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ANALYSIS OF SURFACE MOVEMENTS FROM UNDERMINING IN TIME

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ABSTRACT
Using GNSS method, fixed points of an observation network were repeatedly surveyed on the surface of the undermined area. Below the surface, at the depth of c. 1 km, there were four mining panels exploited subsequently. The main reaction of the surface points to the changes in the rock massif and the movement of the points were different, according to their surface position, local geo-mechanical conditions etc. This paper analyses the time-dependence of the surface points mining subsidence and horizontal movements on the progress of the exploitation.

KEYWORDS: GNSS, mining subsidence, horizontal displacement

INTRODUCTION

Four hard coal mining panels were exploited subsequently in the northern part of the Louky locality near the town Karviná from 2006 to 2010. During this period, the Institute of Geonics monitored the surface movements from undermining using repeated GNSS surveying of fixed points of an observation network. More than 100 geodetic points were fixed to observe the changes of their space position in time. Mining subsidence and horizontal displacement of individual surface points were analysed in connection with the exploitation of the individual mining panels.

The Karviná region lies in the Upper Silesian Coal Basin and it is historically connected with the exploitation of the hard coal deposits for more than 200 years. The research in locality Louky is based on the knowledge of the problems of the hard coal exploitation in the conditions of both Czech and Polish part of the Upper Silesian Coal Basin published e.g. in Knothe 1953, Knothe 1984, Neset 1984. The problems of the geodetic surveying of the undermined area were published e.g. (in Schenk, 1999; Blachowski et al., 2009; Kadlečík et al., 2010; Kajzar et al., 2011. This paper is a continuation to Doležalová et al., 2009 and Doležalová et al., 2010), where the subsidence and horizontal displacement from the GNSS measurements were analysed in given observation network near Karviná.

AREA OF INTEREST

The Louky locality is situated in the mining area of the ČSM colliery in the Upper Silesian Coal Basin near the town Karviná in the north-eastern part of the Czech Republic (see Fig. 1). The northern part of the locality occupies an area of approx. 6 km^2. The area is bounded by the state border with Poland in the east. Two long-term recultivation projects are currently in progress in the observed area. The observed area belongs to the 0. and 1. mining blocks and has been exploited in the past. Due to the significant tectonic faults in the rock massif, the coal seams were mined in an insular way. The longwall method with controlled caving was used as the mining method. The first exploitation started in the 1991. In the following years, there were several horizontal mining panels exploited in eight coal seams at the depth from 780 m to 950 m under the surface, with the exploited thickness from 1.5 m to 4 m. The levelling surveying done by the mining company proved significant subsidence caused by the extraction of these mining panels. Later, another exploitation period started in 2006 and it ended in 2010. Four horizontal coal mining panels were gradually exploited at the depth from 945 m to 1025 m under the surface in this period (see Fig. 1). The average exploited thickness of the mining panels varied from 2.0 to 3.6 m (see Table 1 for details). The longwall mining panels were exploited from the east to the west direction. This period of underground exploitation was monitored by the Institute of Geonics, i.e. the surface changes caused by the exploitation were surveyed by GNSS and aerial photogrammetry. In 2006, the observation point network was fixed on the surface of the northern part of the Louky locality. The points were fixed in profiles and also scattered on the surface in the direct overburden of the planned exploitation of the mining panels and its vicinity (see Fig. 1). The position of individual points was also suited to the possibilities

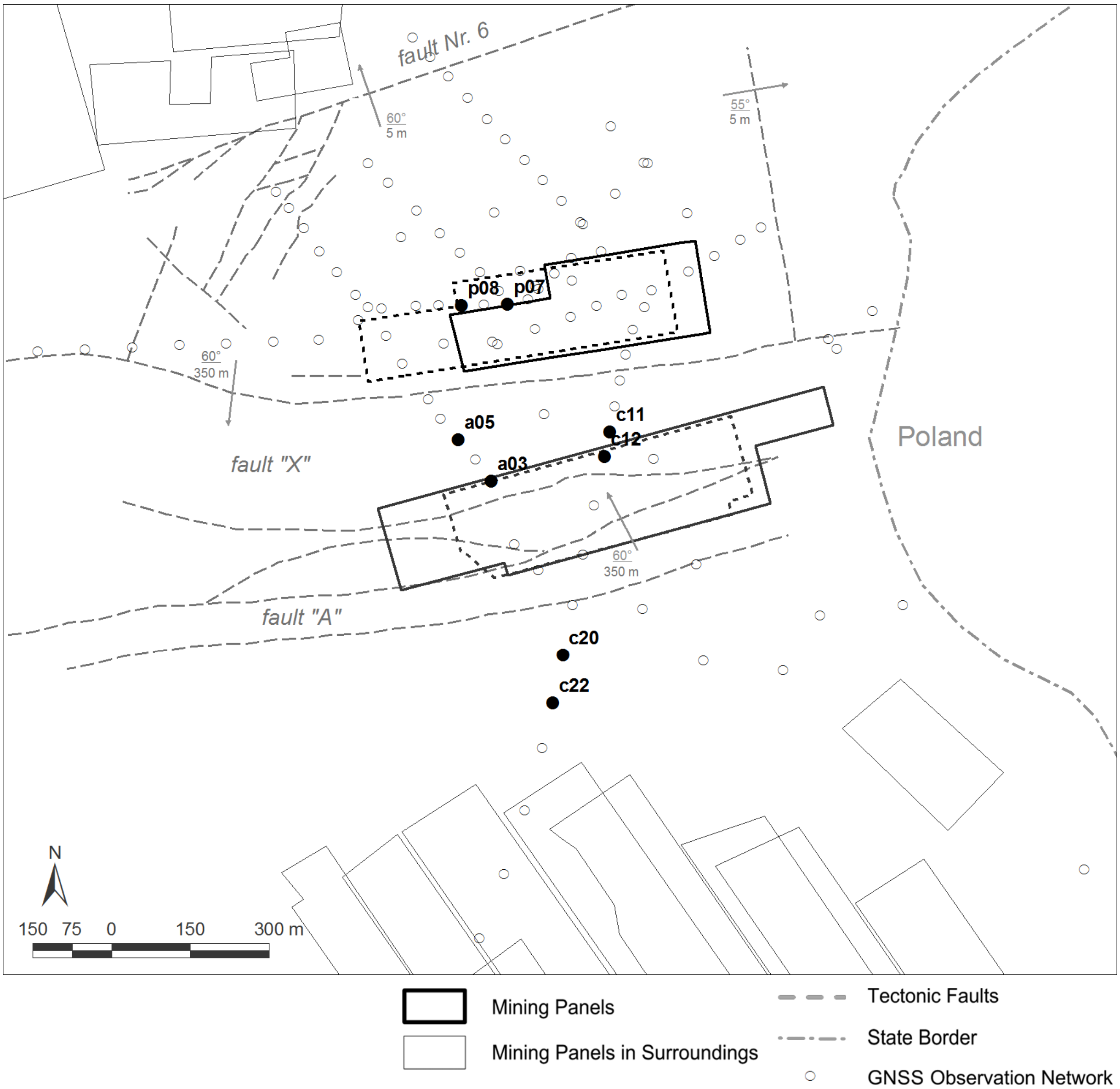


Fig. 1 GNSS observation network, tectonic faults and mining panels exploited from 2006 to 2010 in Louky-North locality and its surroundings.

(limitations) of the GNSS surveying. The points were repeatedly geodetically surveyed by GNSS with Leica GPS System 1200 (static surveying with at least 10 minutes observation for each point) which provided data on changes of spatial positions of the points. The surveying was done c. once a month in the first three years. Since the end of 2009, the surveying interval was prolonged. Since July 2010, there has been no active exploitation in the observed locality. As significant surface movements were expected from undermining, each point was surveyed only once during each surveying campaign, although geodetic surveying supposes to survey each point twice in each campaign for the determination of measurement deviations. Surveying of all the points twice would be too time-consuming and the deviations are rather small compared to real surface movements.

The observed locality is a part of a wider mining area and several mining panels were also exploited in the south of the Louky locality and also in its vicinity (see Fig. 1).

The rock mass consists of 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). There are four tectonic faults in the northern part of the Louky locality (see Fig. 1). The main normal tectonic faults A and X pass in sub-parallel to the mining panels in E-W direction. The

Table 1 Mining panels data.

Mining panel	***a***	***b***	***c***	***d***
Start of exploitation	10/2006	05/2007	01/2009	07/2009
End of exploitation	06/2007	04/2008	12/2009	06/2010
Face length	180 m	190 m	160 m	180 m
Lateral length of longwall advance	480 m	880 m	600 m	670 m
Depth under the surface	945 m	995 m	960 m	1025 m
Average exploited thickness	2.0 m	3.6 m	2.4 m	2.5 m
Mining panel area	78,600 m^2	152,600 m^2	87,000 m^2	99,000 m^2

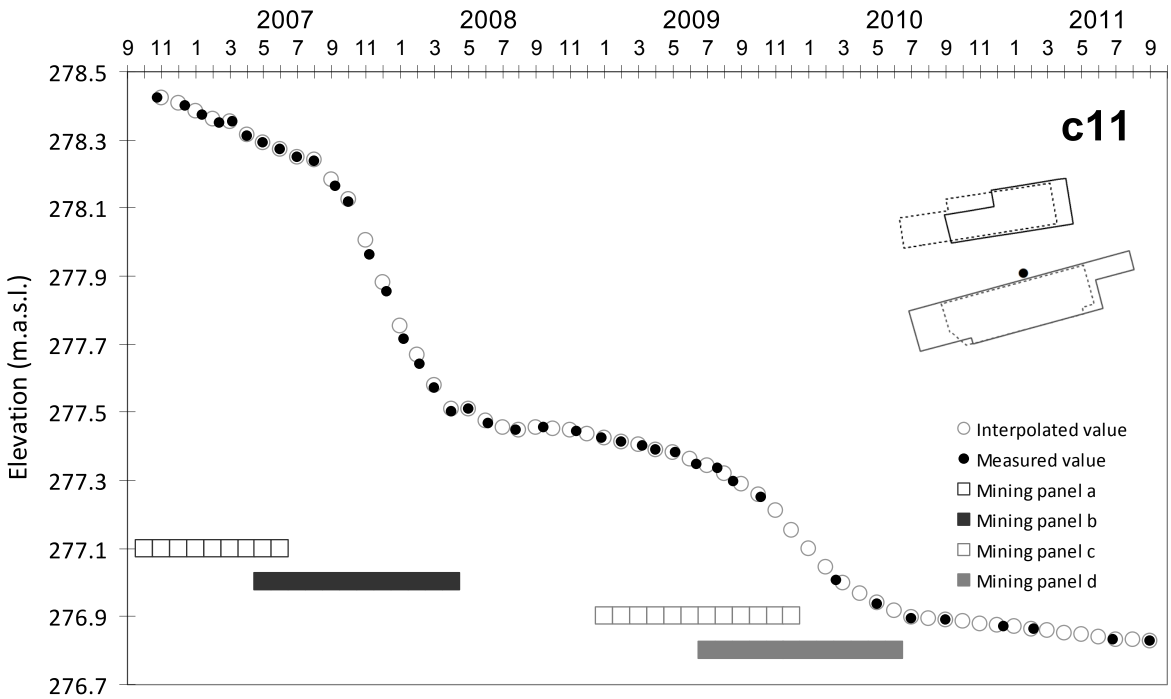
significant tectonic fault A lies southwards to mining panels ***b*** and ***d***. Tectonic fault X lies northwards to mining panels ***b*** and ***d***, i.e. between the pairs of the mining panels (***a***, ***c*** and ***b***, ***d***). Fault X has the thickness of deformation zone of approx. 25-50 m with the amplitude of 350 m, with dip of approx. 60°. Fault X is in overburden of mining panels ***a***, ***c***. Fault A has the fault amplitude of approx. 350 m and 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, approx. 400 m from mining panel ***a***. Then in the east, the unnamed fault is encountered, which passes in the N-S direction (Doležalová et al., 2009).

The results of the GNSS monitoring were published in e.g. (Doležalová et al., 2008; Doležalová et al., 2009; Doležalová et al., 2010; Kajzar et al., 2009; Staš et al., 2009. For the results of the aerial photogrammetry monitoring, please see Kajzar et al., 2011).

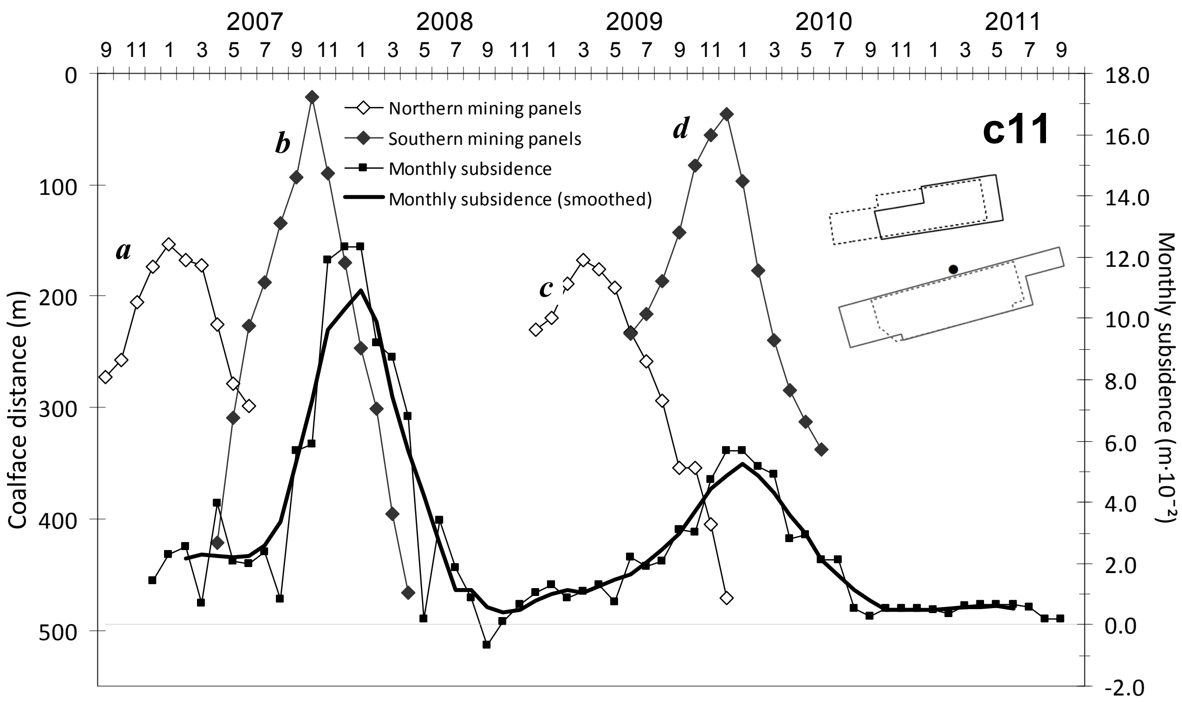
SURFACE MOVEMENTS IN TIME

For the analysis of the behaviour of the surface points as a reaction to the undermining from individual mining panels, pairs of fixed points were selected in different parts of the observed locality. Two points (p07, p08) were selected northwards to fault X, two points (c20, c22) were selected southwards to fault A and four points (a03, a05 and c11, c12) were selected in the area between (see Fig. 1). A set of graphs was prepared for each point. The graphs were prepared from interpolated values (monthly) from surveyed data. The conformity between the measured and interpolated values can be seen in Graph 1. From such interpolated monthly values, four graphs for subsidence and horizontal displacement were prepared for each point. In the first graph, there is the total subsidence of the point in time together with the distance of the coalfaces of individual mining panels from the point projection (see Graph 4). The size of the point subsidence in individual months is presented in Graph 5 and the size of the point horizontal displacement in individual months is presented in Graph 6, together with the coalfaces distances again. The size and directions of the total horizontal displacement of the point is presented in Graph 7. The reaction of the surface points to the exploitation of the mining panels was analysed from such graphs that were prepared for each pair (group) of points. While all the graphs were prepared from the interpolated values, moreover, the curves in the graphs of the monthly subsidence and monthly horizontal displacement were also smoothed. It is evident that the curves of the intensity of subsidence and horizontal displacement show some trends. To smooth the curves and thus to portray the trends better, the statistical method of moving average has been successfully used (the calculation of the moving average value of the monthly subsidence and horizontal displacement was processed from a total of 5 values; all values entering the calculation have the same weight). The result is a smooth curve on which it is usually very well possible to distinguish different periods with varying intensity of changes in the spatial position of the studied points, and subsequently to evaluate these changes in the context of the mining process. Several smoothing methods were tested and this one seems to be best and sufficient for selected purposes. The conformity between data from interpolated and smoothed values of the monthly subsidence is presented in Graph 2; the conformity between data from interpolated and smoothed values of the monthly horizontal displacement is presented in Graph 3.

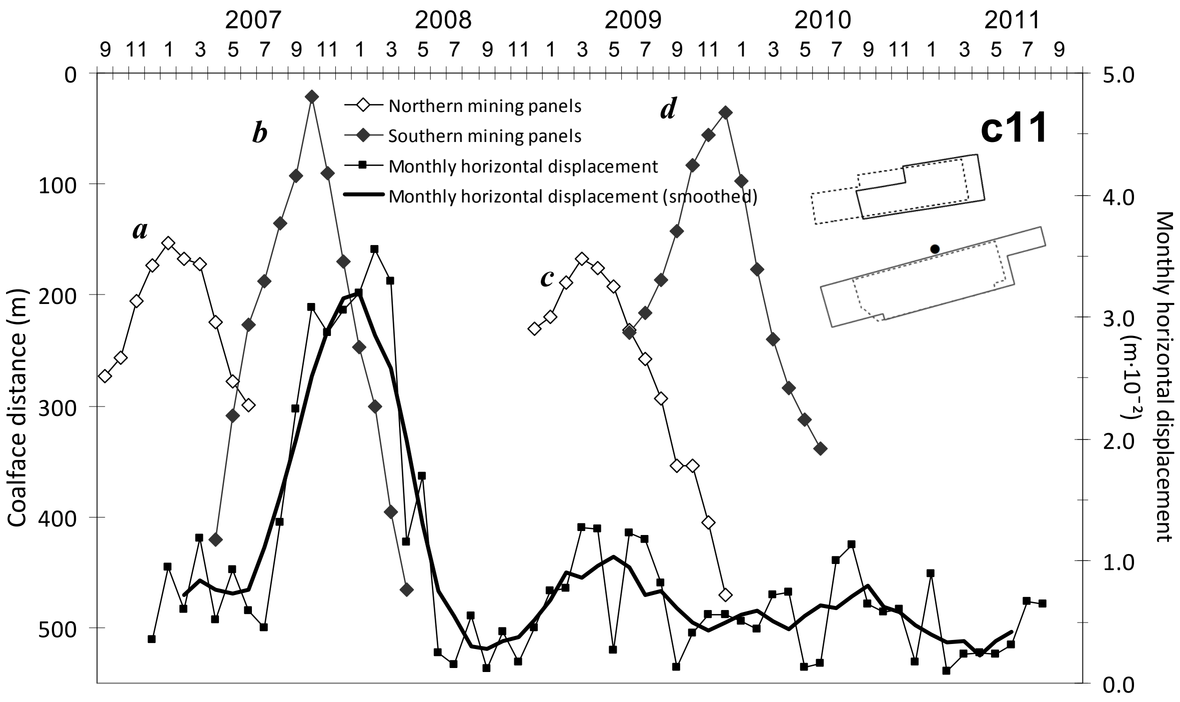
The behaviour of the surface points c20 and c22 is presented in Graphs 4, 5, 6 and 7. These points lie southwards to the mining panels and the tectonic faults. It is apparent that from the graphs of the subsidence and horizontal displacement it is not possible to find any pattern of the reaction of the



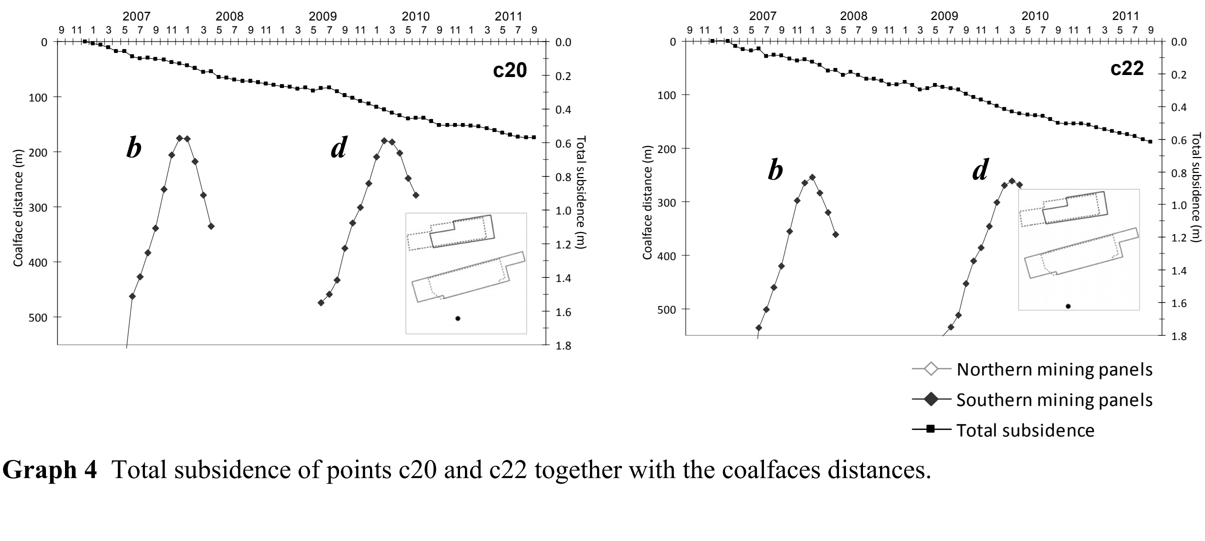
Graph 1 The conformity between the measured and interpolated values (point c11).



Graph 2 The conformity between data from interpolated and smoothed values of the monthly subsidence (point c11).



Graph 3 The conformity between data from interpolated and smoothed values of the monthly horizontal displacement (point c11).

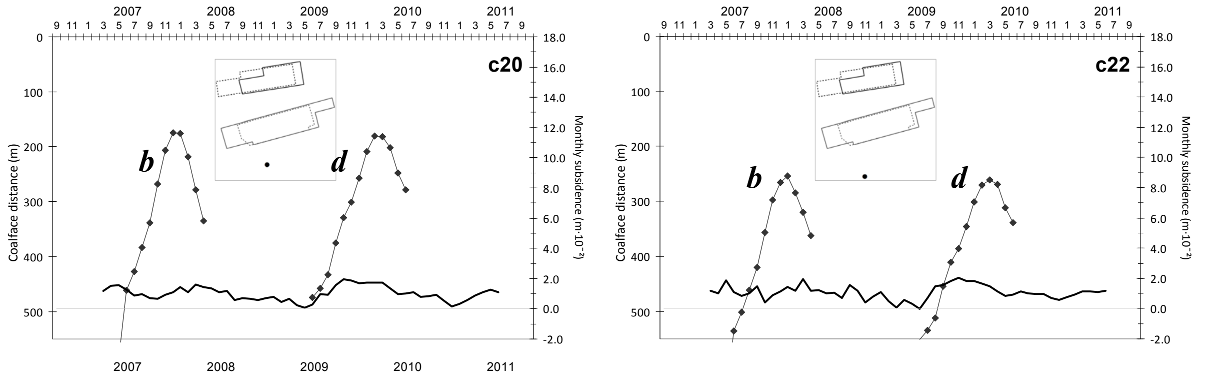


Graph 4 Total subsidence of points c20 and c22 together with the coalfaces distances.

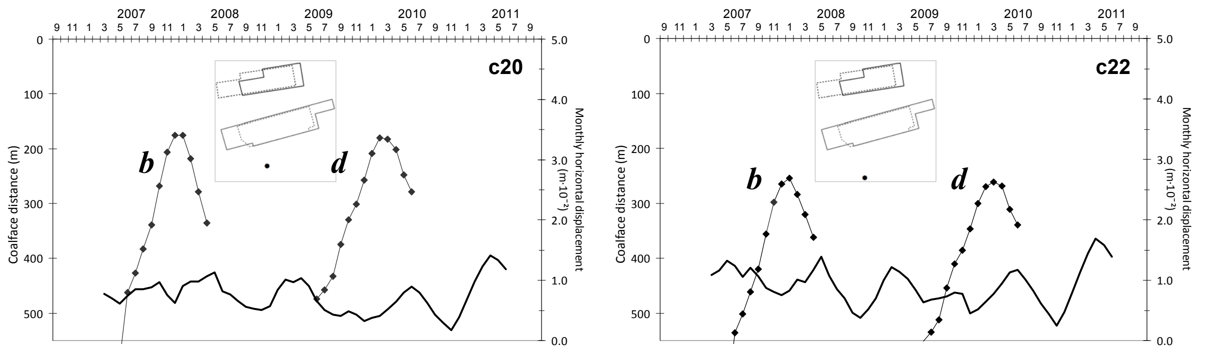
surface points to the undermining from the monitored mining panels. The total subsidence is almost linear, the size of the horizontal movement is within few centimetres and the directions show that the points did not move markedly towards the exploited mining panels, i.e. northwards. On the contrary, especially point c22 apparently moved southwards and therefore it is more influenced by the exploitation in the south vicinity than by the exploitation of the monitored mining panels in locality Louky-North. This conclusion was also confirmed by other of our analyses:

I) the analysis of the subsidence that was done both for the profiles of the surface points and for the surface area from the GNSS surveying (published e.g. (in Doležalová et al., 2009, Staš et al., 2009));
II) the analysis of the horizontal movements both in terms of size and direction from the GNSS surveying (published e.g. in Doležalová et al., 2010; Kajzar et al., 2009);
III) the analysis of the surface changes from the aerial photogrammetry (published in Kajzar et al., 2011).

All of these analyses proved the important



Graph 5 Monthly subsidence of points c20 and c22 together with the coalfaces distances (for legend see Graph 2).

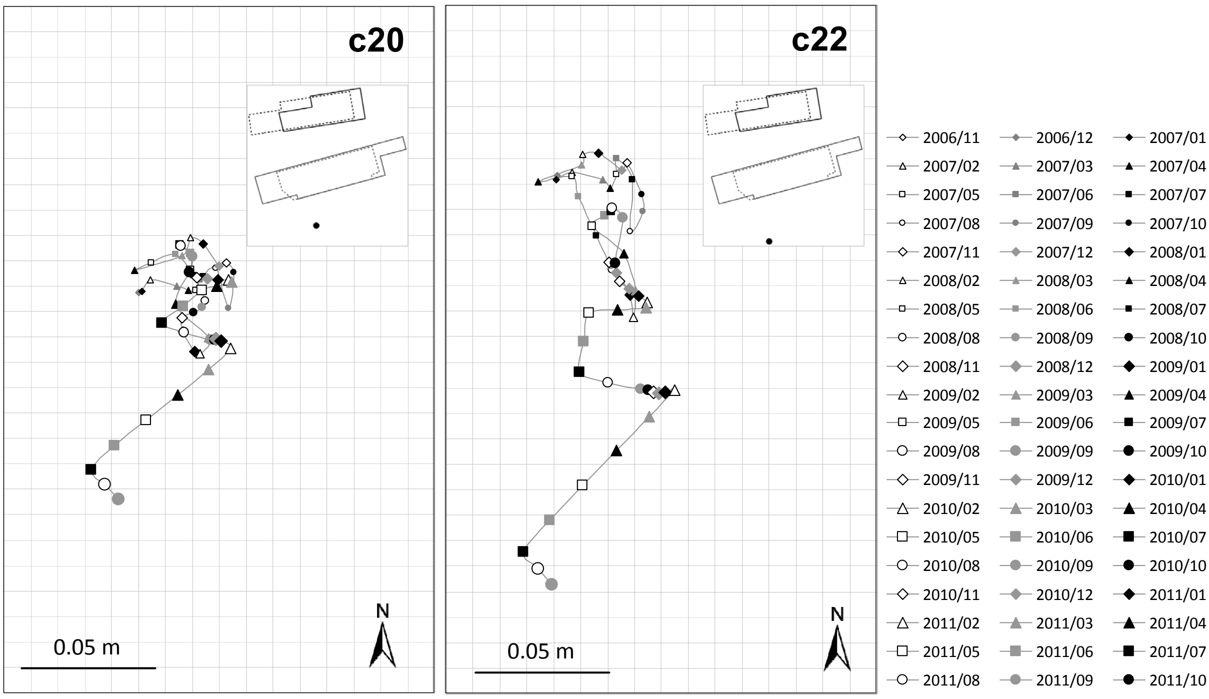


Graph 6 Monthly horizontal displacement of points c20 and c22 together with the coalfaces distances (for legend see Graph 3).

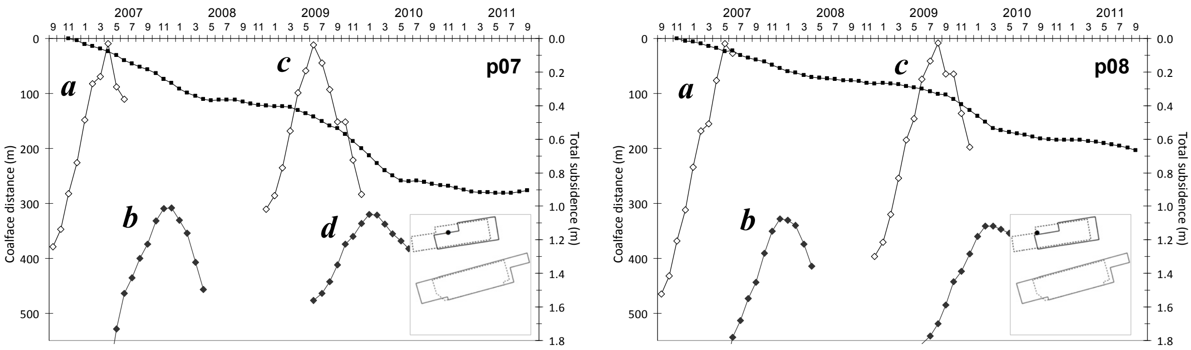
influence of the significant tectonic fault in the Louky-North locality-fault A that creates a natural barrier and the points found southwards to this tectonic fault are screened out of the influence of the monitored mining panels exploitation while they are rather influenced by the mining activity in the surroundings, i.e. to the south from the Louky-North locality.

The behaviour of the surface points p07 and p08 is presented in Graphs 8, 9, 10 and 11. These points lie northwards to the mining panels, on the edge of the northern mining panels' projection respectively. From the graphs of the subsidence and horizontal displacement we can observe some reactions of these surface points to the undermining from the monitored mining panels. There is the increase of the subsidence increment as a reaction to the approach of the mining panels that can be seen both in total and monthly subsidence graphs elaboration (Graphs 8 and 9). Also the monthly horizontal movement increase is apparent (Graph 10). The graphs show that these points lying above mining panel ***c*** and the edge of mining panel ***a*** react to the exploitation of these mining panels and the reaction is more marked after the starts of the exploitations of mining panels ***b*** and ***d***. This behaviour would be expected due to the location of these points over the northern mining panels. Previous analysis showed that the tectonic fault X does not isolate the surface points in its overburden from the influences of the exploitation of the southern mining panels, as it is at fault A. Points are primarily influenced by the closer mining panels in the north, but also the influence of distant southern mining panels is added.

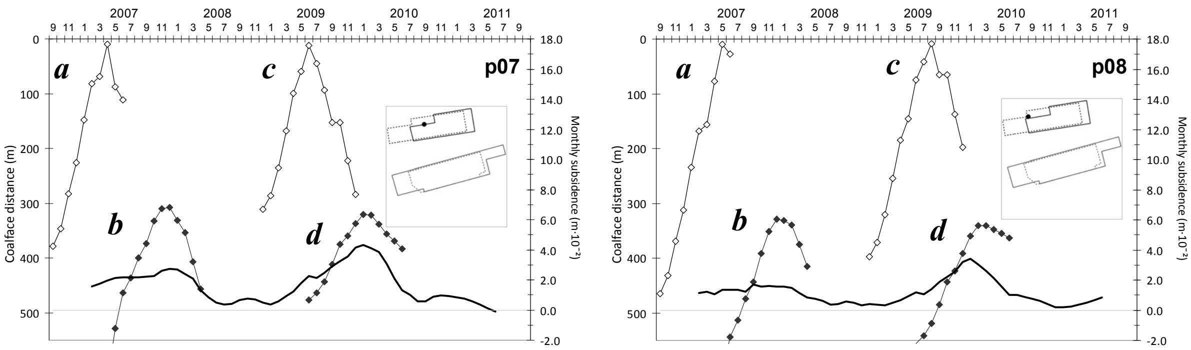
The behaviour of the surface points a03, a05 and c11, c12 is presented in Graphs 12, 13, 14 and 15. These points lie in the centre of the observed locality, between the overburden of the mining panels, on the north edge of the southern mining panels' projection respectively, and between the tectonic faults A and X. It is apparent that from the graphs of the subsidence and horizontal displacement of these points it is possible to find the pattern of the reaction of the surface points to the undermining from the monitored mining panels. From the graph of the monthly subsidence with the current position of the advancing coalfaces (Graph 13), there is an apparent increase in monthly subsidence after the coalfaces were in their closest distance to the point. This is most evident by the progress of the mining panel ***b*** coalface. There is an obvious reaction of the points to the exploitation of



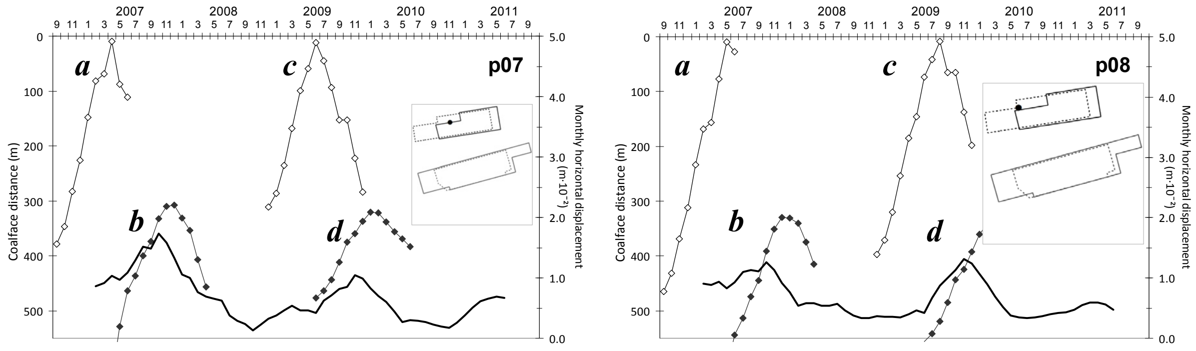
Graph 7 Total horizontal displacements (size and directions) of points c20 and c22.



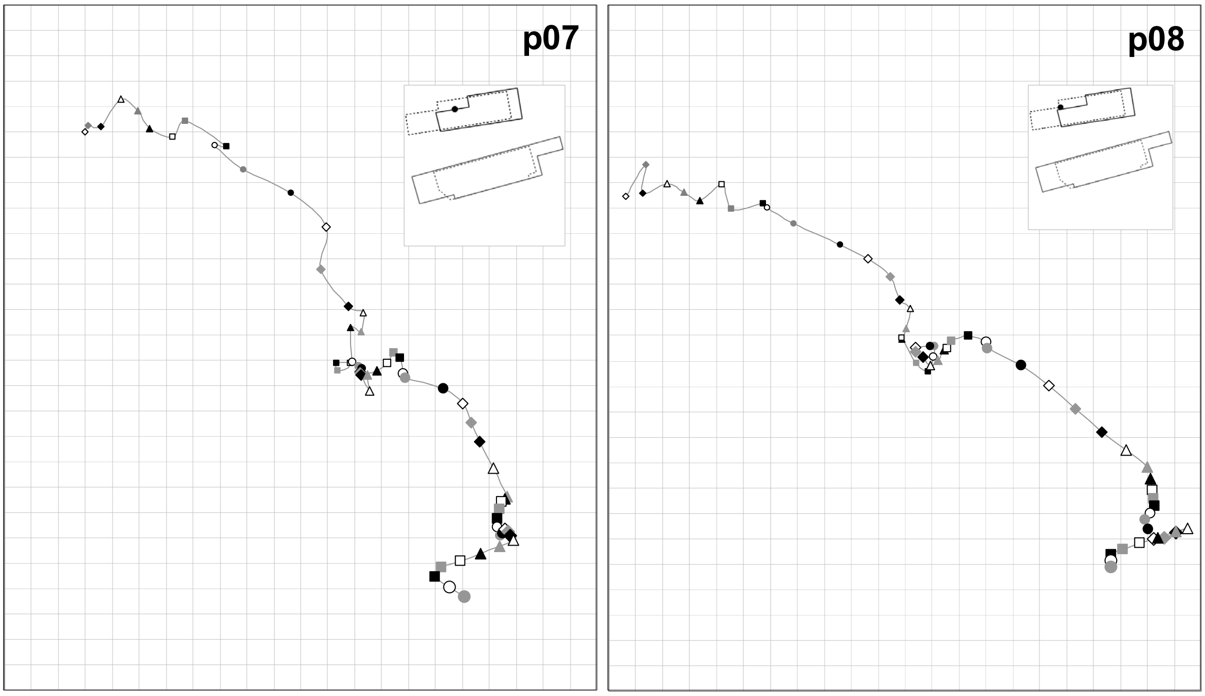
Graph 8 Total subsidence of points p07 and p08 together with the coalfaces distances (for legend see Graph 4).



Graph 9 Monthly subsidence of points p07 and p08 together with the coalfaces distances (for legend see Graph 2).



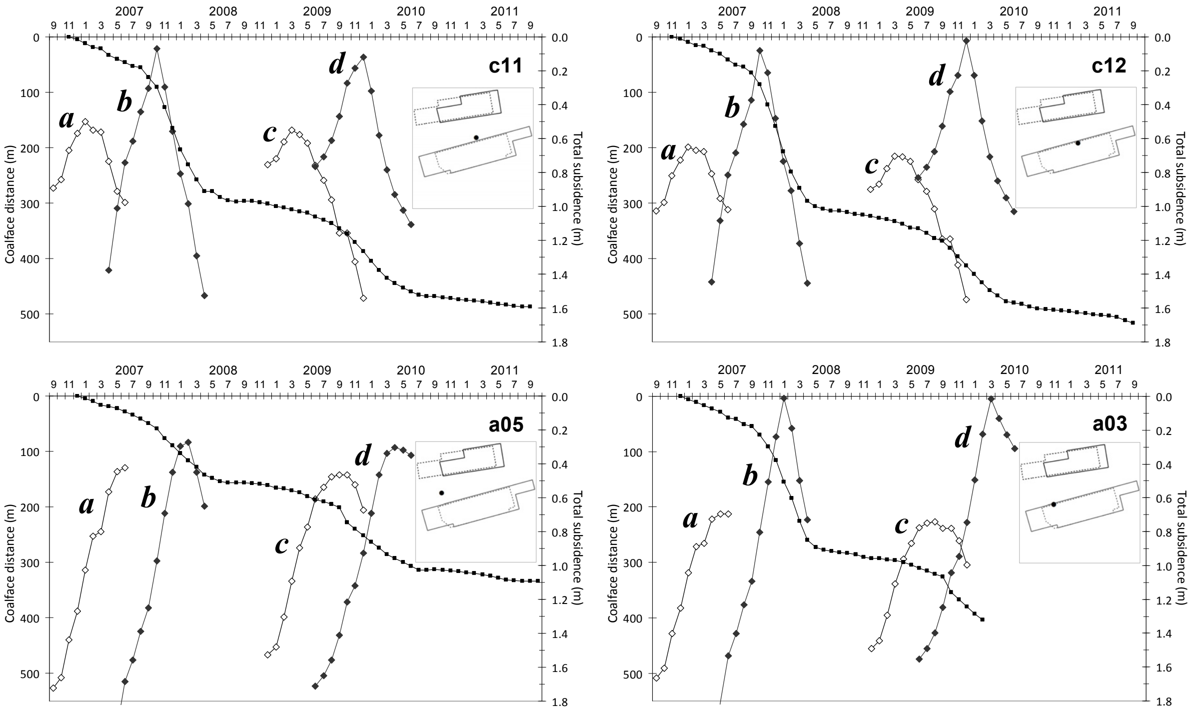
Graph 10 Monthly horizontal displacement of points p07 and p08 together with the coalfaces distances (for legend see Graph 3).



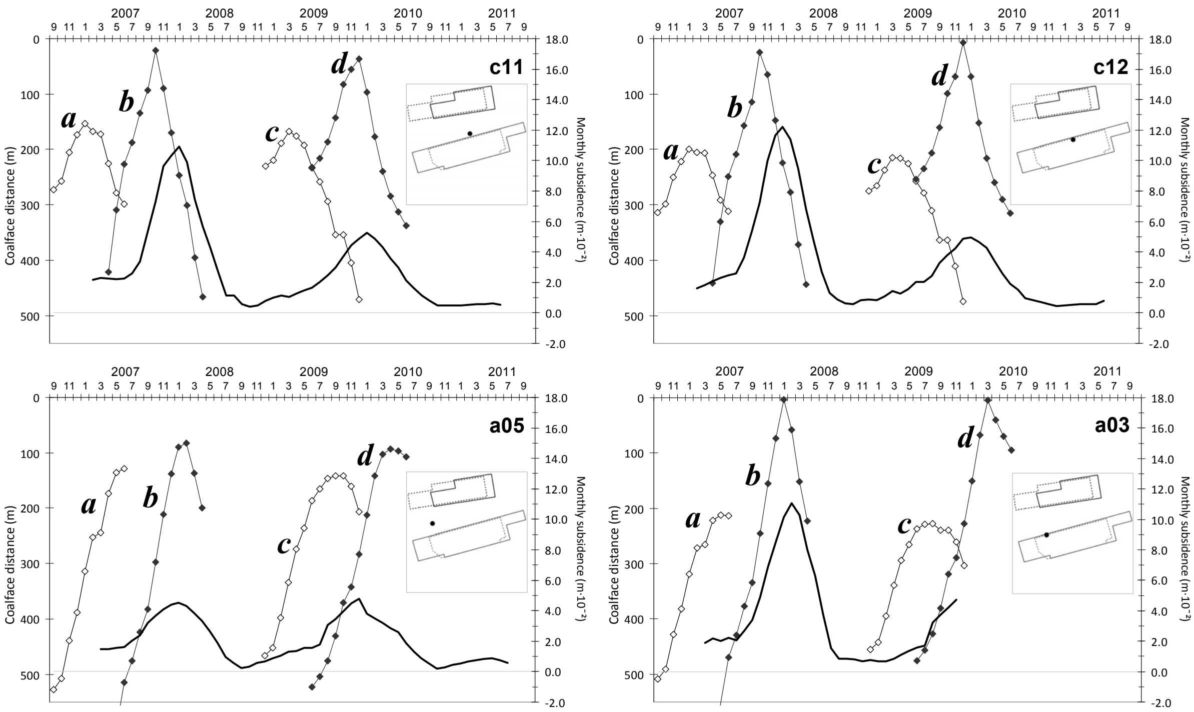
Graph 11 Total horizontal displacements (size and directions) of points p07 and p08 (for legend see Graph 7).

this largest mining panel. This is primarily due to its mining parameters and its time isolation in almost its entirety extraction. There is a marked increase of the subsidence values apparent both on the graphs of the total and monthly subsidence (Graphs 12 and 13). The increase in monthly subsidence correlates well with the shortening and lengthening distance of the coalface to the point, with an interval of a few months. A phase of surface stabilization (subsidence desisting) followed again with this several-month interval after the end of extraction, respectively after the coalface was in a significant distance (about 400 m in this case) from the point.

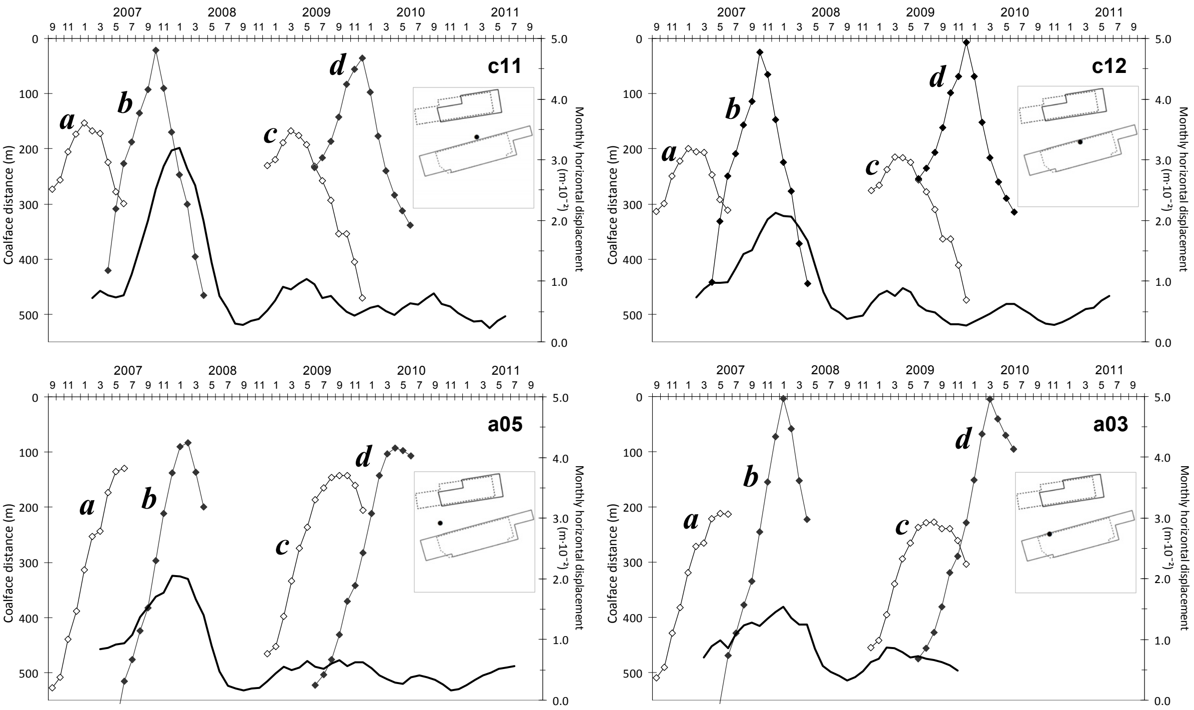
Well apparent, although smaller increase of the monthly subsidence can be distinguished also for the extraction of mining panels ***c*** and ***d***. On the graphs of the total subsidence (Graph 12), we can see the obvious reaction not only to the approaching coalface of the mining panel ***b*** but also mining panel ***d***, combined influence of mining panels ***c*** and ***d*** respectively as they were exploited simultaneously for several months. Since the extraction of these mining panels coincides in most of the time, it is not possible to precisely distinguish the exact start of the major subsidence increases of the individual coalfaces.



Graph 12 Total subsidence of points a03, a05 and c11, c12 together with the coalfaces distances (for legend see Graph 4).



Graph 13 Monthly subsidence of points a03, a05 and c11, c12 together with the coalfaces distances (for legend see Graph 2).



Graph 14 Monthly horizontal displacement of points a03, a05 and c11, c12 together with the coalfaces distances (for legend see Graph 3).

From the graphs of the horizontal directions of the points (Graph 15) it is obvious that the points were mostly influences by the exploitation of the largest mining panel ***b*** and they followed the advancing coalface of this mining panel from the east to the west. Later, the movement to the north can be observed as a reaction to the exploitation of mining panel ***c*** and the backward movement to the south as a reaction to the exploitation of mining panel ***d***.

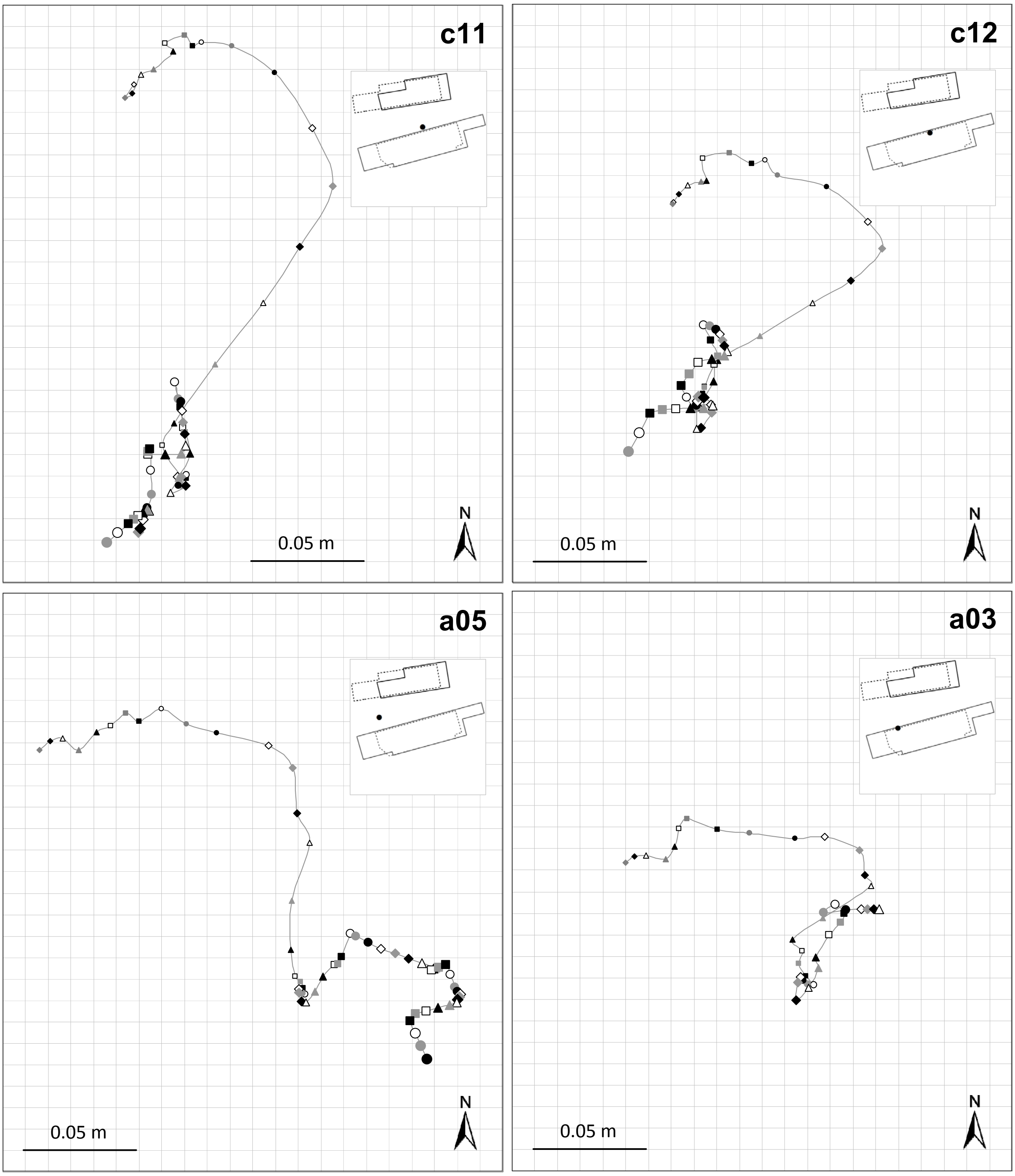
The delay of the main surface subsidence from exploitation of the mining panels can be seen in Graph 13. The trend of the monthly subsidence resembles the curves of the distances of the coalfaces approaching to the point. The increases of the monthly subsidence value react to the approach of the mining panel ***b*** with approx. 2 months delay. Also the trend of the monthly horizontal movement resembles the curves of the distances of the coalfaces approaching to the point and the delay of the main surface horizontal movement from exploitation of the mining panels can be seen in Graph 14. Here the main increases of the monthly horizontal movement values react to the approach of the mining panel ***b*** with approx. 3 months delay.

Also here, in the centre of the observed locality, the points behave as expected due to their location. The points are influenced by both northern and southern mining panels and the tectonic faults do not screen them out. The points are primarily changing their position due to the exploitation of the monitored mining panels in the Louky-North locality and they are not influenced by the farther mining panels in the vicinity.

CONCLUSIONS

From the analysis of the behaviour of the surface points as a reaction to the undermining from the mining panels in the northern part of the Louky locality we may conclude:

- The behaviour of the surface points as a reaction to the exploitation of the mining panels depends not only on the distance of the point from the mining panel, the approaching coalface respectively, but also on the geo-tectonic conditions in given locality.
- The impact of the significant tectonic fault A was confirmed by the analysis of both subsidence and horizontal movements of the points. It was confirmed that this fault creates a natural barrier and the points found southwards to this tectonic fault are screened out of the effects of the monitored mining panels' exploitation while they are rather influenced by the mining activity in the surroundings, i.e. to the south from the Louky-North locality.
- The points in the centre and in the north of the observed locality behave as expected and they reacted to the exploitation of the monitored mining panels.



Graph 15 Total horizontal displacements (size and directions) of points a03, a05 and c11, c12 (for legend see Graph 7).

- The most distinguished reaction of the surface points was to the exploitation of the largest mining panel ***b*** while the reactions to the exploitation of the other mining panels were partly affected by their coincidental exploitation.
- From the reaction of the surface points to the exploitation of the largest mining panel ***b***, it is possible to state the 2 months delay of the most significant subsidence from this undermining and the 3 months delay of the most significant horizontal movements caused by the exploitation of this mining panel.

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