INTERPRETATION OF LEVELLING MEASUREMENTS IN THE AREA OF THE PRÍBRAM URANIUM DEPOSIT AFTER TERMINATION OF MINING

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ABSTRACT
In spite of its exceptional extent, the deep mining in the Príbram area had just only little effects on the landscape, which were practically insignificant, e.g., in comparison with the impact of the deep mining in Ostrava region. Although the mining operations in the area of the local uranium – poly-metallic deposit was terminated more than twelve years ago, one has to take into account that its after-effects will have to be monitored and, if necessary, dealt with during several future decades. Areas of subsidence may be included among topical or only potential hazards to the environment and inhabitants in connection with the uranium industry in the Príbram area.
If the underground exploitation operations have been conducted so that the loosening processes, accompanied by gradual or sudden caving in of empty cavities due to the destruction of the surrounding rock massif, may reach the surface, the surface is in danger of subsidence. Such area is designated as a subsidence area and all building, forestry or agricultural activities are prohibited there. In the area of the Príbram deposit, a total of 9 subsidence areas have been designed, and their monitoring is the subject of this paper. The work, described in this paper, was carried out as part of the Project "Targeted Research of the Academy of Sciences of the Czech Republic" number S 3086005.

KEYWORDS: Príbram uranium deposit, environmental effects of deep mining, mining induced surface deformations, levelling measurements

1. INTRODUCTION

Areas of intensive exploitation of mineral raw materials are subject to anthropogenic effects on the environment. Once the exploitation of the raw-material reserves has been terminated, these areas required increased attention particularly as regards cleaning of historical environmental burdens.

The Príbram area has a long tradition of mining, which dates back to the 11th century. As opposed to the relatively negligible impacts of the past 8 centuries on the environment, the extraction of uranium in the second half of the 20th century had the most pronounced effect. In view of the specific properties of the mined raw material, special hygienic and safety measures had to be observed in the course of mining with regard to the workers in the mining and treatment sectors, as well as with regard to the inhabitants of neighbouring communities. The termination of the exploitation at the beginning of the 1990's did not eliminate the hazards to the environment and inhabitants of the Príbram area. Considerable effort is still being expended in cleaning up and re-cultivating the consequences of mining operations and in monitoring potential hazardous processes and phenomena. One of these problems is the question of the effect of undermined areas on the earth's surface. The effects of mining at depths of 200 to 400 m were already felt in the 1950's and in the subsequent first decade of the winning of the deposit in Bytíz as large sinkings, which occur in the area to date.

2. GEOLOGICAL DESCRIPTION OF THE AREA

The District of Príbram is located in the south-western part of the Central Bohemian Region. It is considerably divided horizontally and forested. Wide, rounded ridges of the highest Central Bohemian hills, the Brdy uplands with the highest peak Tok (865 m), range over the whole western half of the district. Proterozoic and Early Palaeozoic rocks of the Barrandien dominate in the geological structure of the Brdy uplands. The Proterozoic is represented by slates and wackes with intercalations of phthanites, and also products of basic volcanism are in evidence. Of the Early Palaeozoic rocks the most widespread are silicirudites and Cambrian sandstones, Ordovician quartzites and shales. The eastern part of the Príbram

District covers the area of the Benešov Hills. A strongly horizontally divided and tectonically disturbed relief with the deeply sunk Vltava Valley is characteristic for this regional geomorphologic unit (Demek, ed. a kol., 1987). In the geological structure, depicted in the section of the 1:50 000 geological map in Fig. 1, deep eruptive rocks of the Central Bohemian pluton prevail – mostly granodiorites to quartz diorites, less so acid granites. The highest point of the Benešov Hills is Stráž (638 m).

The whole area of the district belongs to the river basin of the River Vltava, which flows from south to north in its eastern part. Many smaller watercourses make up the hydrographical net: the brooks Brzina, Sedlecký, Lišnický, Vápenický and the rivers Kocába, Litavka and Skalice.

The most important groundwater aquifers are located in the Brdy (sometimes also referred to as the Príbram-Jince) Cambrian area. The most aqueous are the formations of the Tremošná conglomerates and Brezové Hory sandstones. The results of good crack pervious ness of these formations are numerous springs in areas where they occur. The most numerous and efficient are the springs at the head of the layers on the north-western slopes of the Brdy hills. The efficiency of the separate springs only range from tenths to a few litres per second, however, it is quite stable. The water-bearing capacity in the area of Proterozoic sediments or deep eruptive rocks of the Central Bohemian pluton is insignificant. Pore perviousness is practically non-existent here. In the Central Bohemian pluton there occur some less significant crack groundwater bodies, the Proterozoic being also deficient in crack circulation of groundwaters (Hynie, 1961, Vlcek, 1971).

No large conservation zone is located on the territory of the Príbram District. A number of small conservation zones of the National Natural Reserve, Natural Reserve however, been declared. In the first instance, the occurrences of original forest associations are protected (the Natural Reserve Na Skalkách, Kuchynka and Getsemanka I and II in the Brdy hills, State Natural Reserve Albertovy skály in the Vltava valley). In the region of the Central Bohemian pluton, granodiorite and granite loggan stones have been assigned to the specific shapes of weathering and removal of deep eruptive rocks (Culek, ed., 1996).

3. THE PRÍBRAM ORE AND URANIUM DEPOSIT

The oldest settlement in the Príbram District dates back to the Bronze Age when the broader vicinity of the Vltava valley was settled. Systematic settlement of the region occurred only during the colonisation in the 13th century. Since the early Middle Ages the exploitation and processing of ores played a significant role in the economy of the Príbram area. Archaeological documents indicate traces of extensive exploitation of local iron ores since the 10th century. The oldest written document concerning mining activity is dated 1311. For long periods, however, mining in the Príbram area was unprofitable. The longest period of prosperity is considered to be 1784 – 1896 when exploitation was highly profitable, mostly due to silver production. The Príbram plant at that time was one of the largest mining operations in the world, providing employment for about 6 000 workers in 1885 (Vlašimský, 1990).

The Príbram uranium – poly-metallic deposit, Fig. 2, occupies a strip running SW to NE, about 24 km long and 1.5 to 2 km wide. The deposit itself is a vein deposit of hydrothermal origin, its genesis being associated with the external contact of the Central Bohemian granitoid pluton originated during the Variscan folding. The most important rocks surrounding the ores are weakly metamorphosed rocks of the Upper Proterozoic (shales), partly covered by Cambrian sediments. The uranium mineralisation is associated with veins running NW and NE. In the area of the deposit the veins are non-uniformly developed and concentrated in so-called vein nodes (Fig. 2). A total of 20 of these have been identified in the deposit, further divided into ten sectors named after the closest municipalities. These sectors are: Trebsko, Kamenná, Lešetice, Brod, Jeruzalém, Háje, Svatá Hora, Bytíz, Skalka and Oborište. A total of over 2 500 ore veins were opened and explored in the deposit, 1 641 of which contained uranium mineralisation.

4. MINING IN THE PRIBRAM URANIUM MINES

The history of mining uranium in the Príbram area commences in 1947 when the hitherto known occurrences of mineralisation were reviewed. These reviews proved the existence of all old occurrences and new ones were found. Development was begun in 1949 and extraction some time later. The deposit gradually became the largest on Czech territory; shaft extraction was carried out in the areas of the municipalities of Trebsko, Kamenná, Lešetice, Konetopy, Brod, Jeruzalém, Háje, Bytíz, Dubenec, Drásov, Skalka, Ostrov and Oborište. Administratively the deposit was divided into five workings (see Appendix 3): Kamenná, Lešetice, Brod, Bytíz and Daleké Dušníky. From 1955 to 1975 the Pribram area was the principal producer of uranium ores in Czechoslovakia. Since the middle of the 1970's the volume of extraction and sale of uranium ores decreased, and some mining sectors were gradually liquidated. Extraction was definitively terminated in 1991. Over the period of exploitation of the deposit, 48.8 thousand tons of uranium, 6.2 thousand tons of lead, 2.4 thousand tons of zinc and 28.9 tons of silver were extracted. 27 working and ventilation shafts were sunk, stopping went down to a depth of 1470 m (28th mining floor), and development reached a depth of 1838 m. The mining covered an area of 1.3 sq. km, and a total of 56 million m^3 of rock was extracted underground. The liquidation and re-cultivation work following extraction and treatment of uranium ores is now within the competence of the State Corporation DIAMO, which until 1992 was styled Koncernový podnik Ceskoslovenský uranový prumysl (Czechoslovak Uranium Industry Concern).

5. IMPACT OF MINING URANIUM ON THE ENVIRONMENT IN THE CLOSEST NEIGHBOURHOOD OF THE DEPOSIT

In spite of its exceptional extent, the deep mining in the Príbram area only had impacts of minor extent on the landscape, which are practically insignificant, e.g., as compared with the impact of open-pit extraction in the North Bohemian Lignite Mining District. Although the extraction of the uranium – poly-metallic deposit in the Pribram area was terminated more than twelve years ago, it is necessary to take into account that its after-effects will have to be monitored and, if necessary, dealt with over a period of several decades. The most serious, immediate or only potential hazards to the environment and inhabitants, associated with the uranium industry in the Príbram area are:

?? Spoil banks,

?? Pit water and waste water from mines and treatment plants,

?? Inhabitants' radiation load,

?? Setting pits of ore treatment plants,

?? Mountain bumps,

?? Subsidence and sinking of the surface – A section on subsidence has been included in this paper.

6. SUBSIDENCE AND SINKING OF THE SURFACE

If the exploitation is conducted so that the loosening processes, during which empty cavities are gradually or suddenly filled due to the destruction of the surrounding rock massif, reach the surface, the surface is in danger of subsiding (Ružicka, 1984). Such areas are designated as subsidence areas, and any construction, forestry or agricultural activity is forbidden there. In the area of the Príbram deposit, there are 9 such subsidence areas listed in Tab. 1. So far subsidence has occurred in two of them, in particular in the areas of vein nodes Bt 4 and Bt 17-22. Such areas represent permanent mining damage with permanent loss in the landscape. As the level of the flooded deposit rises to higher elevations, increased motions in the rock massif can be expected. Substantial motion is expected namely in the Bt-4 area (cf. Tab. 1), which is most subject to subsidence. Further subsidence may be expected here without doubt. This may be initiated not only by the rising level of the mine water, but also due to seismic events, which occur in the deposit, and whose intensity and frequency will increase temporarily in a particular stage of the flooding.

In connection with surface deformation, associated with the undermining of the area, not damages on buildings and engineering networks, which are not owned by the operator of the deposit, have been proved or paid. However, mining objects have been damaged in the past. Perhaps the best-known case was the sudden sinking of the uranium mines cafeteria in the Bytíz sector to a depth of 50 m, which occurred in the middle of the 1980's. In this incident three working prisoners lost their lives.

Based on information and survey data, obtained from the Diamo Company and former Uranium Mines Príbram, the staff of the Institute of Rock Structure and Mechanics of the AS CR analysed the deformation of the terrain at the locations of important surface objects in the areas of Lešetice, Bytíz, Brod and Jeruzalém. The initial data for this analysis were the results of repeated levelling along local levelling traverses, carried out in all the localities mentioned above from 1976 to date by professional geodetic organisations.

Table 1 List of subsidence areas in the Príbram uranium – poly-metallic deposit (after Schrötter et al., 2000). The designation of the areas is made up of the code of the mining sector (Bt – Bytíz, L – Lešetice, J – Jeruzalém, B – Brod) and the numeric designation of the vein.

Subsidence Area	Area (sq. m.)	Circumference (m)
Bt 17-22	16 170	665
Bt 25	1 065	148
Bt 20	10 350	483
Bt 33-37	17 581	630
L 1-17	15 940	575
J 76D	2 779	293
B 34 – B 81	15 681	767
Bt 4 – Bt 5	170 800	3 015
Bt 49	2 500	200

To clarify the surface subsidence connected with destruction of the rock massif at shallow depths, the sparse nets of probes approx. 50 m deep, the purpose of which was to monitor the loosening of rocks overlying mine workings, from which packing mateial was extracted after the probes had been stabilised, were also stabilised at the said localities. In view of the construction of these probes, this involved measurements of changes in the distance, defined by the point of deep anchoring of the length-measurement medium (steel wire, or steel system of rods) and the point, at which it emerged at the level of the collar of the probe. The collars of the separate probes were not connected by levelling, hence only isolated measurements are involved, which cannot be used to assess the surface subsidence manifestations in the surrounding terrain, nor to assess the interference of subsidence with the loosening of the disrupted rock massif due to mining operations.

In the Lešetice area (Figs 4, 5) the levelling traverse, monitoring the important Príbram – Breznice international railway route, which runs above the area of shallow extraction operations, as well as short sections of the levelling traverses running along surface roads, were stabilised. The net of levelling points in this area was also stabilised and levelled in order to monitor surface subsidence, if any, in built-up areas. All these points of the said levelling nets were levelled at nearly monthly intervals from 1976 to date.

By studying the evolution of the time variations of these measurements and, in particular, by analysing the overall changes in the elevations of the levelling points for the whole period in question (Fig. 6) one can conclude that the whole region is stable.

The largest subsidence is about h = 77 mm where the said railway crosses a road. In the immediate neighbourhood of this point, there is, of course, a point, which displays a lift of 48 mm, and points with nearly negligible sinkings and elevations of a few millimetres, which can be attributed to climatic and apparently also to anthropogenic effects. Similarly, the observed motions of anchors of deep probes display only very small, no more than 3 mm, subsidence of the subsurface rock massif, which is evidence of the cohesion of this massif.

In the area of Bytíz (Fig. 8) a net of eight levelling points was monitored, which had been stabilised in the neighbourhood of the buildings of the Bytíz Mine in places where a catastrophic subsidence of 30 m occurred in the middle of the 1960's. South of the municipality along the A-road from Prague to Strakonice and along the B-road from Bytíz to Nová Hospoda, the deep probes, mentioned above were then installed. Such probes, four in all, were also established in the western part of the forest, located between the municipalities of Bytíz and Dubenec, and two probes at the western edge of the built-up area of the Bytíz Mine.

The study of the resultant changes in the elevations of the points of the levelling net over the whole period in questions (approx. 25 years) disclosed a small subsidence (about 10 - 15 mm) of the surface in the southern part of this net, which has not changed over the recent ten years, being evidence of the end of the subsidence effects still occurring when the mine was still quite active. The subsidence phenomena of the rock massif at the depths of the anchors of the probes mentioned above are very small and provide no proof of significant destruction of this massif. The evaluation is shown in Fig. 9.

In the area of Brod and Jeruzalém, mostly deep probes, whose traverses are shown in Fig. 10, were stabilised. The measured changes in elevations in the areas of the anchors of these probes are again very small and do not indicate any more significant disruption of the massif in this region. The evaluation of these measurements is shown in Fig. 11. The levelling traverse stabilised approximately 500 m south-east of the Brod Mine above the exploited region displays negligible elevations and sinkings, which can be attributed to agricultural activity rather than mining. Fig. 12 shows a photograph of deep levelling probes used in monitoring boreholes.

Present seismic monitoring, carried out in the area of the underground gas reservoir, indicate underground shocks with a local magnitude of up to MI = 2.2 (Málek et al., 2000).

The critical interpretation of levelling, carried out at the localities of the former Príbram Uranium Mines, has provided no significant facts concerning the effects of the local mining operations on particular exposed parts of the earth's surface. These measurements, which have been carried out over more than 25 years.

7. RESTORATION OF SURFACE SUBSIDENCE AND SINKING

Filling in of sinks and securing subsidence areas

?? Filling in and conservation of mine workings

?? Supplying water to streams, in which the water discharge has decreased, because pumping has been stopped and mine water drained

The filling in of sinks and old mine workings are carried out by controlled deposition of material obtained from liquidation operations. All these objects area purchased, fenced in and safety zones are marked out along their circuit. These measures apply to all subsidence areas and a total of 370 mine workings emerging on the surface, or approaching the surface to a distance of 100 m. In particular vertical mine workings, emerging on the surface, are hazardous with regard to the safety of persons moving around in their vicinity.

The decrease in the discharge of the Pribram stream and the Stream K Sázkám as a result of stopping pumping and draining mine water was defined by expertise as a mine damage. Measuring objects have been built on both streams, and if the discharge drops below a set critical value, water is supplied to them (Schrötter a kol., 2000).

8. CONCLUSION

The critical interpretation of levelling, carried out at the localities of the former Príbram Uranium Mines, has provided no significant facts concerning the effects of the local mining operations on particular exposed parts of the earth's surface. These measurements, which have been carried out over more than 25 years, indicate no provable deformation effects on the earth's surface due to undermining, apart from locations where the surface has been destructed in the past due to subsidence.

The observed differences in elevation, positive and negative, can mostly be explained as climatic effects, or effects of agriculture and cultivation. The results of the changes in the length bases of deep probes correspond to the sinking of the loosened rock massif at places of deep anchoring of these bases. These have proved in all the localities mentioned above only very negligible association with the studied phenomenon. The results obtained have as yet not led to assumption of any dramatic subsidence, which occurred in the past at the Bytíz locality.

The evaluation of the impacts of mining uranium in the Príbram region leads to the conclusion that much less drastic impacts on the environment occurred here than in other mining districts of the Czech Republic, such as the Ostrava, Kladno areas of the North Bohemian Lignite Mining District. The main reason for these differences is that much lesser volumes of utility raw material were exploited here, to which corresponded significantly smaller interventions in the rock medium. The largest problems with regard to the environment of the Príbram area are the spoil dumps. These represent the largest potential hazard for the atmosphere, soil, groundwater and surface water, which indicates the necessity of restoration and re-cultivation measures and monitoring of hazardous phenomena associated with mine dump management. On the whole, however, the analysis of the impacts of old loads of the uranium industry on the environment is favourable. The area, affected by extraction, with the exception of a few localities under certain weather and atmospheric conditions is not subject to increased radiation load. Neither surface water nor groundwater is being polluted excessively, and buildings and engineering networks have suffered no damage due to subsidence or sinking of the surface. In spite of these positive aspects, it has to be taken into account that the restoration and re-cultivation of the landscape, disrupted by mining, will take decades.

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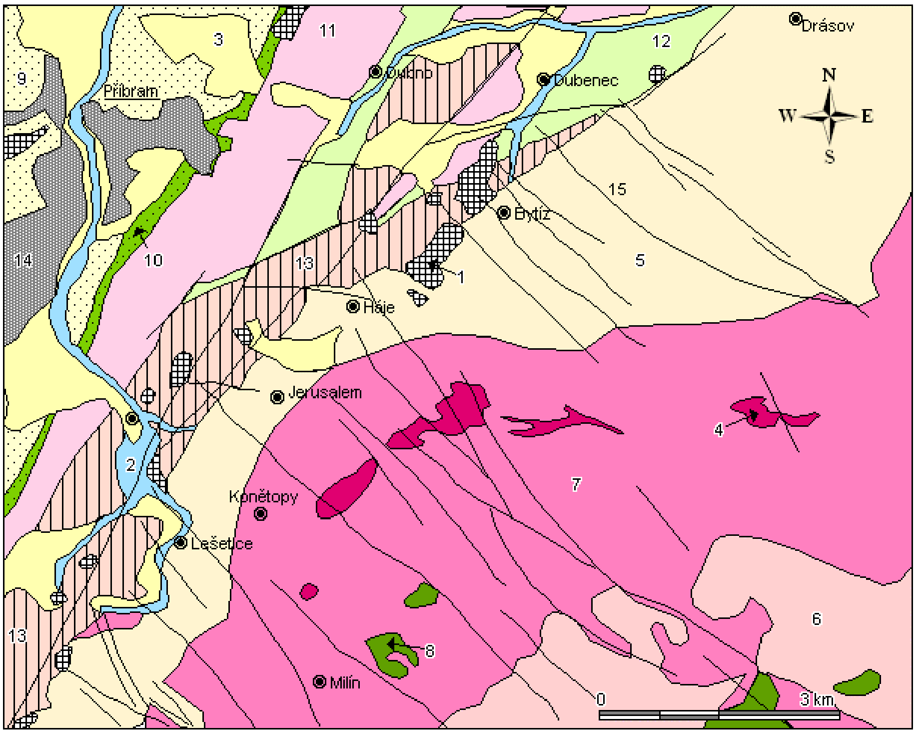

Fig. 1 Vinicity of Príbram - geological map. Modified after the map Príbram 22-21 – Czech Geological Survey 1:50 000. 1 – anthropogeneous deposits, 2 – fluvial deposits, 3 – deluvium. Upper Paleozoic: 4 – fine-grained biotitic granites, 5 – coarse-grained biotitic granites, 6 - coarse-grained amphibole-biotitic granites, 7 – medium grained granodiorite, 8 – pyroxen-amphibolic gabro. Early Cambrian: 9 – Holšín-Horice formation – sandstones, 10 - Holšín-Horice formation – conglomeratres, 11 – Sádek formation, 12 – Žitec-Hluboš formation. Proterozoic: 13 – Štechovice group – siltstones, slates graywacks. 14 – built-up areas, 15 – tectonic faults.

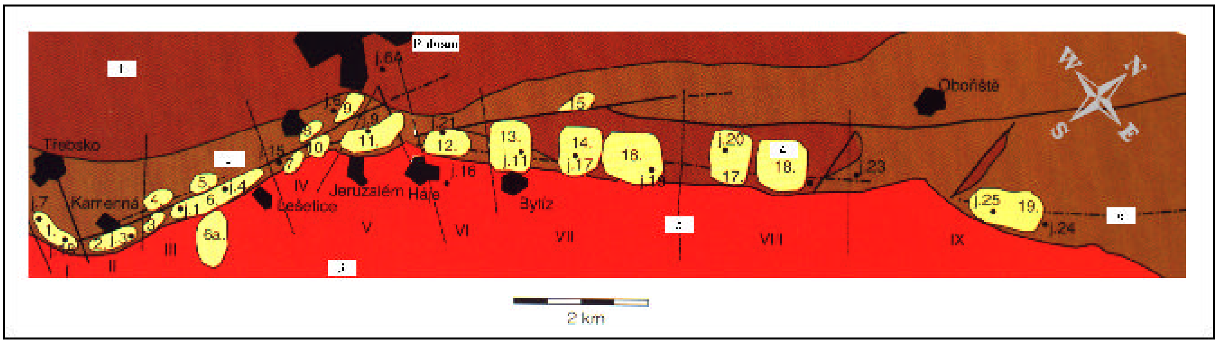

Fig. 2 **Sketch of mining sectors and dyke nodes of the Príbram uranium deposit** (after Kafka, ed. 2003). 1 – sediments of Dobríš formation, 2 – sediments of early cambrian, 3 – granitoids, 4 – dyke nodes, 5 – boundaries of mining sectors, 6 – anticline axis, j – shaft. Mining sectors (in brackets – appropriate dyke nodes): **I. Trebsko** (1. – T1–T33), **II. Kamenná** (2. – K27–47-K42) **III. Lešetice** (3. – D101-D109, 4. – D88-D90, 5. – L9-D3, 6. L1-B34, 6a. – Milín), **IV. Brod** (7. - B128, 8. – B98-B104, 9. - B12, 10. - B 28), **V. Jeruzalém** (11. – J1-J38), **VI. Háje** (12. – H29-H30), **VIa. Svatá Hora**, **VII. Bytíz** (13. - Bt4, 14. - Bt17B-Bt22, 15. - Db1-Db5), 16. – Bt40), **VIII. Skalka** (17. - Sk1-Sk2, 18. – Sk6-Sk12), **IX. Oborište** (19. – ob8-ob27).

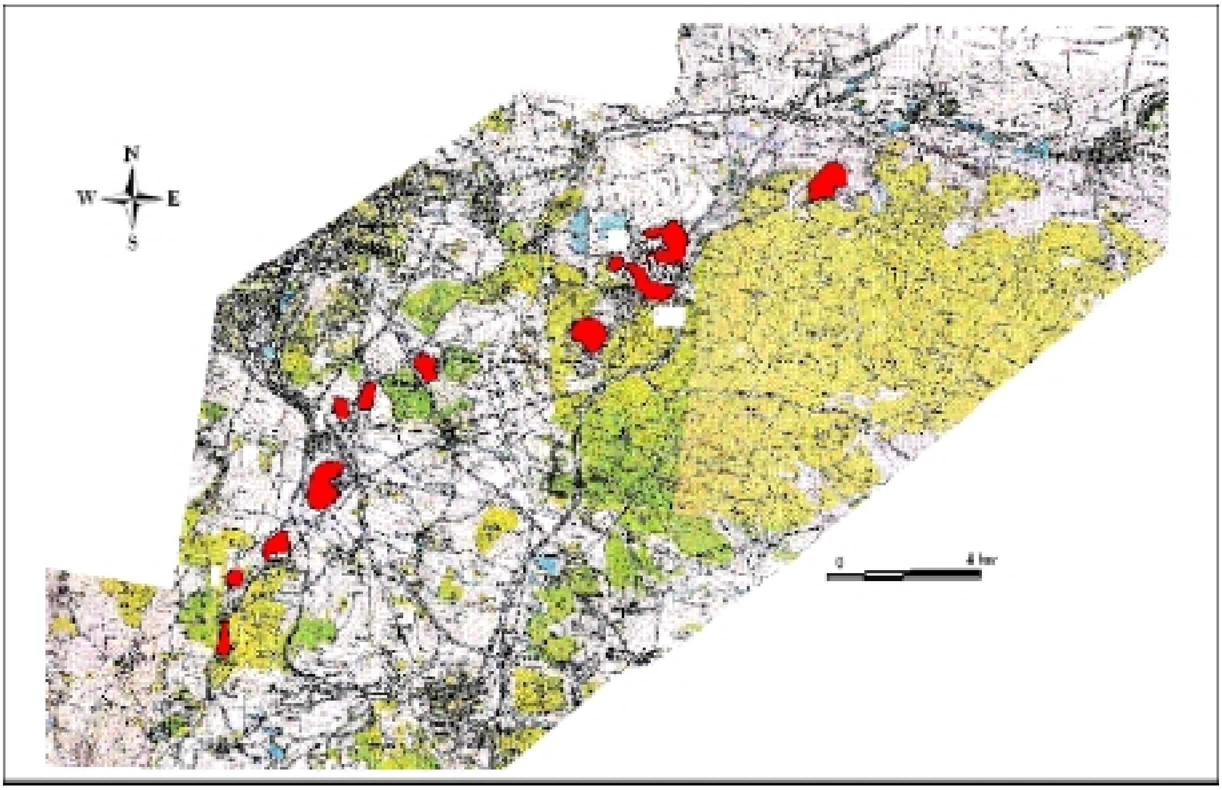

Fig. 3 Areas of surface dumps along the Příbram uranium deposit.
Author: B. Kožíšek – DIAMO, s.p., o.z. SUL Příbram, modified

Fig. 7 Photograph of the measuring station of levelling and deep measurements

Fig. 4 Levelling traverses in the Lešetice area.

Fig. 8 Levelling traverses in the Bytíz area.

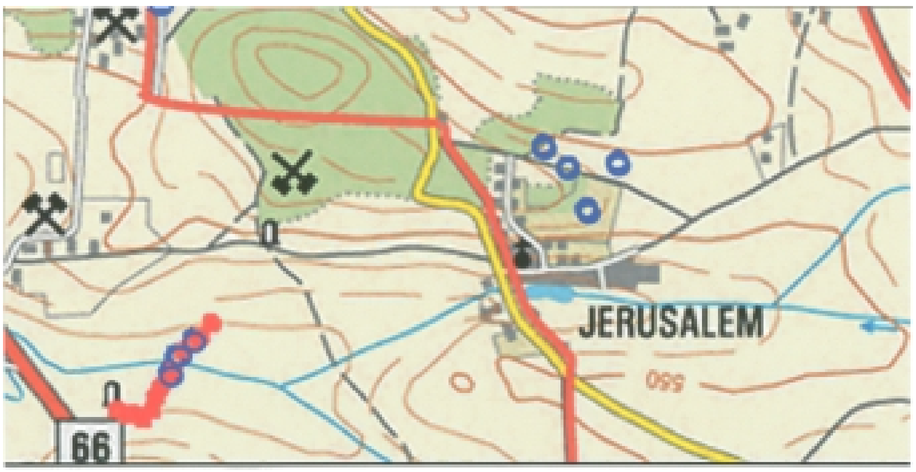

Fig. 10 Levelling traverses in the Brod and Jeruzalém areas

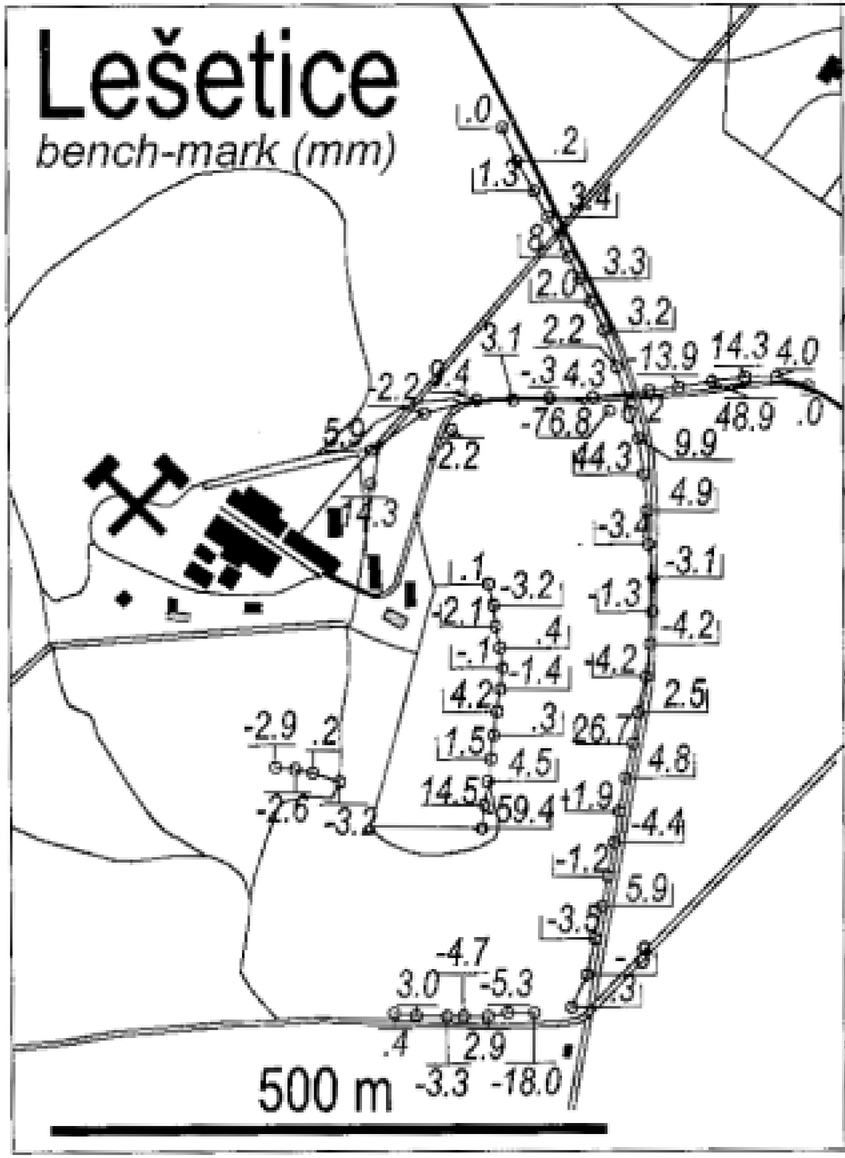

Fig. 6 Levelling traverses in the Lešetice area.

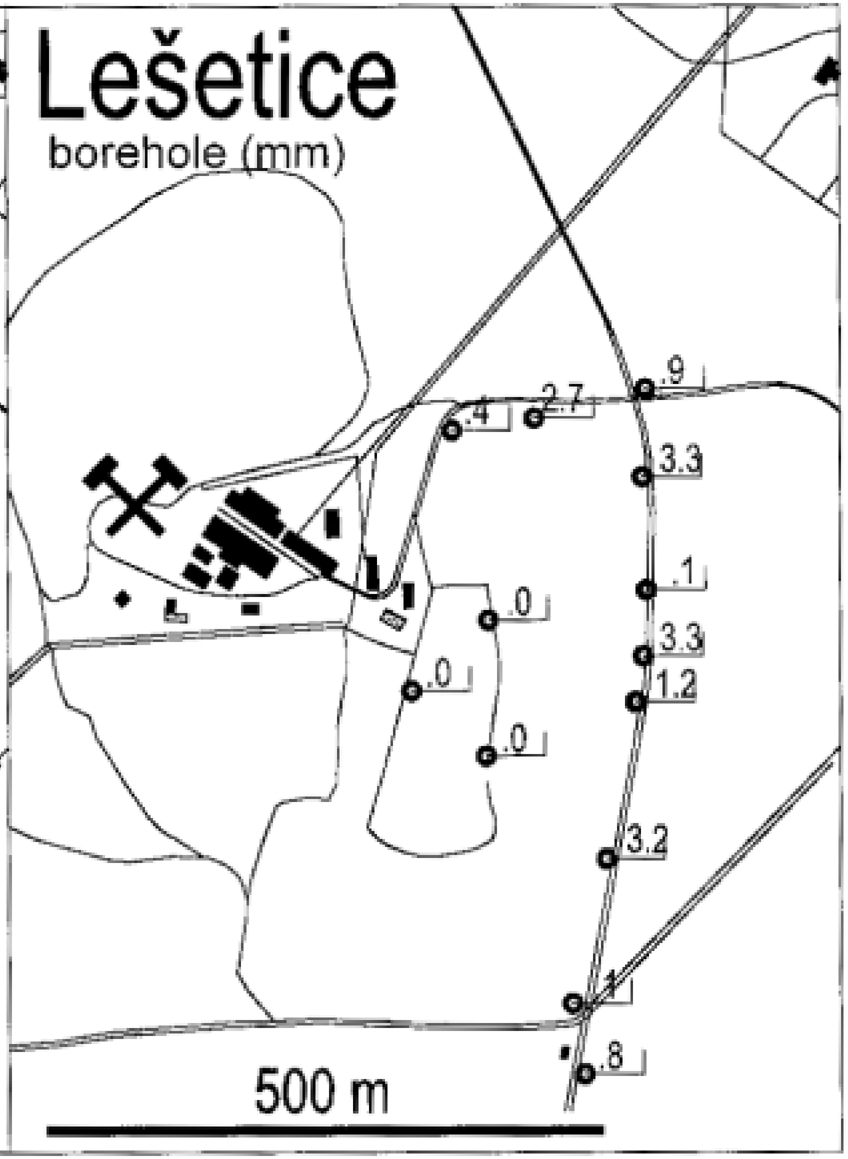

Fig. 5 Levelling traverses along the railway in the neighbourhood of Lešetice

Fig. 4 Levelling traverses in the Lešetice area.

Fig. 8 Levelling traverses in the Bytíz area.

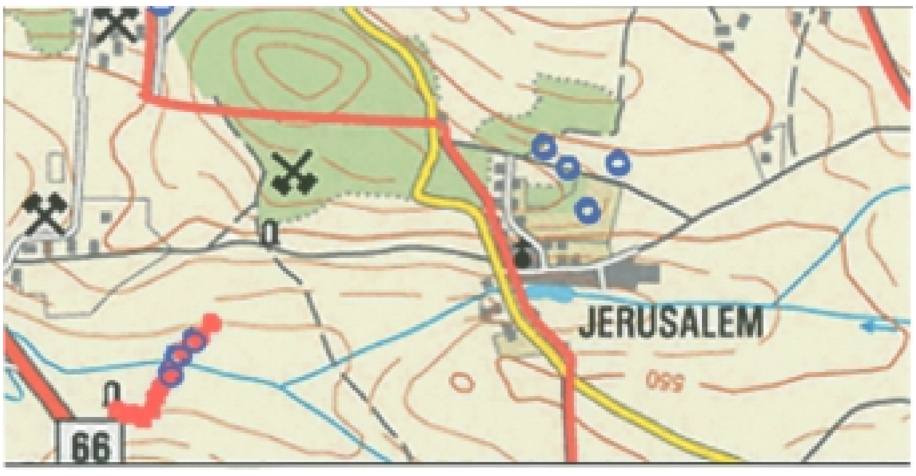

Fig. 10 Levelling traverses in the Brod and Jeruzalém areas

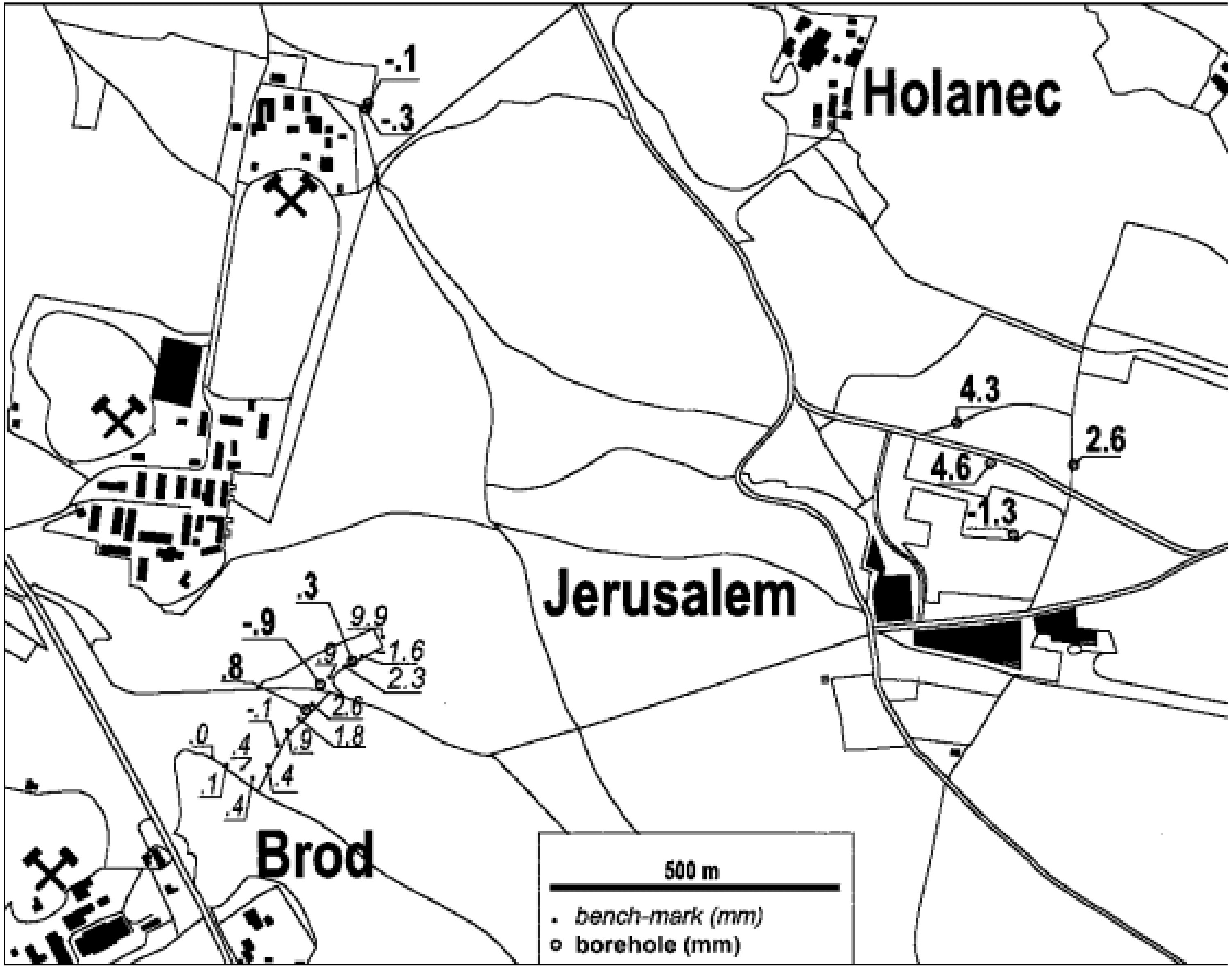

Fig. 11 Subsidence along lines in the Brod – Jeruzalém area

Fig. 12 Photograph of a deep probe