Acta Geodyn. Geomater., Vol. 6, No. 3 (155), 359–367, 2009

# EVALUATION OF MINING SUBSIDENCE USING GPS DATA

**Hana DOLEŽALOVÁ, Vlastimil KAJZAR,**
**Kamil SOUČEK and Lubomír STAŠ**

*Institute of Geonics, Academy of Sciences of the Czech Republic, v.v.i., Studentská str. 1768, 70800 Ostrava-Poruba, Czech Republic*
*Phone +420 596 979 111, Fax +420 596 919 452*
**Corresponding author's e-mail:* dolezalova@ugn.cas.cz

(*Received* February 2009*, accepted* April 2009)

**ABSTRACT**
The observation network was built for the repeated determination of spatial position of points by means of the GPS method. It was built on the surface above extracted mining panels near Karviná, to monitor the development of subsidence depression in non-trivial geo-mechanical conditions. Two years of repeated surveying gave us the information about the process of creating of the subsidence depression in such area. The results gained so far show the important influence of the complicated tectonic situation on the behaviour of surface subsidence. A smooth development of subsidence depression without important irregularities was found out on sites without tectonic faults, while on sites where rock mass is disturbed with tectonic faults, the shape of subsidence depression is very irregular.

**KEYWORDS:** undermining, subsidence depression, tectonic faults

## INTRODUCTION

In 2006, the project was launched at the Institute of Geonics of the Academy of Sciences of the Czech Republic, v.v.i. dealing with the construction and the repeated geodetic surveying of an observation network above extracted mining panels and aimed at monitoring of the impacts from undermining in the vicinity of Karviná. The primary objective was to monitor the development of subsidence depression in non-trivial geo-mechanical conditions; for this purpose the area with several significant tectonic faults was chosen. Therefore, in autumn 2006, the construction of the observation network was commenced for the repeated determination of spatial position of points by means of the GPS method. By evaluation of results from repeated measurements, it is possible to monitor the development of subsidence depression in the area of concern.

## LOCALIZATION AND DESCRIPTION OF THE AREA OF INTEREST

The location is situated in the Upper Silesian Coal Basin in the north part of coal panel in the ČSM Colliery-North, Louky mining area, demarcated by the Darkov Colliery and by the state border on Poland in the east direction. In this area, the exploitation of the mining panel 361 000 with the face length of 180 m and with lateral length of longwall advance of roughly 500 m was planned in the coal seam 36 since October 2006 till June 2007. The extracted coal seam is situated at the depth of 960 m under the surface and its thickness varies in the area of interest (1.4 – 2 m). In approx. 15 % of the mining panel area, the coal seam is affected by erosive development. The longwall mining panel was mined from the east to the west direction. The rock mass in this part consists of typical for the Upper Silesian Coal Basin upper carboniferous molasse sediments consisting mostly of coal-bearing siliciclastic continental deposits. The Upper Silesian Coal Basin is divided into tectonic blocks by a set of normal faults of tens to hundreds of meters amplitude (Dopita, 1997). In the south direction, in distance of approx. 50 m, a significant tectonic normal fault X passes sub-parallel with mining panel blocks in E-W direction. This fault has the thickness of deformation zone of approx. 25-50 m with the amplitude of 350 m, with dip of approx. 60°. Fault X is in overburden of mining panel 361 000. Similarly, in the south direction sub-parallel to the fault X, there passes a significant tectonic fault A with the fault amplitude of approx. 350 m and with dip of 60°, which orientation is opposite and thus the fault deflects from the area of interest. There occurs fault 6 of minor importance in the north side at approx. 400 m from the mining panel 361 000. Then in the east, the unnamed fault is encountered, which passes in the N-S direction (Doležalová et al., 2008).

Together with exploitation of the mining panel 361 000, it was planned to extract the mining panel 361 002. However, due to unfavourable geological conditions, this plan was abandoned and it was decided to exploit mining panel 293 102 instead. This mining panel is situated in the south direction from the exploited mining panel 361 000 in the coal seam

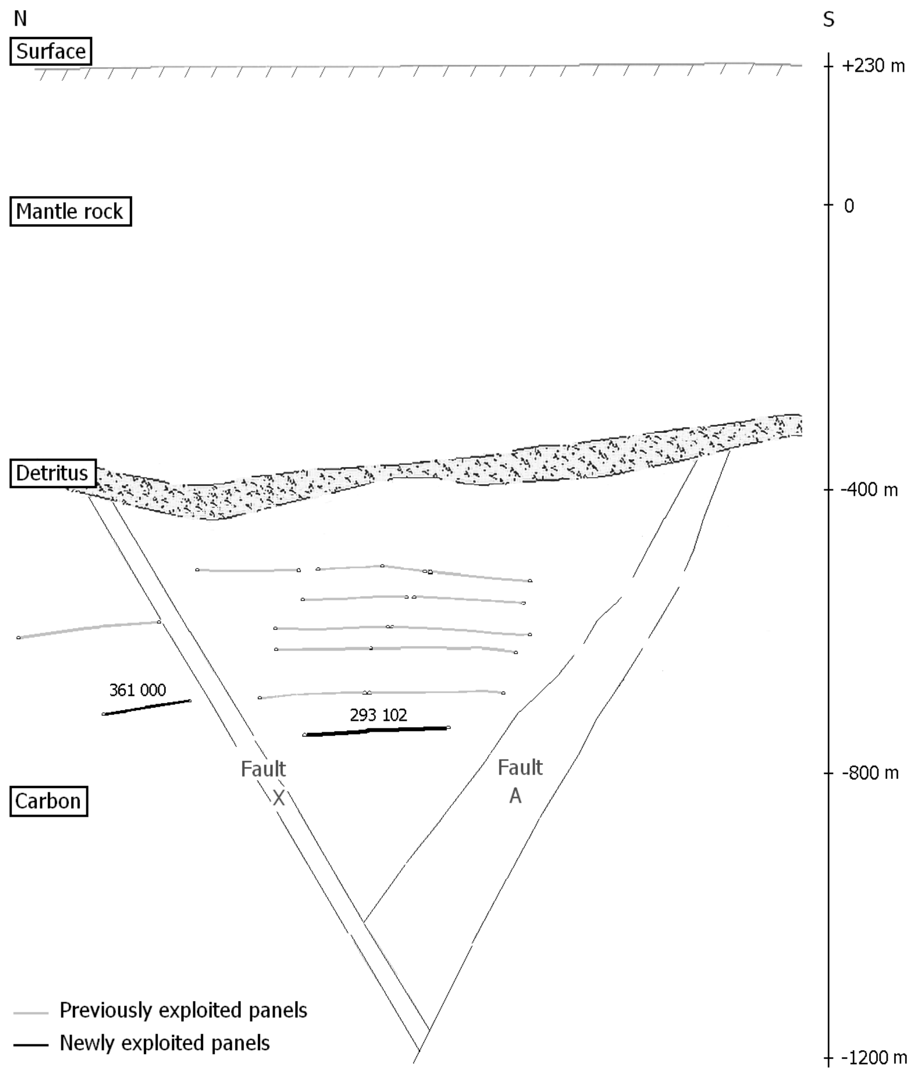



**Fig. 1** Simplified N-S cross-section.

29 at the depth of 990 m under the surface. The face length of the mining panel is 185 m and the lateral length of longwall advance is up to 880 m. The average thickness of extraction is 3.2 m and again, the longwall method with controlled caving was used as the mining method. Exploitation took place since May 2007 till April 2008. In the area of interest, the coal seam No. 29 is situated between tectonic faults X and A (see Fig. 1). Projections of both exploited mining panels, together with tectonic situation in the area of interest, are shown in Figure 2.

In 2006, the area of interest could be characterized as the relatively stabilized area, from the viewpoint of subsidence. In the past, one coal seam was extracted here, situated at the depth of 850 m, in the roof of the mining panel 361 000; its thickness was 2 – 2.5 m. There were also five coal seams exploited at the depth from c. 780 m to 950 m, in the roof of the mining panel 293 102; the thickness varied from 1.3 to 2.3 m. The impact of exploitation of these coal seams on the surface was recorded by repeated levelling and thanks to this measurement, it can be stated that the surface in 2004 showed that the subsidence was moderately slowly decreasing up to 5 cm a year.

## CONSTRUCTION OF THE OBSERVATION NETWORK

The plan of construction of the observation network was based on the assumed effects from undermining in this area according to the model of assumed impacts from exploitation of the originally planned mining panels presented by the company IMGE (OKD, a.s., IMGE, o.z.) in the form of surface iso-lines of subsidence. After the detailed recognition, it was decided to stabilize points in the lines, and/or in the curved lines, passing preferably over the whole subsidence depression reaching behind its edges and further, to stabilize scattered points in places, where it will be necessary to densify the observation network. The location of individual points was adapted to conditions of the landscape where the surface was reclaimed, and the points were appropriately situated for the GPS surveying.

In order to use the existing structures in the area of interest as much as possible, a local road was used for one of the lines of the observation network where the points were stabilized with the nails in the verge (green points, see Fig. 2). These points form a profile, which passes through the subsidence depression from the east in the southwest direction, where this profile reaches the edge of the subsidence depression. There was no other road in the area of interest, which could be used for the stabilization of points. However, there is water piping, which passes through almost across the subsidence depression in the E-W direction above one of the mining panels and this piping can be used for surveying. GPS antenna is always centred directly on the particular site on a high frame of supporting structure. A special holder was designed for this purpose and its structure holds the antenna always in the same place on the frame during each surveying. In this way, 21 points on the individual frames of the piping are surveyed (blue points, see Fig. 2). Several triangulation and levelling points of the national points network are situated in the area of interest and these points were included into observation (pink points, see Fig. 2). As no other suitable structures exist in the area of interest, it was necessary to establish points of the observation network directly in the ground. These points were stabilized by means of one metre steel rods that were hammered into the ground where ended in the ice-free ground. In this way, the three cross profiles were formed and one longitudinal profile; also, several additional points were scattered in this way (yellow points, see Fig. 2). More than 100 points were repeatedly surveyed in total.

## GPS SURVEYING

Surveying has been carried out at the observation network since November 2006 using the two GPS Leica sets, GPS System 1200. Individual points of the observation network are surveyed by means of a rapid static method with observation period of at least 10 minutes for each point. The trigonometric point was selected for a reference station. It is a point of the national network with the defined coordinates in S-JTSK and in ETRS-89 system. This point is situated in Karviná, outside the assumed undermining effects, in the distance of several kilometres from the observation network, near the state border on Poland. The obtained accuracy of GPS surveying in the area of interest is from 5 to 20 mm for spatial position of a point (XYZ). In order to record an incremental development of undermining effects, the interval of roughly 5 weeks was chosen for repeated GPS surveying.

Afterwards, the data from field surveying are processed with computer, by means of the so-called post-processing where the data are also transformed into the local coordinate system. The results of processing from the GPS surveying are the spatial coordinates of the surveyed points in the WGS-84 and S-JTSK systems. Thanks to the stabilization of points of the observation network in the form of the lines and the scattered points, it is possible to express the subsidence of individual points and also in the profiles and over the area.

The first surveying at the observation network took place in November 2006 when the points were surveyed on the piping for the first time and also a few points that were stabilized with rods. Other surveying followed with the incremental stabilization of additional points. However, because of the possibilities of the Grant project and due to inaccurate information concerning the commencement of exploitation of the mining panel 361 000, the points in the area of interest were not surveyed before the commencement of exploitation in October 2006. In the period between October and November 2006, i.e. in the period from the beginning of exploitation till the start of surveying, the small part of mining panel was extracted. But the effects of undermining on the surface were delayed; therefore it is assumed that the surveying began in the period when the undermining effects showed only moderate changes on the surface and only in the small part of the area of interest. Part of the mining panel 361 000, extracted before the commencement of surface geodetic surveying, is highlighted with red colour in Figure 2.

## DEVELOPMENT OF SUBSIDENCE DEPRESSION

During exploitation, when industrial mineral is extracted over a relatively large area, vacant spaces are formed in rock mass. This leads to disturbance of the so far balanced stress-deformation condition in rock mass, which attempts to transform into the other balanced condition again. This induced change of stress condition produces the adequate deformation in the vicinity of the newly formed vacant spaces, which is usually demonstrated with the movement of the surface. The result of these phenomena is the formation of subsidence depression of a bowl shape (in a case of horizontal mining panel bedding).

The extent of the creating subsidence depression is affected by many factors. Factors that mostly affect the resulting size of the subsidence depression are the size of mined out area, the depth of formation of effective area under the surface, i.e. the depth of exploitation and the critical angle of effects.

The subsidence depression develops in the course of time. General evolution of subsidence curve of the monitored point expressed as the share of actual subsidence of this point in the relevant time in total subsidence is illustrated in Figure 3.

Time, which the rock mass needs for development of deformation since the beginning of extraction of the deposit until its consolidation after termination of exploitation, can be divided into four stages (see Fig. 3; Hortvík, 2005):

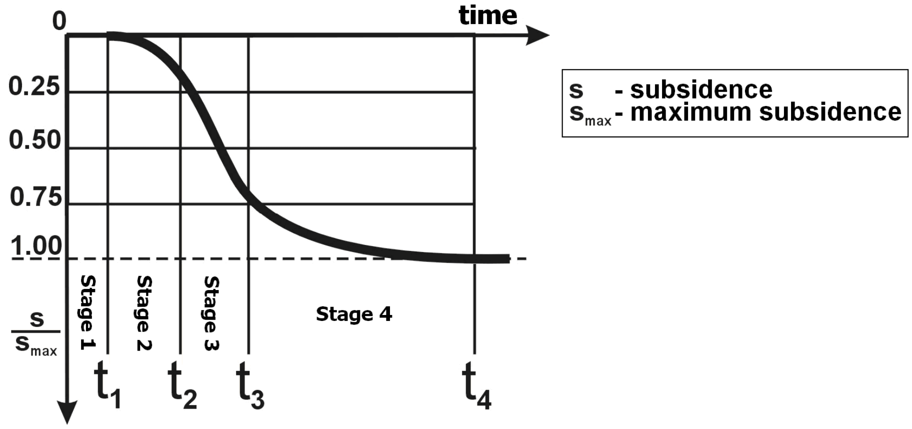



**Fig. 3** Time related development of subsidence of undermined point.

- Stage 1 – time needed to show the first movement, caused by roof fall or by sagging of the overlaying strata, on the surface;
- Stage 2 – acceleration of increments of subsidence per time unit starts;
- Stage 3 – maximum increments of subsidence per time unit takes place;
- Stage 4 – reduction of increments of subsidence, surface is slowly stabilizing, and disturbed overlaying rocks are dislocated to the extracted deposit and pressed down to the original amount or transformed into a new amount, which corresponds to the balanced condition. This stage takes several years, depending on the strength of accompanying rocks.

## EVALUATION OF SUBSIDENCE

The size of subsidence of points, which are repeatedly surveyed by means of the GPS method, is calculated for each point as a difference of heights ascertained by the repeated surveying. In this way, we can ascertain not only the subsidence in individual stages of surveying in the roughly monthly cycle, but we can also determine the total subsidence so far, since the commencement of surveying. The subsidence of points that clearly demonstrates the effect of underground mining on the surface can be expressed, at the relevant observation network, for individual points, for several profiles and also by means of a surface model.

Figure 4 shows the curves of the behaviour of subsidence of points stabilized on a local road with the position above the central part of the mining panel 293 102 (points c12, c14, c16, c18). These points lay in the line with a spacing of approximately 100 m. In each graph, we can differentiate two main parts. In the first part (roughly until the half of 2007) we can see almost regular subsidence of all the illustrated points varying between 12 and 18 cm. The main reason of this subsidence is extraction of the first mining panel.

The second phase of development of subsidence curves can be assessed as the reaction to extraction of the second mining panel, above which these points are situated. From the illustrated course of subsidence of individual points, the stages of gradual subsidence, dramatic changes in the height and subsequent slow decreasing of subsidence are apparent. This behaviour corresponds with the general subsidence curve and demonstrates the immediate effect of exploitation of this mining panel on the monitored points.

Only in the case of point c18, situated behind the tectonic fault A, we can see the almost regular subsidence. The terrain in the vicinity of this point

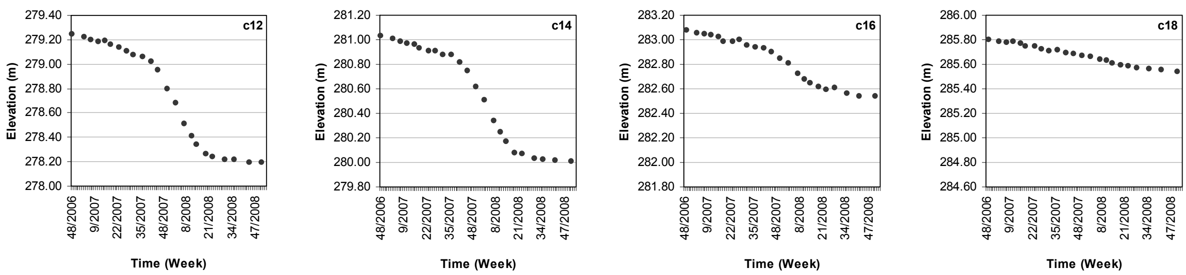



**Fig. 4** Time development of subsidence of selected points of profile C.

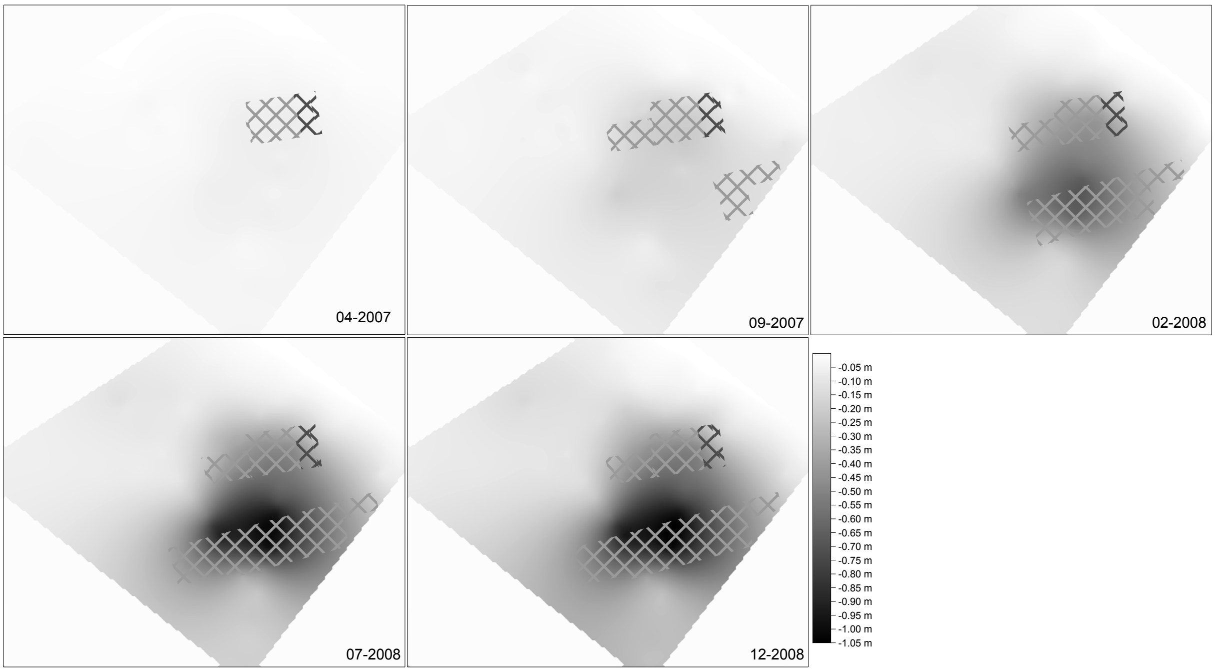



**Fig. 5** Development of subsidence depression.

does not change so dynamically, as one would expect. This is certainly caused by the complicated geo-mechanical situation of local bedrock.

The sufficiently dense network of points enables to assess the effects of exploitation in more complex manner, by creating the line and spatial models.

By means of the line graphs, it is possible to observe the course of the changes concerning the terrain height in the area of interest on a few profiles, i.e. the series of points in the lines passing through in different directions over the whole area. In the profile C (see Graph 2), we can see the behaviour of subsidence of the above-described points in a wider context. Even here, the different development of subsidence is apparent in the profile from the point c18, i.e. behind the tectonic fault A.

Surface mathematical models are prepared for evaluation of surface changes in the area of interest. Figure 5 shows the models outlining the gradual behaviour of formation of the subsidence depression in the period of five months since the beginning of surveying in November 2006 until December 2008. Individual pictures show the extracted areas always as of the relevant date. In the case of the north mining panel 361 000, part of the mining panel is differentiated with dark hatching, which identifies the extracted area before the commencement of GPS surveying.

- During the first period of surveying until April 2007, no important movement of the surface occurred; subsidence occurs up to 8 cm.
- In the next modelled period, exploitation of the mining panel in the coal seam 36 was terminated (June 2007) and exploitation starts in the coal seam 29 (May 2007). From the illustrated model, we can derive the extent of subsidence depression dependent on the extraction of the mining panel 361 000. On the basis of the knowledge from other analyses it is apparent that extraction of the second mining panel 293 102 has no significant effect so far on the shape and the size of the creating subsidence depression. At that moment, the present shape and size of the creating subsidence depression is defined primarily by the extracted mining panel 361 000. The total measured subsidence is up to 20 cm.
- In the following five months, the dynamic development of the changes on the surface occurs. The advance of mining in the mining panel 293 102 contributed significantly to the resulting changes. The maximum subsidence, since the beginning of surveying, reaches almost 70 cm, i.e. the height difference is up to 10 cm per month in average in the most affected part.
- Picture of development of subsidence depression as of July 2008. At that moment, the extraction of both mining panels was terminated (April 2008). The important changes in the height continued also in this period. On the basis of the knowledge from the assessment of points and profiles of the surveyed points, by the end of this modelled period, there comes the phase of subsidence slow decreasing. Probably, the shape of the resulting subsidence depression will not significantly change. The phase of stabilization of the surface starts in the whole area.

- Last picture shows the situation after twenty-five months of monitoring in the area. Relatively minimum changes in terms of the height occur. In the area, where the most dramatic subsidence occurred in previous period, the total change in this period was up to 5 cm only. The whole area stabilizes and the phase of rheologic after-subsidence takes place.

When creating the model, the values ascertained in the irregularly placed points are usually interpolated into the regular network of points (the so-called grid). For this purpose the different interpolation methods are used. Therefore, a choice of interpolation method has a significant influence on the resulting model (e.g. Staněk, 1999). While creating the described model, the method of basic kriging with point assessment was used.

**COMPARISON WITH THE ASSUMED VALUES**

Mining companies model the expected surface effects caused by extraction of mining panels. In the Ostrava-Karviná Coalfield, these effects are determined with the Budryk-Knothe method and are presented with the form of iso-lines of subsidence on the surface, usually first prior to the commencement of exploitation, i.e. the assumed effect from extraction of the planned mining panel and later after termination of exploitation, i.e. the assumed effect from the actually mined out spaces. Initial data for these calculations are the extent of mined out space, its thickness and depth and critical angles of the effects in mining panel roof.

Figure 6 illustrates the above-mentioned spatial model of the subsidence depression in a wider colour spectrum completed with the corresponding iso-lines in red colour and prepared from the values surveyed by GPS since the beginning of surveying until December 2008, together with two models of the assumed undermining effects on the surface.

Part of the model of the assumed effects of exploitation from the planned extracted spaces in the ČSM Colliery, Louky mining area, between 2007-2008 is shown in Figure 6 with blue iso-lines of subsidence (the model was submitted by the Municipal Building Department). This model corresponds with the period of carried out GPS measurements.

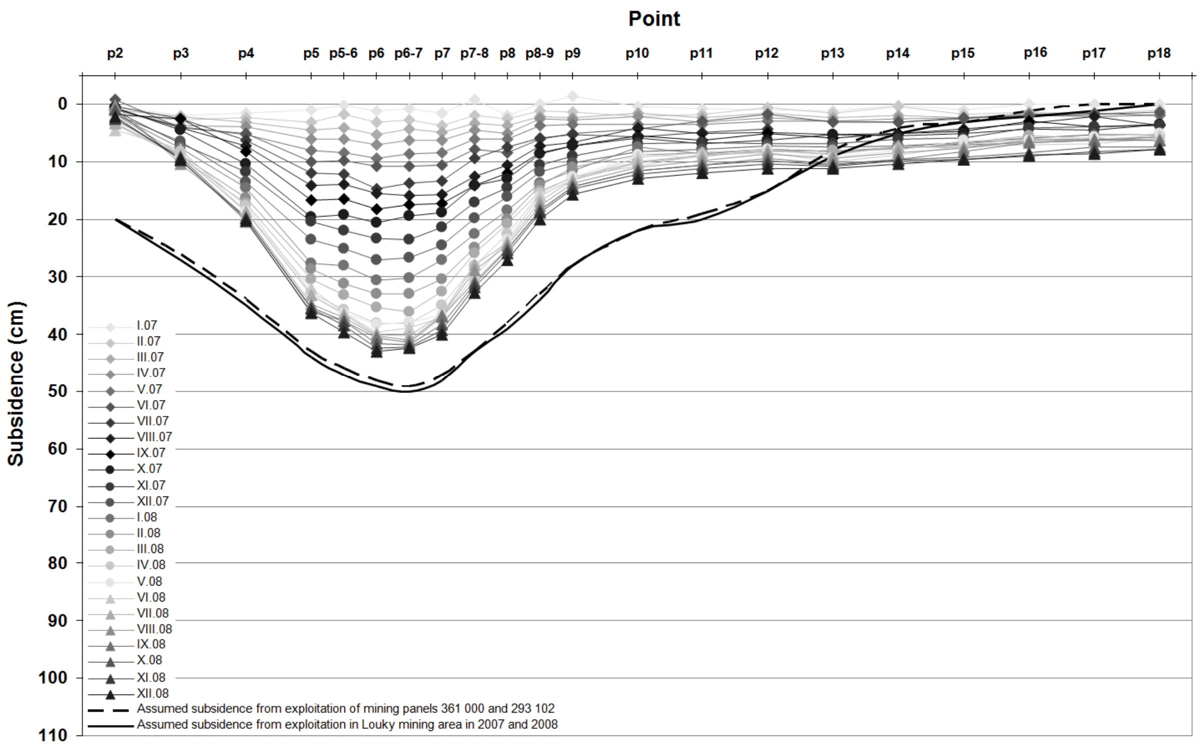
The model of the total assumed effects of exploitation from the actually mined out spaces in the mining panels 361 000 and 293 102 is shown in figure 6 using the green iso-lines (the model was provided by OKD, a.s., IMGE, o.z.). This model does not assume the effects of extraction of other mining panels in the area of interest and was created for the period since the beginning of extraction until the termination of effects on the surface caused by exploitation of both mining panels.

The models of the assumed subsidence differ slightly from each other, primarily in the east and in the south part, where the blue model counts with the effects of undermining caused by the extracted mining panels in the vicinity of the area of interest. In the remaining parts, the behaviour of iso-lines of subsidence of both models is almost identical.

From comparison of both models of the assumed subsidence with the subsidence measured on the surface by means of GPS since the beginning of surveying until December 2008 (red iso-lines), it is apparent that they are not in total agreement. In the place where it was not possible to stabilize points in the sufficient density (south-west part of the subsidence depression), the spatial model of subsidence depression can be slightly distorted from the values measured by GPS, however, it can be stated that for the most area of interest the shape of red iso-lines of actual subsidence does not correspond with the oval iso-lines of the assumed subsidence and distribution of the measured subsidence differs from the assumed values.

The real subsidence of monitored points exceeds the assumed values in the centre of the subsidence depression. Also in the northwest part of subsidence depression the larger subsidence was measured (around 10 cm) behind the assumed boundary of undermining effects (4 cm according to the regulation). On the contrary, in the northeast part of subsidence depression, the real subsidence is significantly smaller in comparison with assumptions; 25 cm were assumed in this area. As these discrepancies do not relate to scattered points only, but always to the groups of points in a certain part of the area, it means that this is not an incidental phenomenon, but it is the result of the complicated geo-mechanical situation, primarily due to close tectonic structures.

The particular values of the measured subsidence of points in the profile P are shown in Graph 1 together with both models of the assumed subsidence. The profile P consists of points surveyed on the supporting structure of the piping (blue profile, Fig. 2). This profile passes through the east to the west above part of the north mining panel 361 000. The continuous development of subsidence depression without any dramatic changes is apparent from the behaviour of the measured subsidence of points. The most eastward point of the profile, point p2, shows a negligible subsidence up to 5 cm only; the other points in the line (p3 to p5) undergo subsidence more significantly. This situation can be caused by fact that exploitation in the most eastward part of the mining panel started earlier that the surveying of the surface points on the piping. Despite this fact, more significant subsidence could be expected in point p2, because this point is situated in the vicinity of a direct roof of the mining panel. The subsidence of point p2 is smaller than in the case of points in the opposite end of profile that are situated in much larger distance from the extracted mining panel. These points (p12 through p18) show a moderate subsidence up to c. 10 cm.

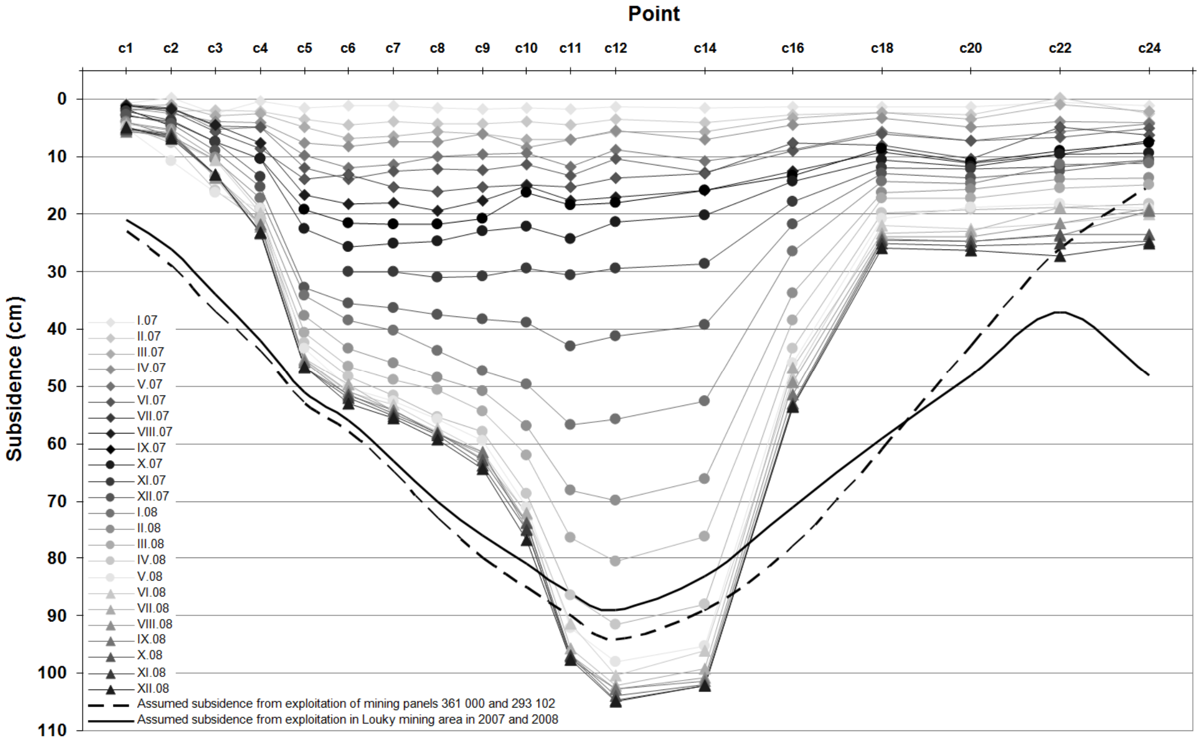



**Graph 1** Subsidence of points in profile P together with models of assumed subsidence.

In comparison of the measured values with the models of the assumed subsidence, it is apparent that the majority of points in the profile do not reach the assumed values. The exception is the west part of profile where the points (p15 through p18) show almost the regular and uniform subsidence to approx. 10 cm, although both assumptions have these points behind the affected boundary, i.e. in the area of subsidence up to 4 cm. This is probably caused by the combination of effects from the former extraction that die away in the area of interest together with the effect of present exploitation in mining area of the Darkov Colliery in the west direction from the area of interest.

The measured subsidence of the points in profile C is, together with both models of the assumed subsidence, shown in Graph 2. Profile C consists of points stabilized by nails in the roadside (green profile, Fig. 2). This profile passes from the east to the southwest above the east part of the mining panel 361 000 and then above the central part of the mining panel 293 102. The measured subsidence of points of this profile show more complicated development of subsidence depression, which is not as smooth as in the case of profile P. The reason is the course of the profile line above both mining panels across tectonic faults. The most eastward point of profile, point c1, shows again a negligible subsidence up to 5 cm, similarly as in the case of profile P. Other points, i.e. points c2 and c3 outside a direct roof of the mining panel, undergo more subsidence. Between points c4 and c5, the significant subsidence is encountered and other points, c6 and c7 in a direct roof of the mining panel 361 000, undergo subsidence by more than 50 cm. Then there is a continuous section of the subsidence depression, up to the point c9. Behind this point, more significant changes occur, due to the position of points above the mining panel 293 102. The maximum subsidence was recorded in point c12, which underwent subsidence of more than 1 m. The behaviour of subsidence of points in the last part of profile C is very dramatic. The difference in subsidence of points c14 and c18 is more than 75 cm, while their distance is roughly 200 m. On the contrary, the continuing section of points c18 through c24 shows a moderate and almost regular subsidence of these points, up to 28 cm. The former section of the significant change of subsidence of close points (c14 through c18) and the continuing section of significantly smaller and almost regular subsidence are probably caused by the complicated tectonic situation in the area of concern. Points c16 and c18 are localized in the area above the tectonic fault A as it is at the level of the coal seam 36.

In comparison of the measured values in profile C and with the models of the assumed subsidence it is apparent that these models do not entirely correspond with the reality. Both models show a continuous course of the subsidence depression, while the measured values show a significant irregularity of subsidence. Similarly as in the case of profile P, the most eastward point of profile is the most stable point with subsidence up to c. 5 cm. It is apparent on the surface model (Fig. 6) that minor subsidence occurs also in other points in the east part of the area of




**Graph 2** Subsidence of points in profile C together with models of assumed subsidence

interest and the values, based on assumption models, have not been achieved here. It can be caused by the particular structure of rock mass with significant tectonic faults in the east.

Similarly, the reason of uniform subsidence of the points in the south end of profile, from the point c18, can be seen in the existence of the tectonic fault A, same as the cause of large subsidence in the centre of profile, i.e. in places between tectonic faults X and A where the greater subsidence was measured than it is suggested by both model assumptions.

By comparison of the development of the subsidence depression in both profiles it is apparent that the profile P, which passes parallel to mining panel blocks in the north from the tectonic fault X, shows almost regular and smooth development in accordance with the theory of a bowl shape of the subsidence depression. On the contrary, in the case of profile C, passing through above both mining panels and across the tectonic faults X and A, a significantly non-uniform subsidence was recorded and a shape of the subsidence depression is very irregular.

## CONCLUSION

The project of monitoring of undermining effects on the surface in the area with non-trivial geo-mechanical conditions will further continue. Additional GPS surveying will be carried out and the behaviour of development of the subsidence depression will be analysed with regard to other potential causes that can affect its shape.

The results gained so far show the important influence of the complicated tectonic situation on the behaviour of surface subsidence. A smooth development of subsidence depression without important irregularities was found out on sites without tectonic faults. On the other side, on sites where rock mass is disturbed with tectonic faults, the shape of subsidence depression is very irregular.

## ACKNOWLEDGEMENT

This paper has been prepared in the frame of grant project of Czech Science Foundation, No. 105/07/1586 and Research project AS CR OZ 30860518.

## REFERENCES

Doležalová, H., Kajzar, V., Staš, L. and Souček, K.: 2008, Evaluation of height changes in subsidence depression near Karviná. Transactions of VŠB-TUO, Civil Engineering Series. Ostrava: VŠB-TUO, (in Czech)

Doležalová, H., Kajzar, V., Staš, L. and Souček, K.: 2008, Observation of subsidence depression by modern geodetic methods. Proceedings of SGEM 2008, Volume II. Albena, Bulgaria, 485–492.

Dopita, M. et al.: 1997, Geology of the Czech part of Upper Silesian Basin. Praha, MŽP ČR, 278 pp., (in Czech).

Hortvík, K.: 2005, Deformation of the surface ground induced by process of inundation of worked out areas after termination of underground mining exploitation, EUROCK 2005, Brno, Czech Republic.

Staněk, F.: 1999: The influence of interpolation method choice on the accuracy of calculation of coal deposit resources, Věstník Českého geologického ústavu 74, 2, (in Czech).

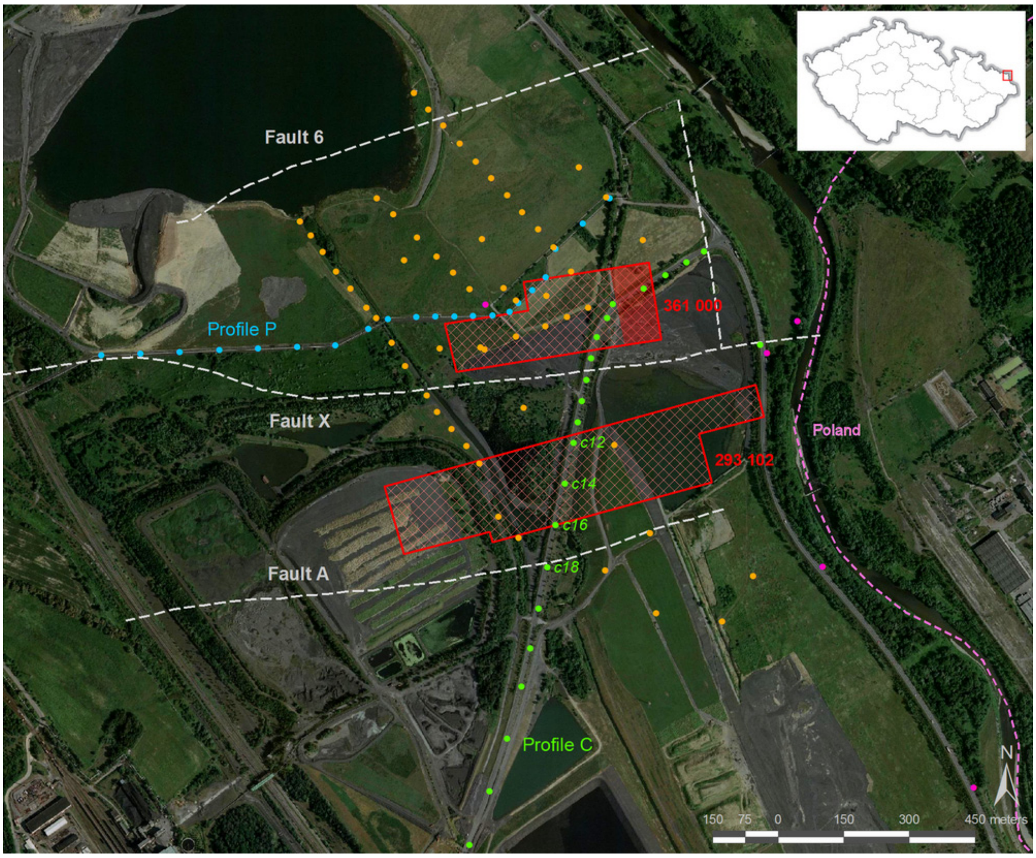



**Fig. 2** Area of interest with tectonic situation, exploited mining panels and observation network.

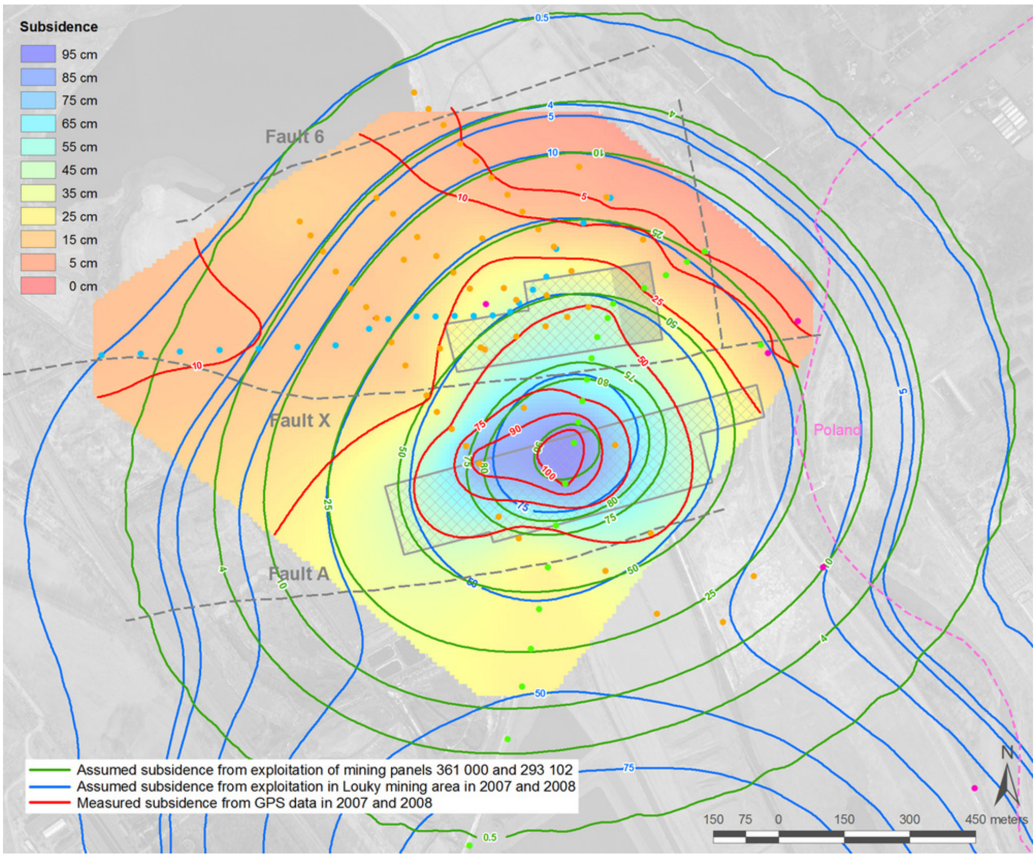



**Fig. 6** Surface model from the measured subsidence and models of assumed subsidence.