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HYDROGEOLOGICAL AND GEOTECHNICAL CHANGES IN SOKOLOV BASIN CAUSED BY COAL MINING

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Abstract. Mining of brown coal in Sokolov Basin interferes with thermal gas rich water with the water level under the pressure. Since beginning of this Century the thermal water at Marie Mine has been pumped to make underground mining feasible. In the last decade thermal water at Jiří coal open–pit mine was pumped to provide geotechnical safe [illegible] measurements in area influenced by pumping, changes in water chemistry regarding to dewatering [illegible]

Keywords: Open–pit coal mining, thermal pressure water and deformation changes.

1. Introduction

For several years coal in the central part of Sokolov Basin has been mined under the pressure level of thermal gas rich water of basal aquifer (Jetel, 1972; Frans, 1984; Fig. 1). Mining occurs in protected zones of Karlovy Vary natural healing thermal springs. Because direct connection between thermal water in Sokolov Basin and Karlovy Vary springs has never been excluded, there is real possibility that mining has a long term impact on these springs (Hynie, 1963; 1964). The set of expensive monitoring devices and measures has been chiefly focused at a geotechnical safety of open–pit coal mining before thermal pressure water effects in mining area and its large environs.

By the end of the last Century and at the beginning of this Century "Josef" coal seam was mined by an underground mining method. Zones where Josef coal seam was separated only by thin layers of clay from underlying water bearing Stare Sedlo strata and crystalline bedrock containing pressure water, were considered unsafe for mining. In such zones mining at Marie Mine occurred. In drifts inrush of thermal water was observed. In October 1901 during excavation of the main drift at No.II shaft of Marie Mine an inrush of thermal water and consequently flooding of drifts occurred (Jordan et al., 1908; Klír,1982). Following the inrush change in capacity of Karlovy Vary springs was observed. After 1908 the original capacity of springs was reached.

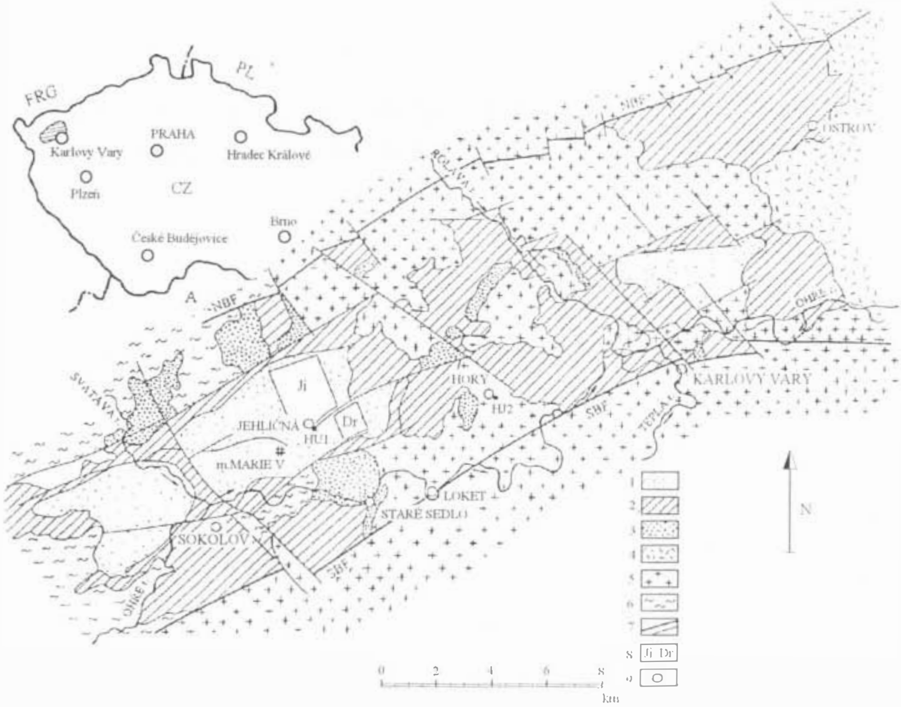


FIG. 1. Schematic geologic map of Sokolov Basin (adapted after V.Havlena 1983):
1 — Cypris claystone strata, 2 — Antonín coal seam and volcanic–detrital strata, 3 — Staré Sedlo strata and Josef coal seam, 4 — Doupovské Mts. pyroclastic rocks, 5 — granite, 6 — crystalline complex, 7 — main faults of basin, 8 — open–pit mines (Ji – Jiří, Dr – Družba), 9 — boreholes.

Antonín [illegible]
the thermal gas rich pressure water with an [illegible]
the impermeable underlying strata [illegible]
pit bott[illegible]
bottom of the open–pit mine gets deeply bellow the thermal water pressure head. One of the key remedy to improve mining safety is pumping the thermal pressure water from the underlying basal aquifer. The objective is to reduce thermal water pressure head and at the same time to limit deformation of discharged volcanic–detrital strata at the open–pit bottom. The pumping impact of thermal water on the geo–hydrological system of the basin's environs is also monitored within operational measures.

Coal mining accompanied by the necessary [illegible]
carried out during next years. For this reason the risk of change of thermal water regime of basin's underlying strata [illegible]
impact on Karlovy Vary thermal springs persists. Project of the Czech Republic

Grant Agency called "Consequences of coal mining on water bearing system of Sokolov Basin in relation to Karlovy Vary thermal water protection" deals with this problem. Project is focused on synthesis of current data regarding proc
in mining area of Jiří open–pit mine and surrounding area.

2. BASIN CHARACTERISTICS

Bedrocks of Sokolov brown coal Basin is f
pluton and crystalline schists. Basal Staré Sedlo strata is characterized by irregular development of sands conglomerates and quarzites including beds of clay. The oldest representative of organogenic sedimentation is Josef coal seam which is 10 m thick. Overlying strata of Josef seam are formed by volcanic–detrital strata formed by tuffs, clay and claystone including tuffite material as an accessory. Above the 40 – 80 m thick volcanic–detrital strata the main Antonín coal seam up to 50 m thick is located. Overlying strata of the
(Fig. 2). Sediments of Sokolov Basin are disturbed by significant tectonic failures striking NE – SW and by a number of diagonal and oblique faults which weaken the strength of volcanic–detrital strata (Fig. 1).

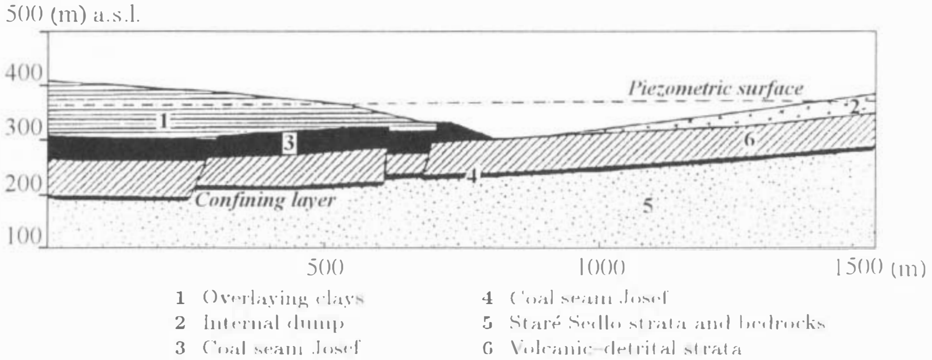


FIG. 2. Schematic section of basin.

Volcanic–detrital strata forms a confining layer of the mineralized thermal gas rich water with a pressure level, and are partially tied to Josef seam, but primarily to the basal aquifer of Staré Sedlo strata and the upper part of the crystalline complex. Water
6000 – 9000 mg.l^{-1}. Chemically water belongs to mineral water of "Carlsbad type" (Dvořák, 1990). Thermal pressure water contains up to 4500 mg.l^{-1} of carbon dioxide and 135 mg.l^{-1} of nitrogen. Saturation pressure ranges between 0.1 – 0.75 MPa (Jetel, 1972).

3. CHANGES CAUSED BY COAL MINING–MONITORING METHODS REVIEW

To ensure geotechnical safety, of open–pit mining and to protect thermal water an extensive exploration program is currently in progress. Most of activities are

focused to provide a stability of the open–pit bottom against a potential break through caused by lifting forces of gas rich water from the basal aquifer, which could result in cessation
conditions in the basin and its environs.

For more than 20 years periodical level survey on the bottom of open–pits and service drifts have been conducted. This survey provides data regarding underl
strata of the mined coal seam during continuous stripping and mining of coal open–pit faces and regarding deformations caused by gas rich thermal water overpressure from the basal aquifer.

In area of coal open–pit mines and its environs observation boreholes where changes of thermal
(Pazdera, 1989 – 1995). Head of this water bellow the bottom of open–pits is locally reduced by drainage boreholes. Temperature changes, gas content and chemistry of pumped thermal water is monitored on the long term basis.

Furthermore at
tensometers
of vertical movements in volcanic–detrital strata more accurate specific boreholes lined by magnetic rings were drilled. To forecast deformation of the open–pit bottom caused by an uncontrolled thermal water overpressure and to assess the stability of confining layer, 3D (the three dimensional) physical model and mathematical modelling has been used for several years (Trčková-Skořepová, 1998; Doležalová, 1992).

The most critical situation
bottom an uncontrollable overpressure of confined water without any local reduction of this water pressure head would reach 0.6 MPa.

4. INTERVENTION IN UNDERGROUND WATER REGIME

4.1. *Marie Mine No.V Shaft Pumping*

Until 1990 the regime of underground water pressure of Josef coal seam basal aquifer
of Marie Mine which at the beginning of this century became the Sokolov Basin drainage centre (Fig. 3). In October 1901 following an inrush of thermal water in No.II shaft of Marie Mine when mine water raised up to the level of Antonín coal seam and flooded mine openings a dewatering of Josef coal seam started. From shaft No.V a warm water of "Carlsbad"
The water level in No.V shaft was kept at 328 m a.s.l. by pumping. Impact of pumping and propagation of depression was monitored through boreholes in No.V shaft neighbourhood. In boreholes not only a water level movement but also a gas phase was monitored. With small variations a condition created following the water inrush was kept for a number of years when No.V shaft was used for dewatering (Fig. 4). Long term monitoring of pressure heads through boreholes proved certain independence of the Josef coal seam aquifer where a depression created by pumping of a thermal water at No.V shaft played a significant role (Pazdera, 1980).

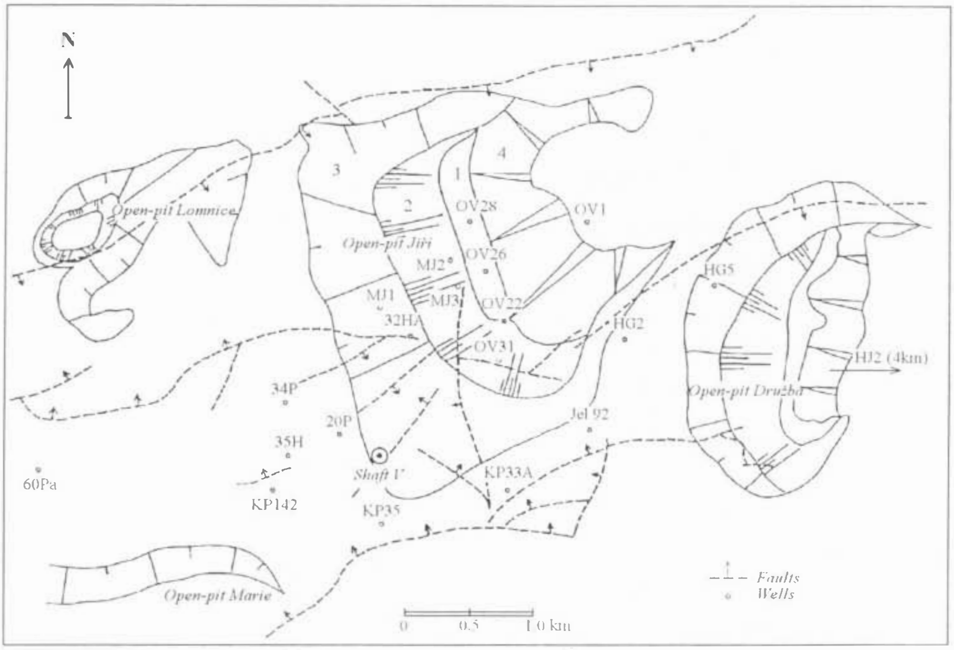


FIG. 3. Situation of open–pit mines and observation boreholes in Sokolov basin.

In recent years before the old flooded workings at Josef coal seam were closed an uncontrolled seeping of water around the shaft casing occurred because the orifice gauge isolation

place between 1990–1991. At that time the pumping period at No.V shaft ended and closing by flooding started.

Though the pumping of thermal water at No.V shaft of Marie Mine lasted for 85 years the pressure head of thermal water in boreholes of Staré Sedlo strata and crystalline bedrock in the wide environs of the shaft was practically not influenced.

4.2. *Jiří Open Pit Mine Pumping*

In 1989 a reduction of thermal

of Jiří open–pit mine started (Fig. 3). The reduction of overpressure by pumping thermal water is necessary to eliminate the possibility of water seepage in underlying strata of the Antonín coal seam specifically in vicinity of tectonic failures and also to prevent inadmissible deformation of the open–pit bottom in locations where a significant overpressure of thermal water was significant (Skořepová,

least favourable condition

take place.

Parallel to local dewatering program in the open–pit mine area and its environs a system of observation boreholes was drilled to monitor changes of pressure water level, temperature, CO_2 content and thermal water chemistry (Pazdera, 1989

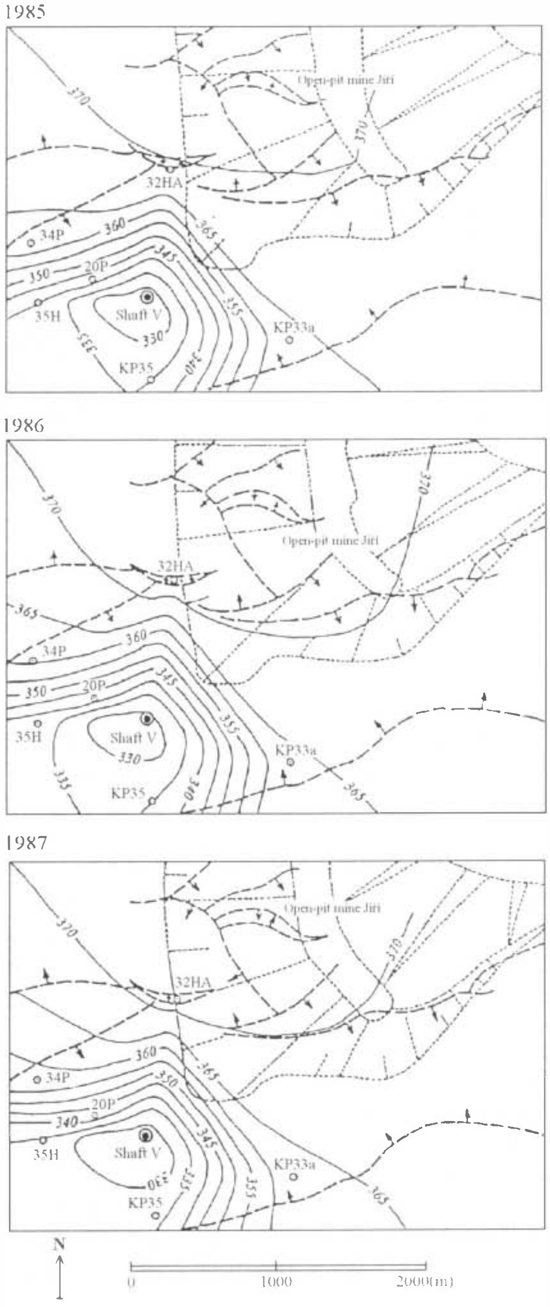


FIG. 4. Depression development in No.V shaft of Marie Mine environs in years 1985–1987

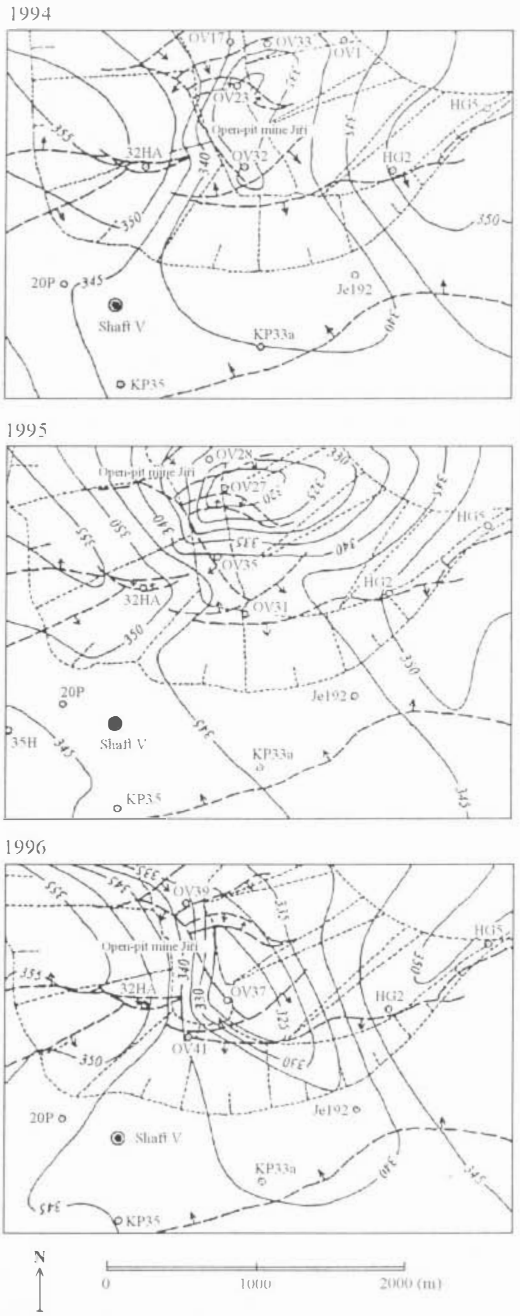
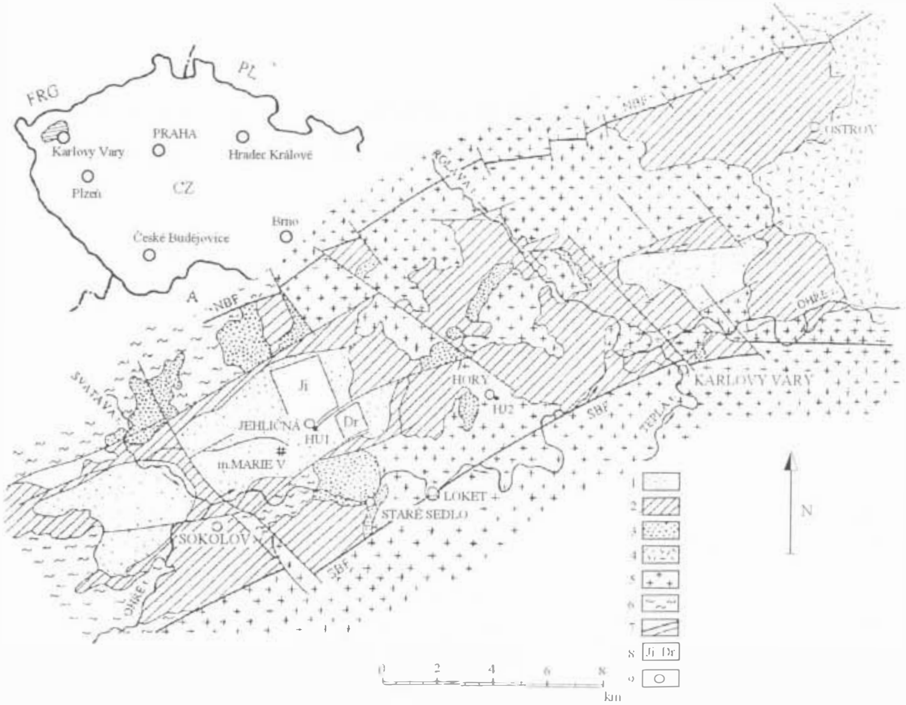


FIG. 5. Depression development in Jiří open-pit mine environs in years 1994 – 1996



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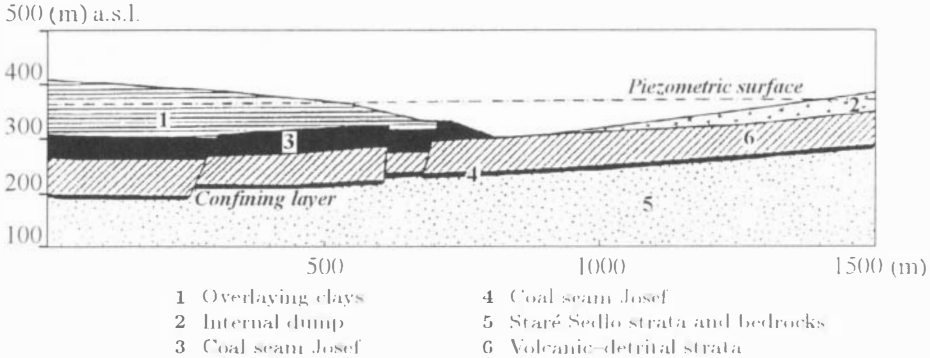

FIG. 2. Schematic

Volcanic–detrital
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In area of coal open–pit mines and its environs observation boreholes where changes of thermal water pressure head are continuously monitored are drilled (Pazdera, 1989–1995). Head of this water bellow the bottom of open–pits is locally reduced by drainage boreholes. Temperature changes, gas content and chemistry of pumped thermal water is monitored on the long term basis.

Furthermore at open–pits geotechnical surveys are conducted. Boreholes for extensometers and for precise inclinometry survey were drilled. To make distribution of vertical movements in volcanic–detrital strata more accurate specific boreholes lined by magnetic rings were drilled. To forecast deformation of the open–pit bottom caused by an uncontrolled thermal water overpressure and to assess the stability of confining layer, 3D (the three dimensional) physical model and mathematical modelling has been used for several years (Trčková-Skořepová, 1998; Doležalová, 1992).

The most critical situation is at Jiří open–pit mine where at the uncovered bottom an uncontrollable overpressure of confined water without any local reduction of this water pressure head would reach 0.6 MPa.

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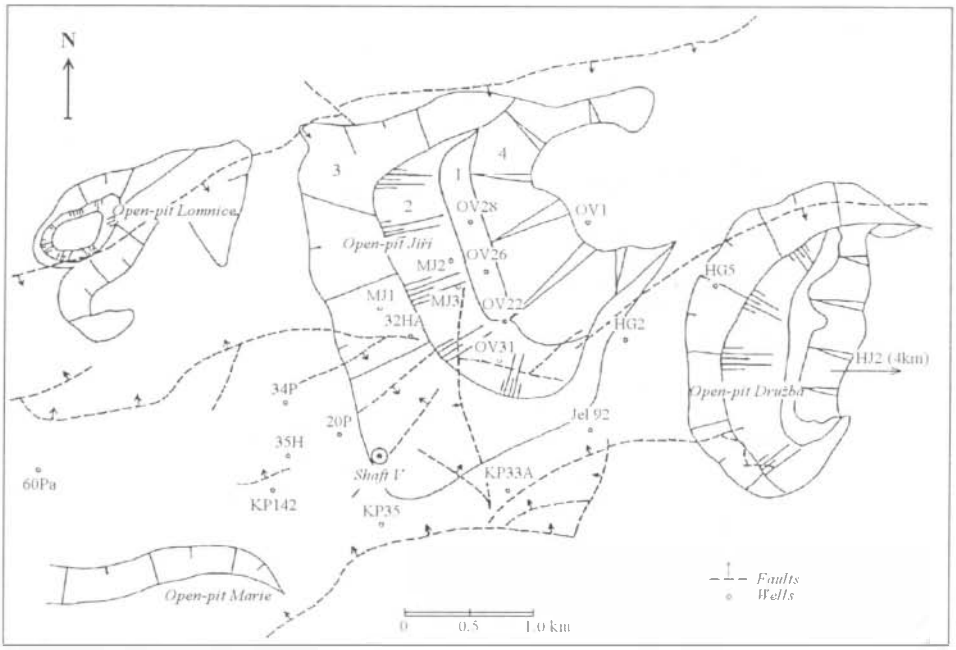

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In 1989 a reduction of thermal water pressure head of basal aquifer in area of Jiří open–pit mine started (Fig. 3). The reduction of overpressure by pumping thermal water is necessary to eliminate the possibility of water seepage in underlying strata of the Antonín coal seam specifically in vicinity of tectonic failures and also to prevent inadmissible deformation of the open–pit bottom in locations where a significant overpressure of thermal water was significant (Skořepová, 1988). Under least favourable condition a breakout of open–pit bottom and its flooding could take place.

Parallel to local dewatering program in the open–pit mine area and its environs a system of observation boreholes was drilled to monitor changes of pressure water level, temperature, CO_2 content and thermal water chemistry (Pazdera, 1989

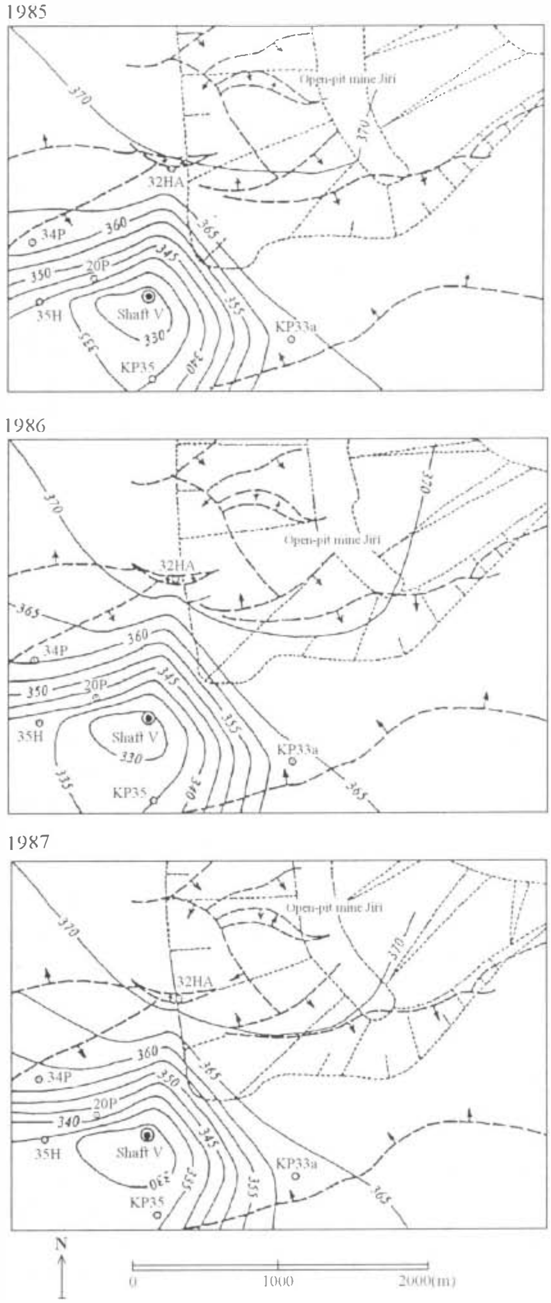

FIG. 4. Depression development in No.V shaft of Marie Mine environs in years 1985 – 1987

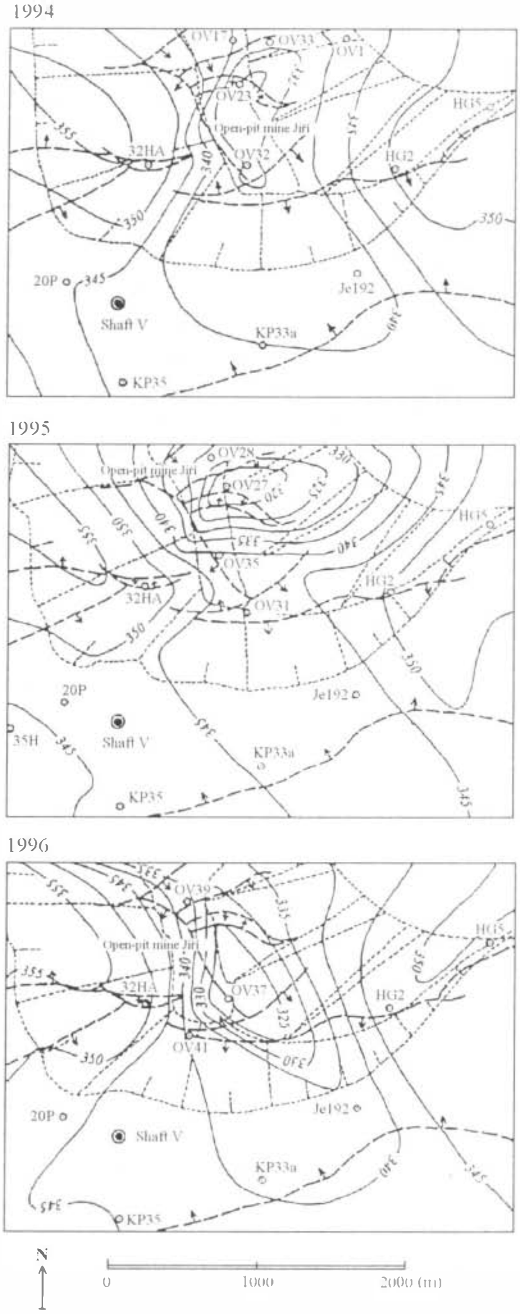

FIG. 5. Depression development in Jiří open-pit mine environs in years 1994–1996

1995). To decrease the pressure head of the water bellow the open–pit bottom, dewatering wells are used.

When the reduction of the water pressure head begun, the volume of the water pumped was around 16.0 l.s^{-1}. Currently in regards to mining conditions (the deepest coal seam mined), the capacity of the water pumped was increased to 32.0 l.s^{-1}. In 1997 in the observation boreholes on the open–pit bottom the water lowered pressure head was around 330 m a.s.l., which is lower by almost 40 m than pressure head before the beginning of the pumping.

Routine measurements of the water level in observation boreholes drilled in basal aquifer not only in area of Jiří open–pit mine but also in boreholes at close and distant environs of the open–pit mine indicate the fast depression propagation (Fig. 5). Decrease of pressure head can be observed in larger distances from the drainage centre all the time. This can be proved by longitudinal sections of thermal water pressure head which cut through Jiří open–pit mine and borehole in its vicinity. Decrease of water pressure head was noticed also at borehole HJ2 situated more than 7 km from Jiří open–pit mine (Fig. 6). In the last six years the water level at this borehole decreased by more than 5 m.

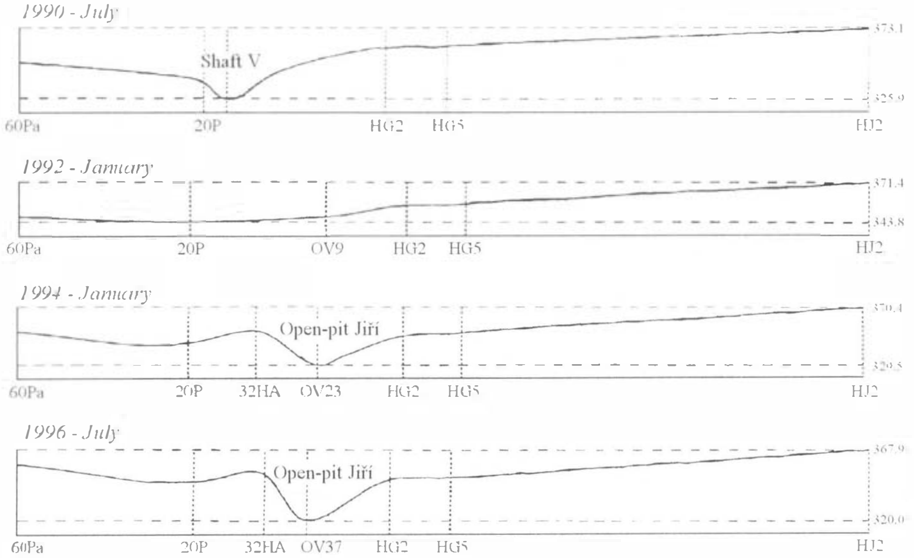

FIG. 6. Thermal water pressure head-longitudinal profiles within Sokolov Basin

5. WATER CHEMISTRY IN RELATION TO DEWATERING PROGRAM

Water chemical analyses from inrush at No.II shaft Marie Mine proved relation with chemical composition of Karlovy Vary thermal water. (Jordan et al., 1908). Long term drop of Karlovy Vary springs yield (1902–1907) suggested that there is a connection of basin thermal water with Karlovy Vary springs. Consequently during underground mining and specifically during coal open–pit mining changes of water chemistry, water temperature and content of carbon dioxide are constantly monitored. Until now a connection of thermal water was neither proved or confirmed.

Basin's thermal water is a mineral water of a "Carlsbad type" occurring through the wide territory of the west Bohemian spring structure (Pačes, 1980; Šmejkal, Pačes 1992; Hanzlík, Krásný, 1998). This type characterizes Na-SO_4 – HCO_3 – Cl mineral composition successions which are changed according to structural conditions of spring structure formation and the petrologic situation influencing mineralization and individual ions ratio (Dvořák, 1990). Successions change is obvious in area of Jiří open–pit mine and its environs where hydrocarbons of different ratio usually prevail over sulphates without significant differences in dewatering and also in observation boreholes. Change of ion ratio in water is conditional upon inflow of descending oxidized water from a shallow aquifer into a deeper parts of the basin. Descending water flows predominantly from NE (Jetel, 1964).

Within Karlovy Vary thermal water prevention program changes in thermal water chemistry at spillway of dewatering boreholes are monitored on regular bases (Fig. 7). At Fig. 8 changes in the water chemistry at selected bore–holes according to dewatering intensity ($l.s^{-1}$) are shown. Changes are expressed by ratios SO_4/Na and Cl/Na ($mequ.l^{-1}$) as characteristic components of "Carlsbad type" mineral water. Contents of Na^+ show only small changes. For comparison water characteristics are marked as follows: A — water from HU–1 borehole (226.3 m), drilled in 1960 in the centre of thermal water occurrence of the Sokolov basin, B — water from No.V shaft of Marie Mine, C — water from Karlovy Vary hot spring – Vřídlo, D — water from HJ2 borehole (1200 m; Fig. 1). For the graph only drainage wells used in a drainage program more than 7 months were selected. Pumping of thermal water from individual wells in not uniform because it depends on local structure, permeability and mining requirements.

From the graph it is obvious that there is no correlation between the pumping intensity of thermal water and its chemistry change as demonstrated by correlation coefficients: $r_{Q,\mathrm{Cl/Na}} = -0.036$, $r_{Q,\mathrm{SO_4/Na}} = 0.21$ (Fig. 8). A certain correlation regarding pumping intensity of thermal water can be monitored at OV 36 borehole where contents of principal ions showed a total decrease of 20 % during borehole dewatering, i.e. from August 1995 to January 1997. The TDS water pumped is between 6000–9000 $mg.l^{-1}$ in relation to borehole location to flow pathways of thermal water in basal aquifer. Temperature of water ranges between 33° to 37 °C. Chloride and natrium ion ratio shows a minor scattering in the entire group of drainage boreholes. Sulphate and natrium ions show a larger scattering of values in individual boreholes.

Location of OV 13 borehole outlines spread of thermal water indicating Na-SO_4 chemism with the TDS around 1000 $mg.l^{-1}$ and temperature of 29 °C. The same type of water is reported from OV 15 borehole showing the TDS between 3300–3600 $mg.l^{-1}$ and temperature 31 °C which suggests that the borehole location is closer to the centre of thermal water territory (Fig. 7). These boreholes were not used for an intensive pumping of thermal water. Composition of this water is

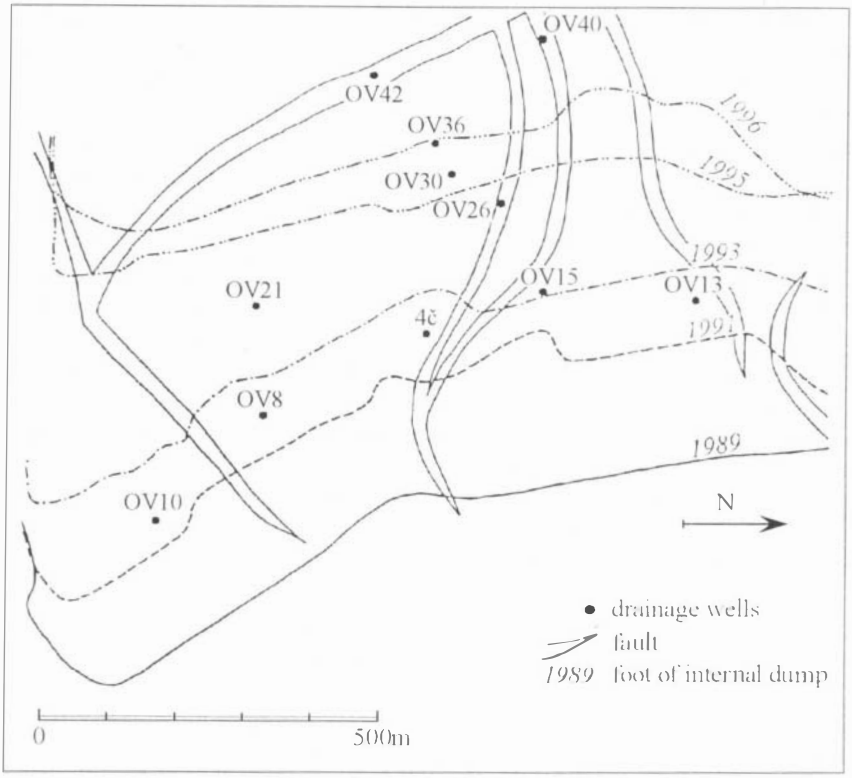

FIG. 7. Situation of selected drainage boreholes on the Jiří open pit bottom for water chemism observation

influenced by sulphate water descending from the perimeter to the centre of the basin, mainly from NE. Process can be speeded up by drainage impact of open pit coal mining on neighbourhood and by intensive dewatering of thermal water from a basal aquifer.

6. OPEN PIT BOTTOM DEFORMATION FORECASTING

To forecast deformation of an open–pit bottom caused by an uncontrolled overpressure of thermal water and to evaluate a confining layer stability necessary data to determine technological condition required to mine the coal seam and also to maintain all safety measures a three dimensional physical models and mathematical modelling was used. This modelling was used to figure out mining procedures at Jiří open–pit mine located in central part of Sokolov Basin.

7. FORECAST ACQUIRED FROM EXPERIMENTS WITH PHYSICAL MODELS

In 1985 a three dimensional physical model (Fig. 9) for modelling of actual mining procedures carried out between 1980–1985 and planned for 1985–1990 was

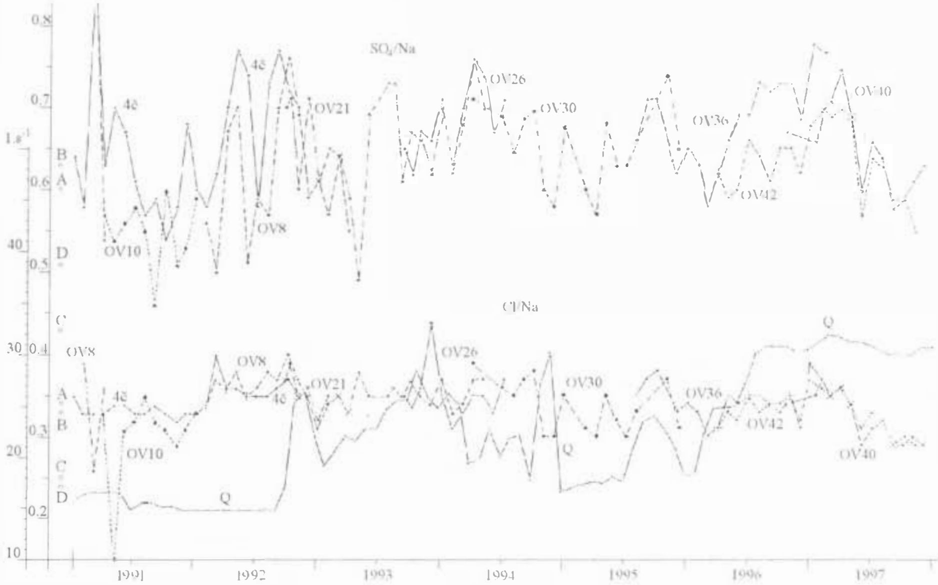

FIG. 8. Relation of thermal water chemism changes in selected observation boreholes and thermal water intensity pumping. A — water from borehole HU 1, B — water from No.V shaft of Marie Mine, C — water from Karlovy Vary hot spring Vřídlo, D — water from borehole HJ 2, Q — intensity of water pumping (l.s^{-1}).

constructed (Skořepová, 1985; 1987). This experiment was carried out with the water level in the model corresponding with the water pressure head of the open–pit i.e. 367 m a.s.l. The maximum lift of underlying strata of the Antonín coal seam recorded on the model was in location where between 1989–1990 the open–pit bottom should had been. In this place according to the dip of underlying strata the uncovered open–pit bottom started to be stressed by uncontrolled overpressure of thermal water reaching in some parts of the open–pit bottom 0.3 MPa. For situations corresponding with mining conditions between 1980–1984 the established deformations on the model were compared with the level survey in the dewatering drift of the open–pit foreground. Values of measured deformations for this period showed a very good correlation (Fig. 10).

In 1987 the physical model to forecast a deformation development for period between 1990–1995 was used (Skořepová, 1988). During those years the bottom of the open–pit mine was gradually brought into most dangerous places. In those places the uncontrolled water pressure of thermal water reached up to 0.6 MPa. The mining field was cut by major geological faults which adversely affected the underlying strata stability. Results of the model experiment showed that in this region the safety mining depends on reduction of water pressure head by pumping. For the year of 1990 following processing of deformation values measured on the model it was recommended to bring down the water pressure head to 350 m a.s.l.

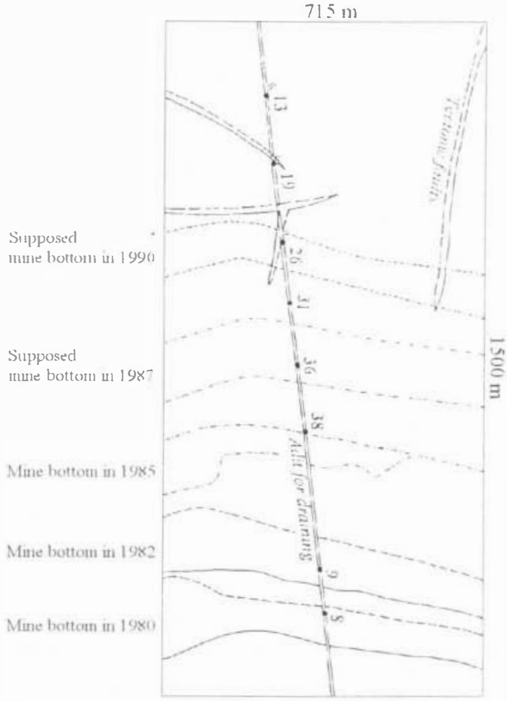

Fig. 9. Scheme of physical model for mining advance on the Jiří open–pit mine in 1980 – 1990

(i.e. by 17 m compared to original level), for 1993 to 337 m a.s.l.. Starting September 1989 on the basis of these recommendations the pumping of the thermal water at the open–pit mine to bring down the water pressure head to 350 m a.s.l. started.

In 1991 a mining company requested if reduction of the water pressure head to 350 m a.s.l. enables safe mining of the coal seam even after 1991 can be determined from the model. New model experiment was designed in such a way to simulate mining procedures in the modelled region from 1984 to 1990 with related mining process according to projected procedures. Simulation of mining procedures in 1989 regarding planing procedures of the open–pit mine till the end of 1992 determined that with the reduction of water pressure head to 350 m a.s.l. the deformation will not exceed values endangering open–pit bottom providing that the minimum width of the open–pit bottom and maximum dip of internal dump will be strictly observed.

In 1992 additional model to simulate mining procedures for period 1989 – 1995 was implemented (Skořepová, 1992). From the end of 1989 in the open–pit area which was modelled the thermal water pressure head was reduced to 350 m a.s.l. This reduction was respected on the model. Following simulation of 1995 planned mining operation major deformations of underlying strata specifically in neighbourhood of modelled faults were shown on the model. Therefore the water pressure

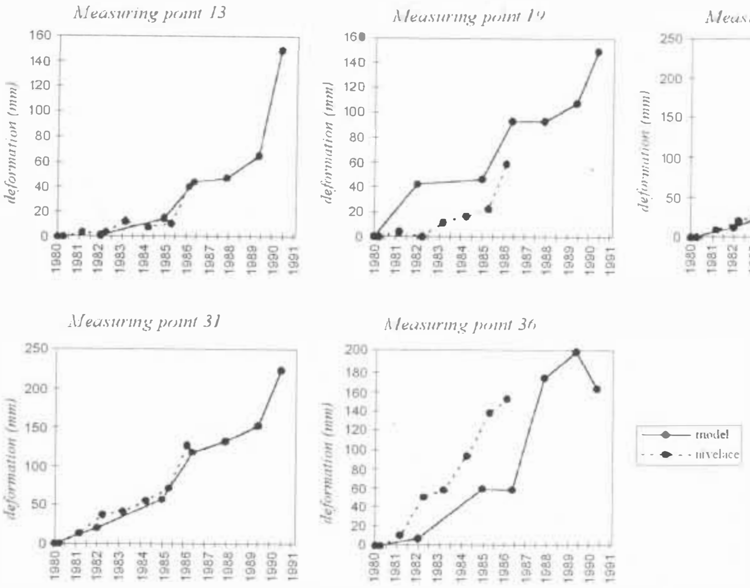

FIG. 10. Comparison of values of vertical deformation determined for various stages of model experiment (excavation 1980–19990) and measured in the drainage adit by levelling. Measuring points for levelling were demolished in 1986 by the excavating process

head of the model was gradually reduced to 340 or to 330 m a.s.l. For the period 1989 – 1992 generally a good agreement of deformations measured on the model with deformations from periodical levelling was established (Fig. 11). According to model experiment results it was recommended to further reduce the water pressure head bellow the 330 m a.s.l. before reaching the most critical places of the open–pit bottom i.e. places with the deepest coal seam in the faulted area. Possibly leave protective coal pillars in the vicinity of faults to prevent major deformations and local fracturing with possible water escape as a result of fracture openings.

8. MATHEMATICAL MODELLING OF OPEN–PIT BOTTOM BEHAVIOUR

In 1985 the stability of Jiří open–pit mine was solved by final elements analyses method for mining procedures implemented in period of 1981 – 1983 and planned for 1984 – 1991 (Doležalová et al., 1985). The selected profiles of mining field the most influenced by thermal water increased pressure were modelled. Two alternative solutions were implemented. First variant of $K_0 = 0.33$ a lateral pressure and more plastic contact between volcanic–detrital layers and basal aquifer, the second one for $K_0 = 0.9$ and a more stiff contact. Both alternatives were calculated for the original water pressure head and for a level reduced by 20 m possibly by 40 m (i.e. 347 m a.s.l.). Calculations indicated that the danger of bottom break through

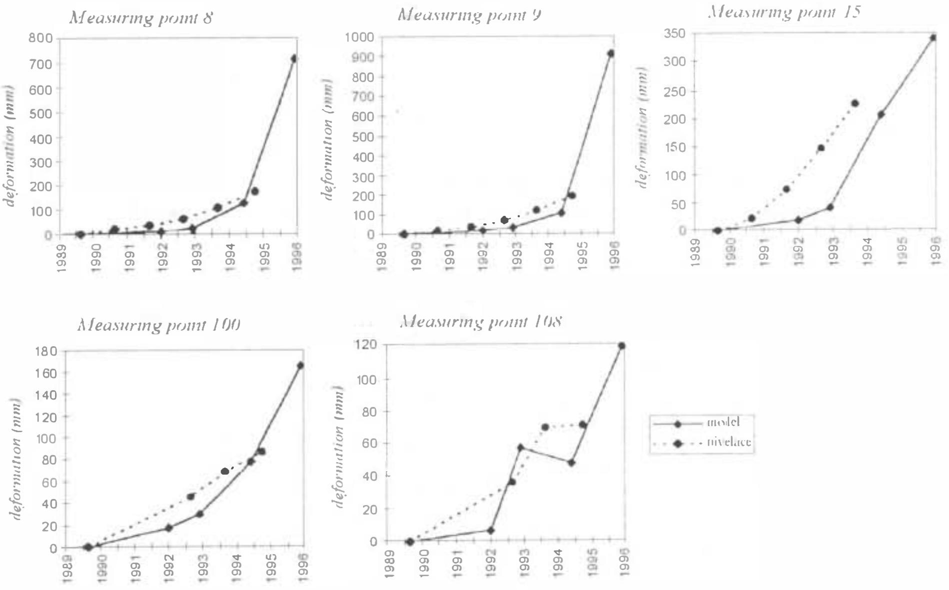

FIG. 11. Comparison of values of vertical deformation determined for various stage of model experiment (excavation stage in 1989–1995) and measured in the drainage adit by levelling

depends first of all on K_0 value applied. For $K_0 = 0.33$ an increase of strain and transformation in as early as following 1985 took place and low effectiveness of water pressure head was displayed. For $K_0 = 0.9$ the entire modelled period of the open–pit bottom appeared stable without any need for the water pressure head reduction. Figure 12 shows the model assigned open–pit bottom deformations compared to the levelling (Doležalová, 1992).

The three dimensional model for 1990 – 1995 mining procedures included also results of open–pit previous calculations and measurements (Doležalová, 1989). Original state in 1990 was modelled for a reduced water level of 350 m a.s.l.: maximum calculated open–pit bottom lift for that year was equal to 45 – 46 cm, for 1992 to 49 cm and for 1995 to 58 cm (Fig. 13). According to model results it was suggested that if the water pressure head of 350 m a.s.l. is maintained, mining procedures in underlying strata of the mined coal seam can be implemented till 1995 without an occurrence of significant tension zones and fracture zones. Model did not show an impact of underlying strata fractures and deformations.

However the levelling and primarily origin of spontaneous inrush of thermal water at open–pit bottom in 1992 indicated that reduction of water pressure head to 350 m a.s.l. is insufficient. Therefore in the following years additional local reduction of water pressure head in agreement with physical model results took place.

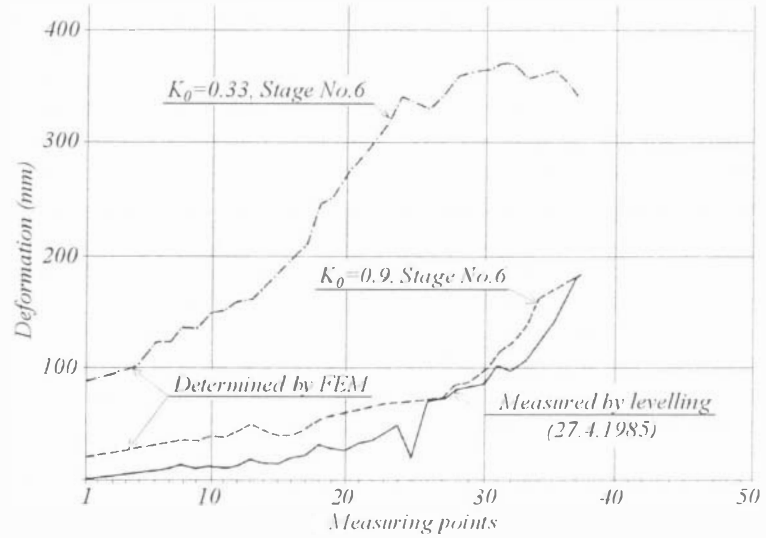

FIG. 12. Comparison of values of vertical deformation determined on measuring points in the drainage adit by levelling with results of FEM calculation (Doležalová, 1992)

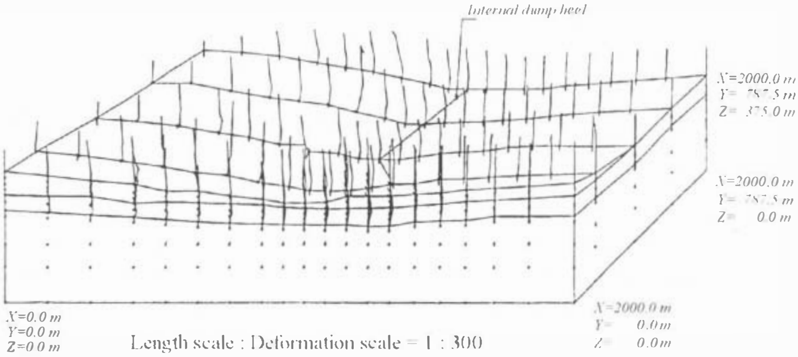

FIG. 13. 3-D numerical model of Jiří the open-pit mine. Total deformations in 1995 (Doležalová, 1989)

In 1991 additional approximate calculations demonstrating the significance of fractures regarding deformation of underlying strata of the Antonín coal seam and the need for their modelling took place (Doležalová et al., 1991a). For this calculation several alternatives in regards to changing stiffness of a contact with underlying strata and specifying mining environment properties were considered. First time an intensive lifting of tectonic faults at the open-pit bottom was modelled. Yet in the same year an other approximate calculations of the open-pit for March 1991 situation were modelled and thus on basis measured vertical movements of stabilized points in dewatering drifts and on the bottom of the open-pit and results of calculations from previous models (Doležalová et al., 1991b). As a reference condition coefficient $K_0 = 0.9$ was considered, water pressure head was gradually reduced from 367 m a.s.l. (reference condition) to 354 m a.s.l., fault zones were modelled with use of contact elements. Mechanical response of fracture system in basal aquifer was also modelled by contact elements along confining layer of pressure water. Constitutive model was designed as non-linear and path dependent. In total 9 alternatives (K_0 changes, reinforcement parameters, impact of shear, model residue coefficient of fractures and contacts in fault zone) were implemented. For $K_0 = 0.82$ results received from model were comparable with measurements in open-pit. Open-pit bottom remained undisturbed, max. deformations 30–50 cm were tied only to block separated by two faults. In alternative with $K_0 = 0.425$ deformations on the open-pit bottom reached 60–130 cm and was created open-pit bottom failure including its rupture by pressure water.

9. DEFORMATION DISTRIBUTION IN VOLCANIC–DETRITAL STRATA

The origin of spontaneous outflows of thermal water from basal aquifer is thought to be related to the character of the Antonín coal seam volcanic–detrital underlying strata displacement and the disturbance of its impermeability caused by unloading following stripping and mining of the coal seam and also by overpressure of thermal gas rich water from the basal aquifer.

By the end of 1994 in the forefield of Jiří open-pit mine a borehole MJ1 fitted with magnetic rings to clarify distribution of vertical movements in volcanic–detrital strata was drilled. The borehole was located in an underground service drift close to stabilized survey point No. 114 where all survey points for periodical levelling of coal seam strata were stabilized. At the outset of the borehole on the steel casing 1.5 m above the service drift footing a bench mark included in the survey point system of levelling was fixed (Sokolovsko ..., 1996; 1998).

Magnetic rings were mounted to rocks of volcanic–detrital strata. For measurement 30 magnetic rings were used. Distance of the first ring mounted 61.030 m bellow the upper part of the upper edge of the casing in service drift from thirtieth ring in upper part of the drift (15.165 m bellow upper edge of the casing) is 45.865 m. From measured distance changes between individual rings vertical movements in various parts of volcanic–detrital strata can be monitored. It concerns only relative deformations related to the upper part of the casing. From change of the distance between the first and the last magnetic ring compared to total deformation established by levelling at the casing head of the borehole possibly at the closest stabilized point it can be determined what part of entire deformation is formed by the change of the interjacent plate thickness.

Measured data from basic survey which took place January 11, 1995 to the end of 1997 were processed. (Measuring of settlement ..., 1996; Periodic report ..., 1996). Table shows change of distance between individual magnetic rings. They are very small mostly at the limit of method accuracy.

Figure 14 shows the change of thickness of volcanic–detrital strata between outside magnetic rings and vertical movement of MJ1 point of a bore hole casing head

TABLE 1. Changes of distance between individual magnetic rings bore–hole MJ1

	01–02	02–03	03–04	04–05	05–06	06–07	07–08	08–09	09–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24	24–25	25–26	26–27	27–28	28–29	29–30
11.1.1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.2.1995	−1	4	−1	−4	4	2	−3	0	3	−2	−2	−10	8	1	−1	4	−3	3	−1	−1	1	0	−2	0	0	8	−1	1	0
22.3.1995	−3	1	−1	−4	4	1	0	−1	1	−4	3	0	0	−3	1	1	−6	5	5	−7	1	−2	0	4	−4	6	1	−2	3
27.4.1995	−1	3	−3	−6	5	2	0	1	0	−5	3	4	−5	−3	3	2	−5	4	3	−6	0	−4	4	2	−2	6	2	1	−1
31.5.1995	−1	3	−2	−6	3	2	0	1	3	−7	4	0	2	−5	4	−2	−2	3	1	0	−6	−1	3	2	−5	6	−2	3	−3
12.7.1995	1	0	1	−7	3	1	1	6	−2	−2	3	−2	2	−5	5	−3	−1	4	−1	1	−7	−2	3	5	−3	4	1	2	−5
12.9.1995	1	0	−1	−4	1	7	−2	3	0	−4	2	2	−3	−1	1	3	−3	2	−7	11	−9	−7	9	2	−1	3	−1	4	−4
25.10.1995	−1	1	−1	−6	3	2	−2	3	1	−4	1	2	−2	−2	4	1	−5	3	1	4	−9	−2	5	3	−2	6	−4	4	−2
23.11.1995	0	−1	1	−8	9	0	−1	2	2	−5	2	2	−3	0	1	3	−5	4	0	7	−13	1	3	2	−4	7	2	2	−3
12.12.1995	−1	0	−1	−6	7	1	−2	6	−1	−4	2	3	−6	1	3	3	−6	4	2	−1	−6	1	0	4	−4	7	−2	2	−2
24.1.1996	−1	0	−2	−4	5	1	−2	4	−2	−3	5	0	−3	−1	3	2	−3	4	0	−1	−1	−5	4	3	−4	7	0	4	−1
13.3.1996	−6	5	−7	−2	6	−1	−2	2	3	−3	2	1	−3	−1	4	2	−8	2	−1	7	−10	−1	0	6	−6	10	−2	3	0
24.4.1996	−3	4	−6	−1	3	1	0	3	2	−5	4	12	−3	0	2	2	−5	5	1	1	−6	0	−2	3	−3	10	−2	5	−1
29.5.1996	−4	2	−3	−4	5	0	5	0	0	−4	4	−1	−2	−1	3	6	−7	3	2	1	−7	−1	0	6	−6	13	−2	5	−6
25.6.1996	−3	2	−2	−5	2	3	0	2	1	−3	3	1	−2	−1	3	3	−6	4	4	0	−8	1	0	3	−4	8	2	3	−1
24.7.1996	−3	3	−1	−7	4	3	1	3	1	−5	2	0	0	−1	0	6	−6	4	5	−2	−6	0	−1	6	−5	8	1	2	2
29.8.1996	−2	2	1	−6	4	1	1	1	1	−4	4	1	−1	−2	2	5	−6	3	2	0	−9	1	2	5	−4	7	2	4	0
28.1.1997	−3	0	2	−5	6	2	−1	3	0	−6	5	0	−1	−1	2	4	−6	3	2	2	−7	−1	1	3	0	8	−1	2	2
26.3.1997	−3	−1	2	−6	6	2	−1	6	−4	−4	4	0	−1	−2	3	8	−9	5	0	4	−7	1	−1	6	−4	10	0	4	2
28.5.1997	0	−1	3	−6	4	2	−3	7	−1	−4	0	6	−2	−3	3	6	−8	2	3	4	−7	1	4	2	−1	7	−2	2	2
23.7.1997	0	0	4	−8	6	4	−1	1	0	−7	7	−2	0	−2	2	6	−5	3	4	−2	−5	2	−1	4	−2	11	0	3	3
16.9.1997	0	3	−3	−5	5	2	1	2	3	−5	2	−1	0	0	2	5	−5	4	0	1	−5	0	0	5	−4	12	0	3	2
10.11.1997	−4	1	2	−6	5	−1	3	4	−5	−2	4	3	−3	−1	8	3	−5	1	−2	1	−5	4	−1	4	2	6	2	−3	7

Magnetic ring 01 situated deepest, magnetic ring 30 situated in the upper part of bore–hole.

and at stabilized point No. 114 in the service drift for the entire monitored period. While during three monitored years the thickness of interjacent strata between outside rings increased by only 25 mm, entire lift measured by precision levelling at the casing head of the borehole MJ1 reached 75.9 mm and 80 mm at point No. 114.

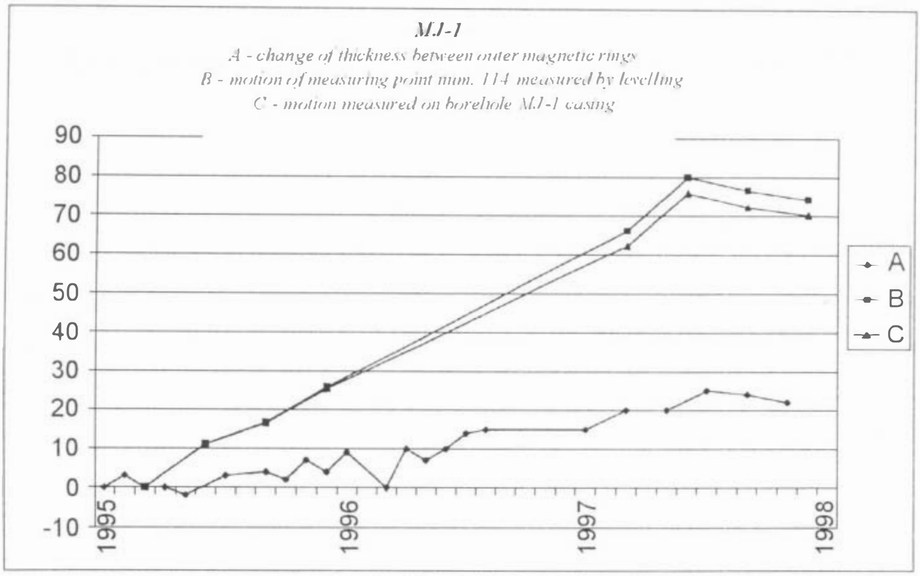

FIG. 14. Borehole MJ1 — distance alteration between marginal magnetic rings in comparison with borehole casing head MJ1 motion and with motion determined on the levelling point No. 114

From results given it can be concluded that only 30 % of the total lift between outer benchmarks corresponds with the change of interjacent strata thickness. If the remaining 70 % deformation corresponds with the lowest part of interjacent strata bellow the last magnetic ring and the Josef coal seam which is hardly possible (Voborníková, Pazdera, 1997; 1998) or if the impermeable volcanic–detrital interjacent strata is lifted which behaves as strained plate cannot be figured out. In the location where MJ1 borehole is situated the thickness of interjacent strata including Josef coal seam reaches approximately 66 m.

In 1996, on the bottom of Jiří open–pit mine two new boreholes MJ2 and MJ3 were drilled and magnetic rings placed. These boreholes were situated near OV40A and OV46A hydrogeologically monitored boreholes ending in volcanic–detrital strata and OV40 and OV46 boreholes drilled in basal strata. At hole MJ2 movements of 18 rings (distance between the 1st and 18th ring was 25.821 m), at hole MJ3 27 rings (distance between the 1st and the 27th ring was 39.239 m) were monitored. Thickness of volcanic–detrital strata including Josef coal seam in area where boreholes are situated is 50 – 52 m. Measured data of borehole MJ2 from 21.10.1996 to 12.12.1997 and borehole MJ3 from 21.10.1996 to 9.9.1997 were processed before they were lost due to mining activity.

In borehole MJ2 where the maximum change of the distance between the first and the last magnetic ring during the last measurement on 12.12.1997 was detected, equals to 30 mm (Fig. 15). As obvious from the same Figure the measured lift value at the casing head of MJ2 borehole fluctuates around 40 mm (42 mm as a maximum) in the same period. The lift at the casing head of OV40 borehole reached 112 mm and at OV40A borehole as much as 130 mm. Again the deformation of interjacent strata accounts only for 23 % – 27 % of the entire interjacent strata lift. It is true that the distance between the outside magnetic rings is only 50 % of the entire volcanic–detrital strata thickness (including Josef coal seam) but it concerns the upper part of interjacent strata where according to some experts (Voborníková, Pazdera, 1997; 1998) the maximum interjacent strata deformation is concentrated and the massif "breathing out" following mining out the overburden and coal seam took place.

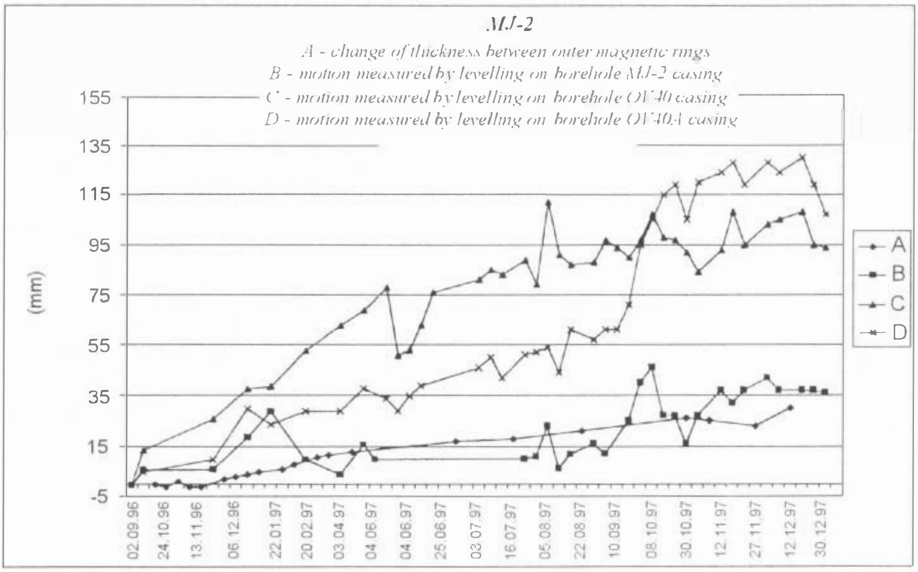

FIG. 15. Borehole MJ2 — distance alteration between marginal magnetic rings in comparison with motion of MJ2, OV40 and OV40A borehole casing heads

The shortest period could be processed from measurements of MJ3 borehole. The maximum measured change of distance between the first and the last magnetic ring reached 34 mm and the maximum lift recorded at the borehole casing head was 41 mm. Given values are corresponding with values measured in MJ2 borehole located approximately 60 m away. The survey program was shorter but on the other hand distance between outside magnetic rings was significantly larger. A comparison with the levelling of OV46 and OV46A boreholes could not be done because only after the end of the monitored period these boreholes were included in the network of points used for the levelling.

10. Conclusion

Based on results of Sokolov Basin exploration program implemented in the end of seventies and results of the long term measurements implemented at boreholes near No.V shaft of Marie Mine, an observation regarding separate Josef coal seam collector from Staré Sedlo strata and crystalline bedrock was presented (Pazdera, 1980). At present time it is said that as a consequence of the mining activity Josef coal seam collector in the east half of the basin central part is fed by water running along faults or disturbed massif from underlying basal aquifer. Water in the Josef coal seam collector is characteristic by its different chemism ($Na-HCO_3-SO_4$), changed by mixing with highly mineralized water of carbon dioxide content according to places with direct connection of Staré Sedlo strata (Pazdera, Vobornı́ková, 1994).

This observation is based on different development of the depression near No.V shaft of Marie Mine and on Jiří open–pit mine. While pumping the water from Josef coal seam at No. V shaft practically did not influence the water pressure head in boreholes of Staré Sedlo strata and crystalline bedrock in the wide environs of the shaft, ten years pumping of the water from Jiří open–pit mine from underlying strata of Josef coal seam showed significant lowering of the water pressure head not only in the open–pit environs but also in distant HJ2 borehole and other. Final results of measurements with long term pumping of the water from Jiří open–pit mine indicate a significant expansion of a depression in the south east to east direction. Currently when Jiří open–pit drainage centre in agreement with the mining procedure is moving further to the west of HJ2 borehole and therefore away from Karlovy Vary springs the decrease of the water level in HJ2 borehole is stopped. It can be assumed that the hydrogeological conditions were stabilized in such a way that the water supply to the basin could cover the volume of water pumped out. So far this theory has not been verified because the time during which the decrease of the water level in HJ2 borehole had been stopped was very short. From view of geotechnical safety of Jiří open–pit mine and consequently also Družba open–pit mine it will be necessary to maintain the water pressure head at lower level while the danger of depression expansion towards Karlovy Vary will persist.

A fact that this extensive drainage of gas rich thermal water of the basal aquifer does not have any significant impact on the chemical alteration of water composition or the reduction of basic elements including the TDS also can be noted. This indicates a certain autonomy of thermal water occurrence on the basin's territory even during a significant intervention to hydrogeological conditions due to open–pit mining.

Both modelling methods of open–pit coal seam mining brought a lot of new information. Physical model proved the ability to forecast deformation processes with adequate accuracy. Also signalization of potential loss of coal seam underlying strata impermeability in locations of tectonic failure proved as well founded. Actually in open–pit bottom last couple of years in area of so called double fault several inrushes of thermal water occurred. Precaution measures first of all the need for substantial local reduction of thermal water pressure head recommended according to these experiments were applied.

For the most part the results of interactive mathematical modelling were not of prognosis character. But regarding a stress condition, transformation changes and possibility of hydraulic rock failure of the open–pit bottom caused by loss of impermeability of underlying Antonín coal seam volcanic detrital strata they offered geotechnical know–how. Results of model solutions are applied to proposals for open–pit safety measures.

It shows that during last three years when the deformation of volcanic–detrital strata were monitored by magnetic rings fitted in boreholes that those deformations do not reach values causing a failure of rocks forming the strata and loss of rock impermeability. The major portion of the lift of open–pit bottom registered by a periodical level survey from fixed survey points in service drifts is caused by movement of volcanic–detrital strata as a whole and actually only a small portion (up to 30 %) is caused by the change in strata thickness. As the changes between magnetic rings indicate they are related primarily to the upper part of the boreholes i.e. to lower part of Antonín coal seam and upper part of volcanic–detrital strata. These strata probably behave as a stressed plate. Than it very much depends on its shape — concave or convex if tension zones with a possibility of pressure water penetration to interjacent strata forms. Other situation is in an immediate vicinity of tectonic faults where movements along these faults might occur. The mentioned assumption can approve or disapprove by the additional measurements carried out in more boreholes.

According to the synthesis of all scientific data acquired from analysis of results and trends from the long term measurement and measures carried out in open–pits in relation to coal mining there a conclusion can be made that there is a definite need to modify present measuring or to expand the system by new measurements. The objective is to gain data required for protection of Karlovy Vary thermal water springs because present monitoring is focused mainly to protect safety of the mining. It is necessary provide continuous monitoring of the gas phase capacity in selected borehole. At the same time it is necessary to limit drilling of new observation boreholes to a minimum because of the plugging problem when are liquidated (uncontrolled outflows of thermal water) and the sealing property of volcanic–detrital strata is reduced. As confirmed by analysis to verify the expected barrier in Ohře River valley an observation borehole on the right hand bank of this river is required.

Protective measures must provide both a safe mining of the coal seam and primarily prevent improper changes of hydrogeological conditions in area which could result in endangering Karlovy Vary thermal springs.

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HYDROLOGICKÉ A GEOTECHNICKÉ ZMĚNY V SOKOLOVSKÉ PÁNVI VYVOLANÉ TĚŽBOU UHLÍ

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Těžba hnědého uhlí v centrální části sokolovské pánve ovlivňuje režim tlakových, termálních, proplyněných vod. Těžba probíhá v ochranných pásmech přírodních léčivých karlovarských pramenů. Vzhledem k tomu, že nikdy nebyla vyloučena přímá spojitost mezi termálními vodami v sokolovské pánvi a karlovarskými prameny, existuje reálná možnost dlouhodobého ovlivnění těchto pramenů účinky těžby (Hynie, 1963; 1964). Soubor nákladných opatření a pozorování je zaměřen především na zajištění geotechnické bezpečnosti lomové těžby uhlí před účinky termálních tlakových vod v dobývacím prostoru a jeho okolí. Od velkého průvalu termálních vod ve sloji Josef na jámě II dolu Marie v říjnu 1901 se termální vody stabilně čerpaly na jámě V dolu Marie, pro umožnění těžby sloje Antonín hlubinným způsobem. Čerpání termální vody bylo ukončeno v létech 1989 – 1990, kdy se odvodňovací centrum přesunulo do dobývacího prostoru lomu Jiří. V příspěvku jsou uvedeny poznatky, získané vyhodnocením režimních měření na vrtech v oblasti ovlivněné čerpáním, změny chemismu vod ve vztahu k odvodňování a výsledky geotechnického výzkumu.

Na základě průzkumných prací na Sokolovsku v 70. letech, výsledků režimních měření, prováděných dlouhodobě na vrtech v okolí jámy V dolu Marie i v prostoru lomu Jiří, byl vysloven názor o samostatném kolektoru sloje Josef, odděleném od bazálního kolektoru starosedelského souvrství a krystalinika (Pazdera, 1980). V současné době se uvádí, že kolektor souvrství sloje Josef je ve východní polovině centrální části pánve dotován vodou z bazálního kolektoru. Voda v kolektoru sloje Josef je charakteristická svým odlišným chemismem ($Na–HCO_3–SO_4$), který se mění mísením s mineralizovanou teplou vodou s obsahem oxidu uhličitého, podle míst s přímým propojením se starosedelským souvrstvím (Pazdera, Voborníková, 1994).

Dlouhodobé čerpání vod ze sloje Josef na jámě V prakticky neovlivnilo výtlačné úrovně ve vrtech do bazálního kolektoru v jejím širším okolí. Desetileté čerpání vod na lomu Jiří z podloží sloje Josef se však projevilo výrazným snížením výtlačných úrovní nejen v okolí lomu, ale i na velmi vzdálených vrtech, např. HJ12 (7 km). Výsledky zpracování režimních měření prokazují významnější šíření deprese směrem na JV až V, při dlouhodobém čerpání vod na lomu Jiří a zvláště při spontánních vývěrech termální vody na dně lomu. V souvislosti se zajištěním geotechnické bezpečnosti těžby na lomu Jiří a následně i lomu Družba bude nutno v těchto dobývacích prostorech nadále udržovat hluboce sníženou výtlačnou úroveň termálních vod a bude stále trvat nebezpečí rozšiřování deprese směrem ke Karlovým Varům.

Lze konstatovat, že intenzivní odvodňování proplyněné termální vody z bazálního kolektoru se dosud výrazně neprojevuje na změně jejího chemického složení, respektive na úbytku základních složek i celkové mineralizace. Tento poznatek naznačuje určitou autonomnost území výskytu termální vody v pánvi i při výrazném zásahu do hydrogeologických poměrů následkem lomové těžby uhlí.

Metody modelování dějů, probíhajících při lomové těžbě uhelné sloje, poskytly nové poznatky. Fyzikální modely prokázaly schopnost predikovat deformační procesy s dostatečnou přesností. Signalizace možného porušení nepropustnosti podloží sloje v místech tektonických poruch se ukázala opodstatněnou. Na lomu došlo v průběhu posledních let k několika výronům termálních vod v území "dvojitého zlomu". Ochranná opatření, především nutnost výrazného snižování výtlačné úrovně termálních vod, která byla navržena podle výsledků modelových pokusů, byla v lomu aplikována. Výsledky interaktivního matematického modelování neměly většinou charakter prognózy, poskytly však geotechnické poznatky o změnách napjatosti a možnosti hydraulického porušení dna lomu následkem porušení podložního izolátoru sloje.

Sledování deformací v podložním vulkanodetritickém souvrství na vrtech, osazených magnetickými kroužky, ukazují, že deformace meziloží nedosahují tak velké hodnoty, aby jejich následkem docházelo k výraznému rozvolňování vulkanodetritických hornin a snížení jejich nepropustnosti. Větší část zdvihu, který je registrován na stabilizovaných bodech v účelových chodbách a na dně lomu, je zřejmě způsobena pohybem meziloží jako celku a jen menší část (do 30%) připadá na změnu mocnosti meziloží. Meziloží se pravděpodobně chová jako namáhaná deska, pro kterou je důležitý tvar — konkávnost nebo konvexnost, vytvářející podmínky pro vznik tahových zón s možností průniku tlakové vody do meziloží. Měření na dalších vrtech s magnetickými kroužky mohou stávající předpoklady potvrdit, nebo vyvrátit.

Na základě syntézy poznatků, získaných z vyhodnocení výsledků, trendů dlouhodobých měření a opatření, prováděných na lomu v průběhu těžby uhlí, vyplývá potřeba úpravy stávajících měření, případně rozšíření systému o nová měření. Cílem je získávat informace důležité především pro ochranu karlovarských termálních pramenů, neboť dosavadní měření jsou cílena hlavně k zajištění bezpečné těžby uhlí. Pozornost je třeba zaměřit na průběžné sledování změn vydatnosti plynné fáze na vybraných vrtech. Současně je potřebné omezit hloubení nových pozorovacích vrtů na nezbytně nutný počet, neboť dochází k potížím při jejich likvidaci (nekontrolované úniky termální vody) a snižuje se těsnící účinek vulkanodetritického souvrství. Vyplývá potřeba realizace doplňujícího pozorovacího vrtu na pravém břehu Ohře pro ověření předpokládané hydraulické bariéry v údolí této řeky.

Ochranná opatření musí zabezpečit nejen geotechnickou bezpečnost lomové těžby uhelné sloje, ale především zabránit nepřípustným změnám hydrogeologických poměrů v oblasti, které mohou vést k ohrožení karlovarských termálních pramenů.