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EVALUATION OF VERTICAL AND HORIZONTAL MOVEMENTS IN THE SUBSIDENCE DEPRESSION NEAR KARVINÁ

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ABSTRACT
An observation network was built to observe the process of creating of a subsidence depression above exploited coal mining panels near Karviná. Points of the observation network were periodically surveyed by geodetic GPS method from 2006 to 2009. This method enables the evaluation of both vertical subsidence and horizontal shifts. Such complex evaluation of processes on the surface of the undermined area makes it possible to understand the progress of the subsidence depression caused by undermining. The results have shown on areas of irregular development of the subsidence depression. The irregularities are caused by a complicated tectonic situation and former exploitation in given locality and also active exploitation in the surroundings of given locality.

KEYWORDS: subsidence depression, GPS, horizontal shifts

INTRODUCTION

Since 2006, nearly 100 geodetic points have been stabilized on the surface affected by undermining from black coal exploitation. These points were repeatedly geodetically surveyed by GPS which provided data on changes of spatial positions of the points. The evaluation of subsidence is the most common way to observe the surface effects from undermining. But the evaluation of horizontal movements can markedly enrich the research of the effects from undermining because it shows on the direction of the total movements of surface points. This paper is a continuation to Doležalová et al.(2009) where the subsidence and the comparison between the assumed and the measured surface subsidence were analysed at given observation network near Karviná. In this paper, we would like to analyse also the horizontal shifts caused by undermining in the same area.

AREA OF INTEREST

The locality is situated in the Upper Silesian Coal Basin near the town Karviná. Four horizontal coal mining panels were gradually exploited there at the depth of c. 1,000 m under the surface from 2006 to 2009. The exploited thickness varied from 1.4 to 3.2 m. The rock mass is disturbed by four tectonic faults (see Fig. 3). The locality is a part of a wider mining area and the underground exploitation was in the progress there in the past. Several mining panels were exploited there in the late nineties (see Fig. 2). The surface in 2006 was almost stabilized, with the subsidence of c. 5 cm a year. The detailed information on locality, exploited mining panels and tectonic faults (including the picture of a simplified cross-section) was published in Doležalová et al. (2009).

An observation network was built as a net of stabilized points (see Fig. 3). The points were stabilized either in profiles or as scattered points. The location of individual points was adapted to conditions of the landscape (due to surface reclamation) and the points were suitably situated for the GPS surveying. The points were stabilized with the nails in the roadside and with one meter steel rods hammered into the ground. Several triangulation and levelling points of the national network were included into surveying and also points on frames of supporting structure of a water piping were surveyed with a special GPS antenna holder. Nearly 100 points were repeatedly surveyed in total, once a month. The points were surveyed by a static GPS method with observation of at least 10 minutes per each point. The reference 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 (see Fig. 3). Accuracy of a surveyed point is dependent upon various factors, including the number of satellites tracked, constellation geometry, observation time, ephemeris accuracy, the length of a baseline and others. For the used GPS equipment, the stated accuracy for static surveying with subsequent post-processing is in horizontal position of a point 5 mm + 0.5 ppm and in vertical position of a point 10 mm + 0.5 ppm. Since the surveyed points were only 3 km far from the reference point, constellation geometry was controlled during the whole observation and precise ephemeris were input into post-processing, the real accuracy of

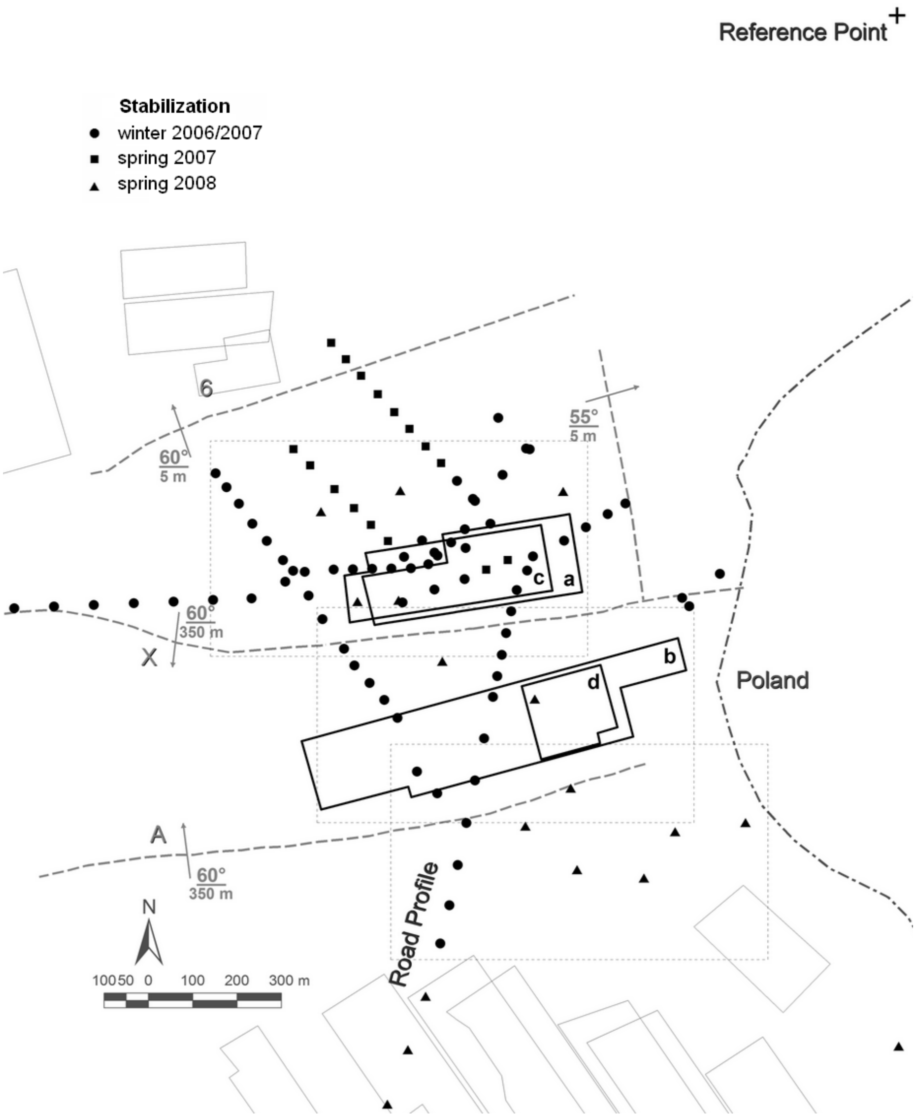

Fig. 3 Observation network, tectonic situation and exploited mining panels in given locality and its surroundings.

surveyed points may be estimated within interval from 5 to 20 mm. Tests that were done in given locality confirmed this presumption. For detailed information, please see Doležalová et al. (2009).

VERTICAL SUBSIDENCE

Evaluation of vertical subsidence is the most common way of evaluation of the effects of undermining on the surface. Vertical component of the general movement of the undermined surface point is major than the horizontal component. That is why levelling is mostly used to survey the undermined surface. But GPS offers the possibility to evaluate not only vertical subsidence but also horizontal shifts because it provides the spatial position of a surveyed point.

The evaluation of vertical subsidence from the data gained by GPS on given observation network near Karviná can be done in several ways. Evaluation of subsidence of single points or profiles of points can be done, especially to compare the behaviour of close points that are differently affected by undermining. Areal evaluation of subsidence of the whole surface can be done to observe the development of the subsidence depression and to demark its margin.

From the total subsidence that was measured on the Road profile (Fig. 3) from December 2006 to November 2009, the behaviour of points during the development of the subsidence depression can be seen (Fig. 1). The progress of exploitation of the mining panels in time is displayed on the right side of Figure 1. Most of the points show the expected reaction to the exploitation of the mining panels. Mainly during the exploitation of the second mining panel ***b*** (V.07 – IV.08), the acceleration of increments of subsidence per time unit is evident. During the interval between the end of exploitation of the second mining panel ***b*** and the start of the exploitation of the third mining panel ***c*** (IV.08 – I.09), the period of a slow stabilization of the surface can be seen. Later, as the exploitation of the third and fourth mining panels was continuing (***c*** and ***d***, from I.09, respectively VII.09), the acceleration of increments of subsidence per time unit occurred again.

The general shape of the subsidence curve shows on irregularities of subsidence in different parts of the subsidence depression (Fig. 1). The end points of the Road profile stabilized in the southern part of the observed area (points c18, c20, c22, c24; total distance is c. 300 m) subside nearly the same way. The size of the subsidence of these points is almost the same in individual intervals and the subsidence is almost regular. No other points show such development of the subsidence. On the contrary, the part of the subsidence depression between points c14 and c18 shows on considerable difference in the subsidence of these points (the distance is c. 200 m).

In Figure 2, there is a subsidence map of the observed locality made from GPS data surveyed on stabilized points from December 2006 to September 2009. From this map, the extent of the affected area can be seen. It is obvious that the subsidence depression that was created above the exploited mining panels is not bounded and it is a part of a wider subsiding area. This is markedly evident especially in the north-west part of the observed locality. In this part, subsidence of at least 0.1 - 0.2 m was measured. This map also shows on irregularities that occurred during the creation of the subsidence depression. While the north-east points that are close to the surface projection of the mining panels show a small subsidence and the margin of the subsidence depression can be detected here, the north-west points that are much farther to the surface projection of the mining panels show a major subsidence and the margin of the subsidence depression cannot be detected here.

ANALYSIS OF HORIZONTAL SHIFTS

Horizontal movement of a surface point can be defined as a change in its position in a horizontal plane (on x-axis and y-axis). The size of the horizontal shift from undermining is much smaller than the ascertained and previously described subsidence. However, its diagnosis effectively complements the evaluation of movements and surface deformation processes in the area of interest. Based on graphical evaluation of horizontal shifts, we are able to define the influence of the mining activity on the resulting change in the position of surveyed points.

The analysis of horizontal shifts is based on observations carried out from the end of 2006 to the end of 2009 (about 3,000 records). The analysis can be processed for the so-called total shifts of points, i.e. from the beginning of the monitoring until the last actual observation. It is also possible to do partial shifts analysis, i.e. the analysis of shifts in a shorter time period. The results can be compared with the mining activities during the analysed period. It complements our idea about the occurred changes that happened in this period when the spatial positions of points changed because of the development of the subsidence depression.

Figures 4, 5 and 6 show in details the horizontal shifts of points since their stabilization to the last surveying in the end of 2009. The position of individual detail figures is indicated in Figure 3. The detail figures show the shifts in five-month intervals (see legend); the colours correspond with indicated progress of mining. The points are divided into three groups according to the date of their stabilization, using picture symbols. The resulting trajectories of the points are five-hundredfold enlarged.

The dynamics of the development of shifts is not uniform and it is closely linked with the mining activities, same as the subsidence is. The change of the spatial position is always the most marked in the period of active mining, which was also obvious from the previously evaluated subsidence of surveyed points. Vectors of the maximum shifts reach the value of 0.25 m.

Determining the directions of point movements is a greater benefit to the evaluation of the process of subsidence depression formation. In a homogeneous environment, i.e. in the ideal geo-mechanical conditions (an area with no tectonic faults, no effects from undermining in the surroundings, etc.), the development trajectories of individual curves should correspond to the ongoing mining. During the active mining period, major changes of positions can be expected than during the non-active mining period. The direction of the shift in each moment should direct toward the actual centre of gravity of the exploited mass, whose position is continuously changing according to the process of exploitation.

At the first sight, the movements of individual points correspond to expected movements in the context of position of points in the observation network towards the exploited mining panels. However, by a close-up view it is possible to locate subareas, in which the points behave partly or totally out of the said presumption.

Trajectories of the shift curves confirm the assumptions of the influence of mining activities in the surroundings (the assumptions were first derived from the subsidence models). The first case is the impact of the effects from north-west direction (Fig. 4). Because of the interpenetration of exploitation effects, it is not possible to precisely define the boundary line of the areas. The dot-and-dash line in Figure 4 defines the approximate boundary of the dominant influence of activity on both sides, i.e. the boundary that divides the area into a part that is mostly affected by the exploitation of observed mining panels (***a, b, c, d***) and a part that is mostly affected by the exploitation of mining panels in the north-west surroundings.

It is similar in the southern part of the observed area. According to the size and thickness of mining panel ***b*** (293102), it was assumed that the direction of movements of all points in both near and distant surroundings will be significantly affected by exploitation of this panel. The graphic analysis of horizontal shifts (Figs. 5 and 6) shows that the points stabilized behind (southwards) the line corresponding to the depicted tectonic fault A, are not significantly affected by this mining panel. It seems that the resulting trajectory of the horizontal curves is completely determined by the effects of active mining processes from the south. Northwards, the points are affected by the exploitation of the major south mining panel ***b*** to a considerable distance, in contrast with the development described in the southern part. From these results, we may suggest that the tectonic fault A makes a natural barrier (Staš et al., 2009).

COMPLEX EVALUATION

Exploitation effects of two close mining areas were monitored at given locality. However, the mining interference of the overburden of each of them had a quite different character which was projected into their effects on the surface, as expected. The overburden in northern area was affected by a former mining activity only partially. Also, the exploitation was proceeded in the underbed of the inclined X fault. In Figure 1, we can see that the subsidence of points surveyed above mining panel ***a*** (361000) didn't exceed 0.15 m during the exploitation of this panel. The same situation (only 0.15 m of subsidence) was documented during the exploitation of mining panel ***c*** (362000) which was exploited as the second bench of the 36th layer under panel ***a*** (361000) (until the start of exploitation of mining panel ***d*** (300102) in the southern part of the area). Taking account of the thickness of both exploited layers, c. 3 - 3.5 m of total layer height was exploited. This process was documented with only c. 0.3 m subsidence on surveyed point above these mining panels. The calculated surface maps of subsidence during the exploitation of mining panel ***a*** (please see Doležalová et al., 2009) display the development of the subsidence depression that is developing in an unsymmetrical way and it is obviously deformed by the existence of a failure material near the X fault.

A totally different reaction may be seen above the southern mining panel ***b*** (293102). The overburden of this panel is strongly affected by multiple mining activities from formerly exploited layers in the overburden. Also, mining panel ***b*** (293102) lies in the overburden of both limiting faults A and X. The total thickness of the exploited layer was c. 3 - 3.5 m. Although quantitatively it corresponds to the exploited mass in the northern part, the effects on the surface are much bigger. Figure 1 shows that the exploitation of mining panel ***b*** (293102) caused 0.9 m subsidence on surveyed points situated directly above the panel. Such effect is three times bigger than in the northern part.

Analysing also the time trajectory of horizontal shifts (see Figs. 4 - 6), the difference is even more apparent. Horizontal shifts during the exploitation of the northern mining panels are several times smaller than the shifts during the exploitation of the southern mining panel ***b*** (293102). This can be also seen on surveyed points stabilized northwards to the "northern" mining panels ***a*** (361000) and ***c*** (362000). Such behaviour of the massif confirms the important influence of both close tectonic faults and geometry and properties of the anthropogenically disturbed part of the massif in the overburden of panel ***b*** (293102). The high degree of massif failure in these areas enables an easier rearrangement of rock materials which leads to the deformations of the assumed–predicted shape of the subsidence depression on the surface (Knothe, 1953; Novák and Sedlák, 2004). The marked difference in behaviour of surveyed points c16 and c18 (see Figs. 1 and 6) may be a striking example. Between these points, there goes a projection of the margin of the area that is affected by an intensive mining activity and it is also an area of the occurrence of significant fault A.

CONCLUSION

We may conclude:

- The possibility of using GPS to monitor the development of the subsidence depression was successfully verified and the advantage of knowledge of the total shift vector of the surveyed points (and/or the whole trajectory) for the understanding of the movement causes was proved.
- It was proved that the shape of the subsidence depression markedly depends among others on the structure, geometry of the tectonic zoning and the massive failure of the overburden massif.
- It was proved that the commonly used models of the prediction of subsidence depression development globally provide a real image about the progress of the subsidence depression. However in concrete cases, the effects of undermining on the surface may markedly differ from these presumptions.

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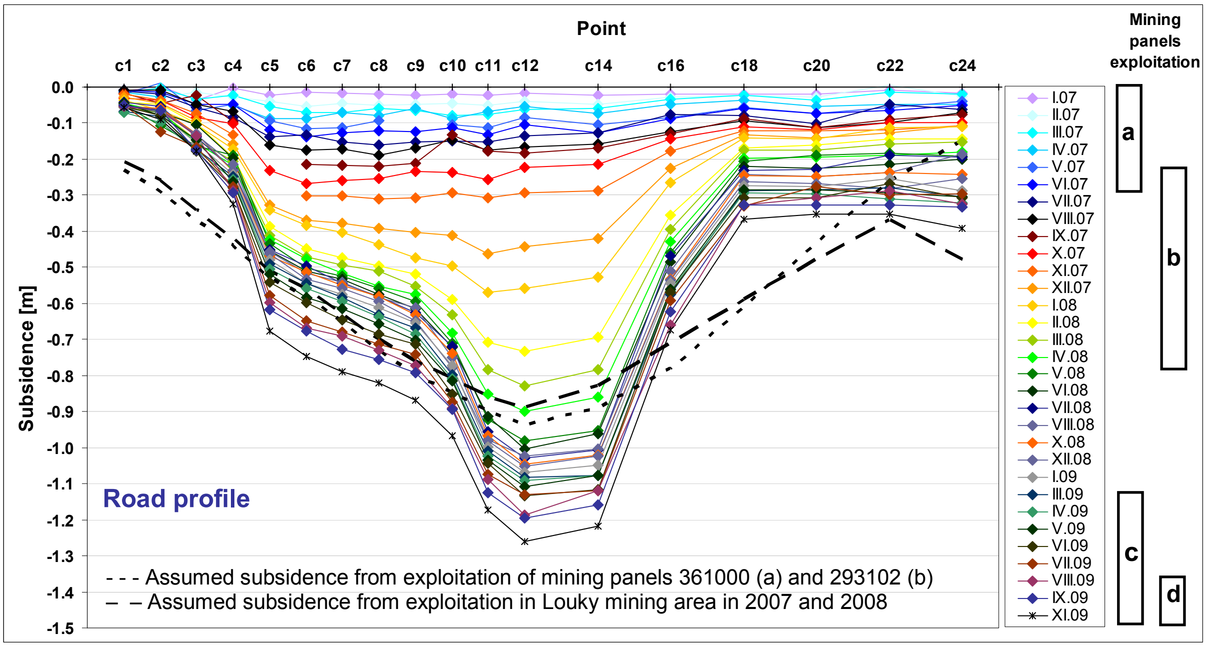

Fig. 1 Total subsidence of the Road profile.

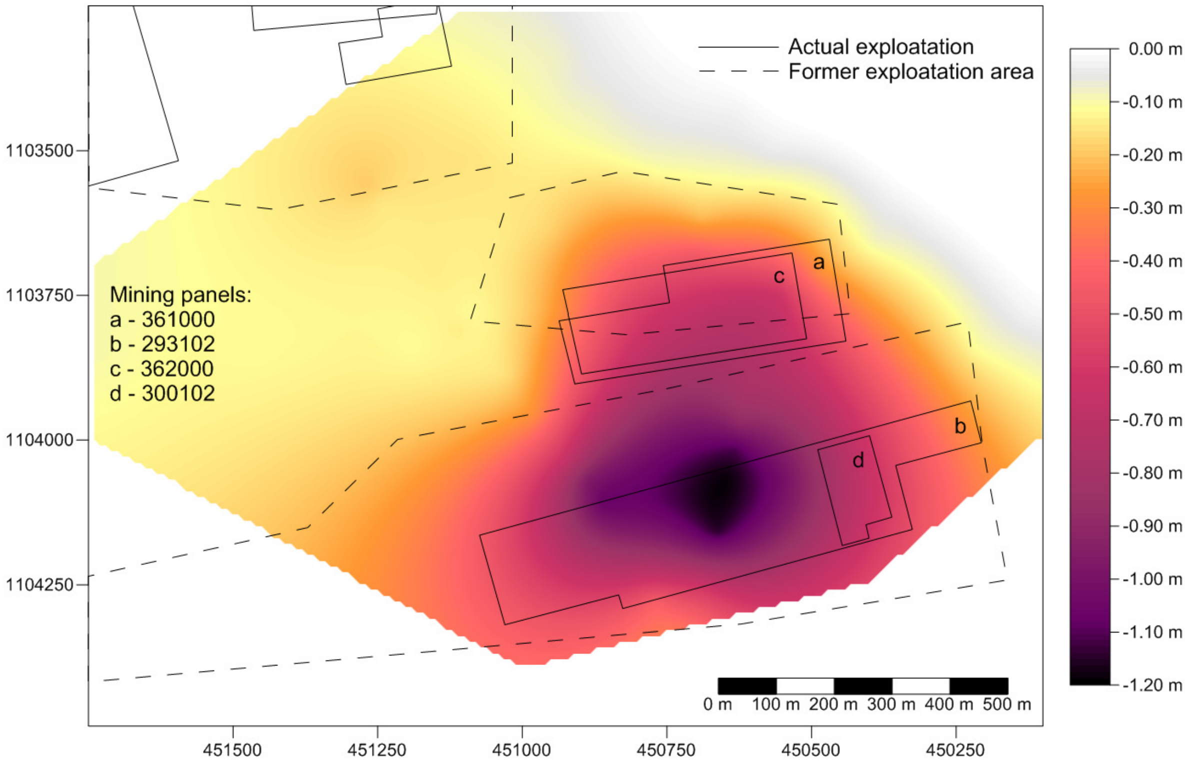

Fig. 2 Areal model of the total subsidence (XII.06 – IX.09).

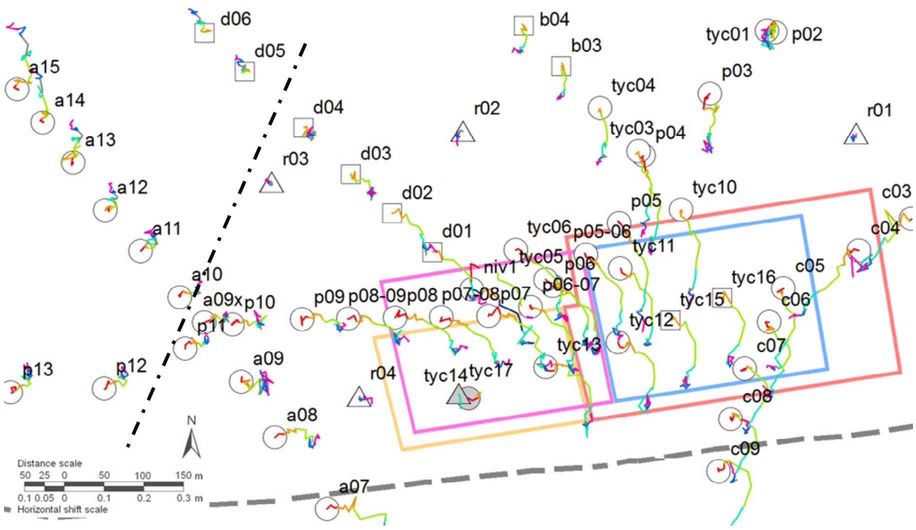

Fig. 4 Horizontal movement analysis in detail – northern part (for legend please see Fig. 6).

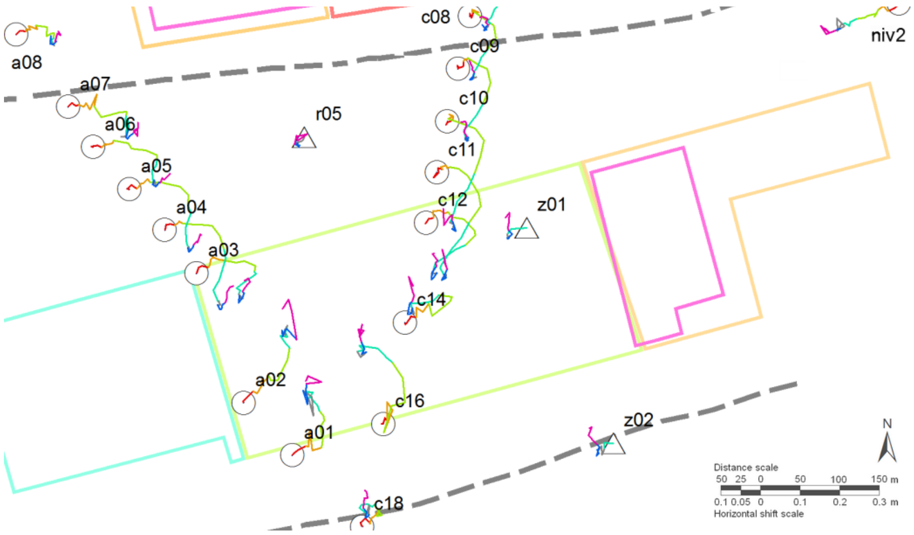

Fig. 5 Horizontal movement analysis in detail – central part (for legend please see Fig. 6).

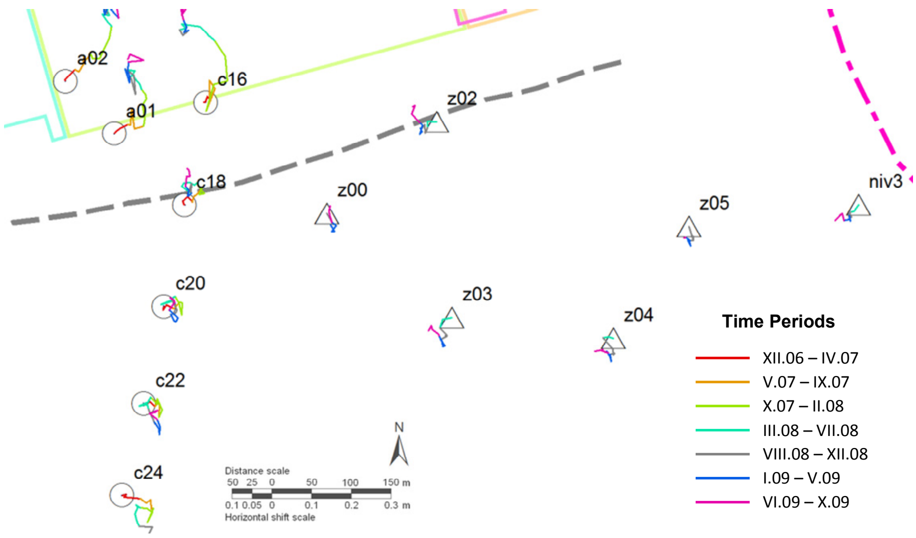

Fig. 6 Horizontal movement analysis in detail – southern part.