing	U_BI_1
zone of scattered individual residences	U_BI_2
zone of mixed individual housing	U_BI_4
zone of family houses	U_BI_6
zone of unspecified individual housing	U_BI_0
mine's interest area	U_DL_2
production zone	
small-scale production zone	U_V_1
unspecified production zone	U_V_0
mixed production zone	U_V_5
industrial production zone	U_V_3
zone of heavy industry	U_TP
zone of technical facilities	U_T
zone of sports and recreation	U_SR
central zone	U_C
zone of collective housing	U_BH
zone of gardening allotments	U_ZO
zone of public grounds	U_VP
zone of civic amenities	U_O

The last active slide area in the study area is in the north, at the boundary of Detmarovice and Doubrava municipalities. This one is predominantly on an area of 88.2% without subsidence in the zones of alternating fine-grained sandy and gravelly sediments *Nk* (40.2%) and the predominantly cohensionless glaciofluvial and glacial sediments zone *Gf-Gl* (34.2%). The current built-up area takes up 6.2% of the total slide surface area, but future development is planned for an area representing 57.3%. Subject to a Doubrava municipality land use plan, development is planned for scattered individual residences and gardens (U_BI_3), and a mixed zone (U_S) is the subject of a Detmarovice municipality land use plan.

According to Geofund records, a significant surface area of 55.6 ha in Doubrava and Karvina municipalities forms part of the so-called *other areal shaped slide areas* and this is classified as a potential slide. This area is situated on subsidence intervals from "up to 50 cm" (8.3%) to "200-300 cm" (12.3%).

There are 3 *active very small slide areas* located in Doubrava municipality in the study area. All three areas are situated on a dominant slope deformation described above as "other slide" areas. The first is found in the built-up area, in the subsidence interval of "100-200 cm" and in the zone of polygenetic loess sediments *Lp*. The second is in a forest, in the subsidence interval of "100-200 cm" and in the predominantly cohensionless glaciofluvial and glacial sediments zone *Gf-Gl* while the last is situated in the subsidence interval of "up to 50 cm" and in the zone of polygenetic loess sediments *Lp*.

4. CONCLUSIONS

The study of subsidence distribution implies trends which confirm that the area unaffected by subsidence impacts decreased over time due to the expansion of the subsidence basin (Fig. 5), and thus a redistribution of impacts occurred in the study area (Figs. 3, 4). These impacts were caused by black coal mining in the Karvina Mine, the CSA Plant and in allotments of Karvina-Doly I, Doubrava and Darkov. The locality with the highest subsidence values of over 500 cm is situated at the site of the main final sedimentation reservoir of the CSA Plant, almost 80 m north of the railway line. Subsidence values over 600 cm were also identified in sites between the Stonavka River and Lipiny Street. While the subsidence value was higher than 400 cm in time period 1983-1990, it was increased to higher value than 600 cm in time period 1983-2005.

It is also possible to observe similar increasing tendency for current built-up area. It can be seen in figures 3 and 4. As the result of the observations in these periods, underground mining activities considerably had a negative impact on the current built-up area (Fig. 6). Despite this, the built-up area erected on the most affected subsidence interval of "500-1200 cm" during the last time period of 1983-2005 is only 1%.

According to the table of Land Use Plan Categorization (Table 1), development planned for the most impacted subsidence interval of "500-1200 cm" is in the U_V_0 category of Unspecified Production Zone and also in the U_DL_2 zone of mining interest. This development area covers 1.54% of the overall planned development (Fig. 7).

An example of evaluation of mutual relationships between undermining and engineering-geological zones is the site with the highest subsidence values of "500-1200 cm". This site contains only zones of spoil banks, stock piles and dumps *An* and zones of settling basins and waste dumps *Ao*. The *An* zone is represented by carboniferous waste rock, slag and fly ash, while the *Ao* zone is composed of anthropogenic deposits such as rubble and solid municipal waste, (Fig. 8).

Conclusions from the slope deformation analyses in the study area imply that there are three active areal shaped slide areas, one so-called other areal shaped slide area (55.6 ha) and three active very small slide areas. A possible risk is posed by the active areal shaped slide areas which have an overall surface area of 12.05 ha. The first active landslide is located along the western margin of the interest map sheet. It is located at subsidence intervals from “100-200 cm” (39.7%) to “300-500 cm” (6.2%), and it lies in the predominantly cohesive drift zone *Gm* (68.4%) and in the polygenetic loess sediment zone *Lp* (17.4%). An alarming finding is that on 91.54% of this landslide surface area there is an active slope deformation and also planned development in the U_BI_2 category covering the zone of scattered individual residences. Another spatially significant active slide area of 6.3 ha in the study area is a landslide in the north, on the boundary of the municipalities of Detmarovice and Doubrava. This one is predominantly situated on territory unaffected by subsidence (88.2%) and falling within the zones of alternating fine-grained sandy and gravelly sediments *Nk* (40.2%) and the predominantly cohensionless glaciofluvial and glacial sediments one *Gf-Gl* (34.2%). The current built-up area occupies 6.2% of the total surface area of the landslide, but a negative discovery is that future development is planned for an area covering 57.3%. This should predominantly entail a zone of scattered individual residences and gardens (U_BI_3) subject to a Doubrava municipality land use plan and a mixed zone (U_S) subject to a Detmarovice municipality land use plan.

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