Jezero Most

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Abstrakt

Tato práce představuje stručné shrnutí dostupných poznatků o jezeře Most, zejména vývoj geografických, geologických i hydrologických a hydrogeologických charakteristik lokality. Práce je rozdělena na části, které obsahují popis původního stavu před povrchovou těžbou, historii dopadů těžební činnosti v krajině, charakteristiku materiálů tvořících výsypku a způsoby jejího vzniku. Další části obsahují popis vývoje geotechnických a hydrogeologických podmínek lokality a také popis současného stavu obnovy a rekultivace území s nově vytvořeným povrchem.

Lake Most

The paper presents a brief summary of the available knowledge on the lake Most, mainly the development of geographical, geological and both hydrological and hydro-geological characteristics of the site. The entire article is divided into sections that contain a description of the original state before surface mining, the history of mining activity impacts in the landscape, the characteristics of the material forming the dump and the ways of its creation. Further sections contain description of the development of the geotechnical and hydro-geological conditions of the site and also a description of the current state of the recovery and reclamation of the territory with the newly created surface.

See Most

Diese Arbeit stellt eine kurze Zusammenfassung der zugänglichen Erkenntnisse zu dem See Most dar, insbesondere die Entwicklung der geographischen, geologischen sowie hydrologischen und hydrogeologischen Standortsausprägungen. . Die Arbeit ist auf Abschnitte verteilt, die die Beschreibung des ursprünglichen Zustandes vor dem Abbau, Geschichte der Wirkungen der Bergbautätigkeit in der Landschaft, die Charakteristik der die Kippe bildenden Materialien und die Art und Weise deren Entstehung enthalten. Weitere Abschnitte beschreiben die Entwicklung der geotechnischen und hydrogeologischen Bedingungen des Standortes sowie auch den gegenwärtigen Zustand der Wiederherstellung und Rekultivierung des Geländes einschl. der neu gestaltete Oberfläche.

Klíčová slova: Jezero Most, napouštění, historie, geologie, geografie, Česká republika.
Key words: Lake Most, Flooding, History, Geology, Geography, Geotechnics, Czech Republic.

1 General informations

The Lake Most is located below the hill Hněvín (399 m above sea level), close to the moved Church of the Assumption of the Virgin Mary in Most (Czech Republic). The Lake Most was formed on the site of the former royal town of Most, which had to give way to brown coal mining in the second half of the 20th century. Coal mining was definitely terminated as of 24th August 1999 (PKU 2020).

The Lake Most is located in the central part of the Most Basin (former North Bohemian Brown Coal Basin, SHP), which is a geomorphological whole in the Podkrušnohorský region of the Krušné Mountains location (Fig. 1). The tectonic foundation of the basin is located in the districts of Chomutov, Most, Teplice and Louny (see Fig. 1). The Most Basin is a relic of the Tertiary sedimentary basin, filled with sedimentary material, it falls mainly into the Miocene period. Between 22 and 17 million years ago, up to 500 meters of clay, sand and organic matter was piled up in this basin (Kváček et al. 2004, Matys Grygar et al. 2014). A brown coal seam has developed on most of the basin area, formed from peat layers deposited in the Tertiary marsh. In places where rivers flowed into the marsh, supplying the marsh with water, the peat sedimentation was suppressed by sand deposition. In these places, the seam is completely replaced by river or delta sediments or split into several benches. According to the manifestation of these influences on the seam profile, the Most Basin is divided into several parts. The Žatec Delta area has been affected most by the deposition of sands. In other areas, a more or less continuous brown coal seam with a thickness of 25 - 45 m has developed, the area of the Most Basin is 870 km^2. The deepest part of the basin is the so-called central area between the towns of Litvínov, Osek, Duchcov and the villages of Lom and Mariánské Radčice (Uličný et al. 2000).

Since the 18th century, mining operations have been taking place in the Most Basin, which changed the originally flat relief of the basin. At first, the coal extraction was carried out underground and was connected with the industrial development of the town of Most. In 1895, progressing underground mining at the Anna Mine resulted in the burst of quicksand (Hurník 1961) into the chamber 1294 and the destruction of 25 houses and damage of 57 houses (Valášek and Chytka 2009).

After 1948, there was a rapid development of open-pit coal mining, which resulted in the demolition of the historical Most in 1965–1987 and the construction of a new town.

Tab. 1: Basic characteristics of lake Most.

Flooding	since October 2008 to September 2014
Surface level of the lake	199 m asl (± 60 cm)
Surface area of the lake	309.09 ha
Water volume of the lake	ca 70.5 mil. m^3
The catchment area	1 050 ha
Max. depth of the lake	75.0 m
Perimeter of the bank	8 956.51 m
Location of the lake	The Lake Most is situated in the central part of the Most Basin, approx. 2 km to the north from the city Most. The water reservoir was formed in the endorheic depression of the former mining locations of the large mine Most – Ležáky and minor quarries Richard, Bedřich, Evžen – Ležáky II, Jan, Segen Gottes, Mariahilf.
Cadastral territories	Most I, Kopisty, Konobrže, Pařidla, Střimice, Růžodol
Water source	Water from the river Ohře, it is directed into the lake from the Nechranice dam by the feeder (with a discharge of 0.6 – 1.2 m3.s-1) from the industrial water pipeline Nechranice of a total length of 4.9 km.
Limnologic characteristics	Meromictic lake
	Anthropogenic endorheic lake

1.1 Flooding the Lake Most

According to PKU (2020), the flooding of the residual pit of the Most - Ležáky mine (Fig. 2) was commenced on 24th October 2008 as an extensive hydric reclamation provided by the state enterprise Palivový kombinát Ústí as part of the revitalization of the area affected by mining activities.

Since 2002, when the draining of mine water in the lowest part of the bottom of the residual pit was finished, water had accumulated exclusively from atmospheric precipitation and springs on the slopes of the mine until the start of flooding. As of the start of the flooding, the lake had an area of 21.6 ha, a depth of 21.12 m and a surface level of 145.12 m above sea level. On 31 December 2008 the lake surface level reached 154.62 m above sea level. Within two months of the start of the flooding, the water level has increased by 9.50 m and the surface area has more than doubled to 45.42 ha (PKU 2020).

At the end of the first half of 2009 the water surface level increased by another 18.57 m to the level of 173.19 m above sea level and the lake area reached 96.50 ha. In the second half of 2009, the water surface level increased further by 6.49 m, as at 31st December 2009 it reached 179.68 m above sea level. At this level, the water surface area was 139.30 ha. In the first half of 2010, a flooding of similar intensity took place and by 30th June the water surface level of the Lake Most reached the level of 186.24 m above sea level and thus increased by another 6.56 m. The water surface area was then 178.40 ha and the lake water volume were 39.2 million m^3. At the end of 2010 the lake surface level reached 190.75 m above sea level and the lake surface area increased to 229.35 ha. The volume of water in the lake was 49.907 million m^3. The surface level thus increased by 4.51 m in the second half of 2010 and by 45.63 m since the beginning of the flooding. During the first half of 2011, the water surface level increased by another 3.97 m to a height of 194.72 m above sea level, reaching an area of 267.34 ha with a total water volume of 60.28 million m3. In the second half of 2011, the water surface level increased by another 2.24 m and the level reached 196.96 m. The water volume in the lake increased to 67.997 million m^3 and the water surface area to 289.87 ha. Overall, the water surface level has increased by 51.84 m since the beginning of the flooding. In the first half of 2012, the water surface level reached 198.03 m above sea level, which corresponds to an area of 297.91 ha with a total water volume of 69.809 million m^3. Since the beginning of flooding the water surface level has increased by 52.91 m (PKU 2020).

In June 2012, an update of the water management evaluation was elaborated, and it newly determined the water level fluctuation around the dimension of 199.00 m above sea level with a range of ± 60 cm. Between May 2014 and September 2014, a total of 5.0 million m^3 of water was transferred to the Lake Most, which increased the volume of the water reservoir with an area of 309.41 ha to 70.480 million m^3. In September 2014, the level of the Lake Most reached a height of 199.14 m above sea level. (PKU 2020).

In the period of interruption of the flooding of the Lake Most, further updates of the water management evaluation were elaborated in July 2013 and June 2014. The data from June 2012 to July 2013 were very valuable, when the Lake Most was left to the natural development of water level. A total of 5 million m^3 of water was needed to achieve a permanent water surface level. In May 2014, the flooding of the Most Lake to the final permanent water surface level of 199.00 m above sea level was commenced. In September 2014, the permanent water surface level was reached. From this date until the end of 2019, the water reservoir will be in the test operation mode. In the case of water reservoirs in general, water loss during flooding is caused by leakage due to water pressure, due to a given filter coefficient corresponding to the type of soil in the unsaturated state and due to the saturation of soils with water. These losses gradually decrease after the first flooding of each water reservoir due to sedimentation of the suspended substances into the surface sealing layers, thereby limiting the penetration of water into the preferential pathways. These preferential routes are also gradually closed after water saturation due to the swelling processes of clay soils. Therefore, at the time of the test operation, it is necessary to keep the fluctuations of the water surface level around the constant dimension with a deviation as small as possible (PKU 2020).

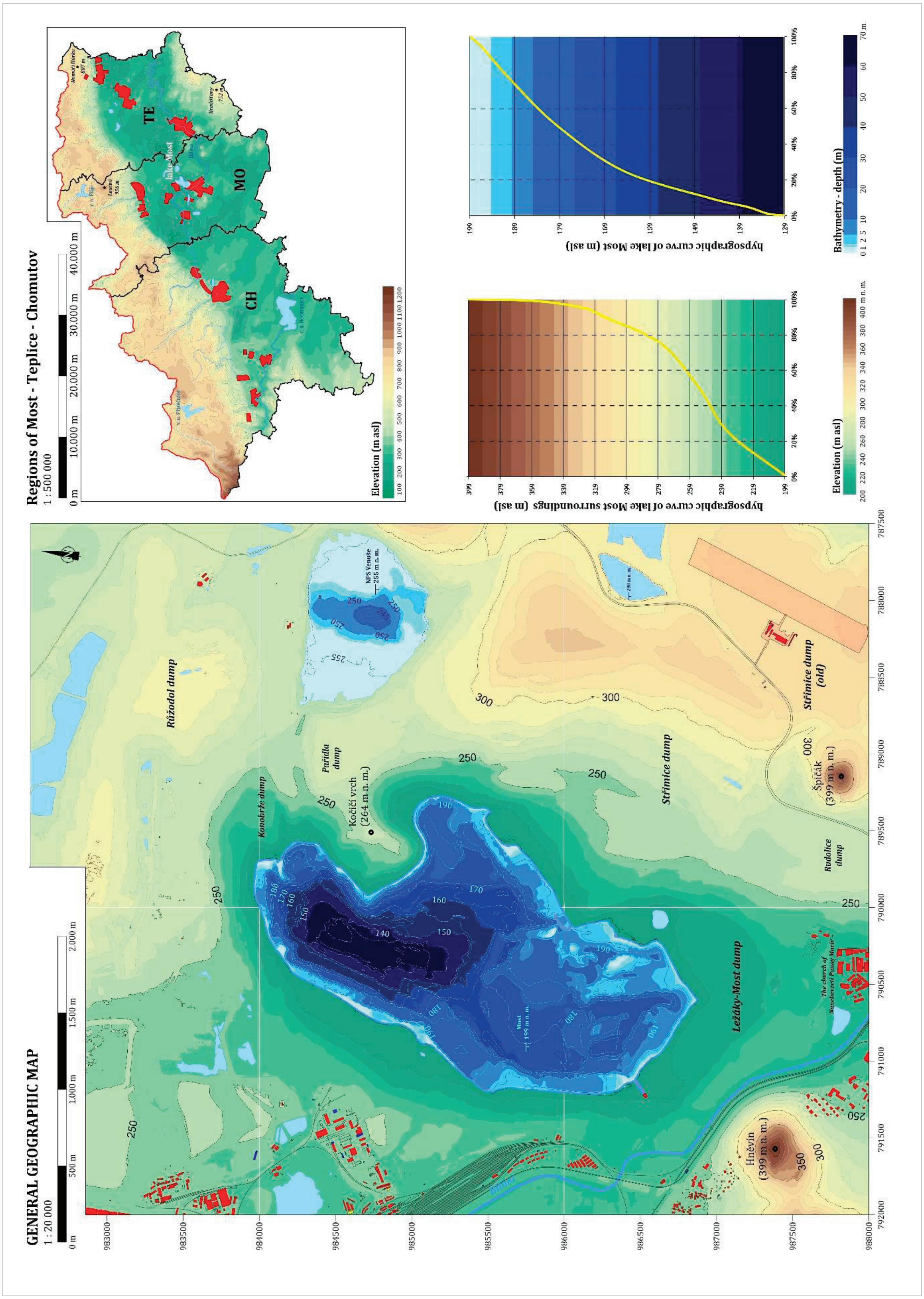

Fig. 1: General geographic information about the lake Most.

2 Mining history

The first records of significant mining activities in the area of interest date back to 1791, when digging work was commenced at the Magdalena Mine near Střimice and in 1850 manual shaft mining at the Mariahilfe mine. In 1870, the mine Viktor was opened near the village of Střimice. In 1873, the owner (Osek Monastery) sold the Magdalena and Viktor mining area to the Prague-Duchcov Railway Company, which opened the Bedřich Mine there. It was mined in both, underground and surface ways. The mine Julius II founded in 1878 (later renamed M. J. Hus) also intervened in the area of the future Ležáky mine. In the second half of the 19th century, the Segen-gottes mine was also established in the location of the former Most hospital (Kloš et al. 2009).

The ownership of the mine fields Mariahilfe, Magdalena and Viktor were then transferred to the new company Baldauf and Rudolph, which concentrated mining work in the newly built underground mine Richard in 1901. The specialized company Berndt also started to mine overburden at the newly opened Richard mine (in the first half of the 20th century it was provided by external organizations for overburden extractions) and in 1903 the first coal was mined here. The coal extraction was carried out manually and the yield ranged between 200-300 thousand of tons per year. In the year 1924, 407 thousand of tones were mined. In 1921, "The Czech business company Ústí nad Labem" became the new owner of the Richard mine. In 1939, the mine became the property of the Sudetenländische Bergbau Aktiengesellschaft (SUBAG), which was part of the Reichswerke Hermann Göring concern. After the deployment of more modern mining technology in 1944, mining reached a yield of 875 thousand t/year. The Richard mine became the foundation of the future Ležáky mine (Seidl 1998, Pichler 2004a,b, Kloš et al. 2009).

2.1 Development of the underground mining

The Evžen mine (Prince Eugen) was founded by the mining company of the Terezie mine in 1901 as a PERUTZ underground mine in Most. Soon after, it was renamed Prinz Eugen after the fall of imperial Austria to Eugen, Evžen unofficially. In 1906, the Evžen mine had mined 157,000 t/year, in the years 1926-1930 this was around 250 000 t/year. Between 1931 and 1939, mining gradually decreased to 142 000 t/year. In the years 1941-1944 the average annual production again exceeded 200 000 t/year. At that time, the purely underground operation of the Evžen mine started to become a mixed operation of the underground mine and surface mine, but its mining yield from the above seamed parts was transported by cable car to the Julius II mine. After World War II, a new railway station was established in the middle of the mining pit of the Evžen shaft station, to which mining yield of up to 400,000 t/year was gradually transferred (Macůrek, 2004).

The Jan Mine was founded in 1870 by the mining company of Jan, Ltd. It had a 38.5 m deep pit and gradually drilled on both sides of the Obrnice-Most track. The mine was originally underground, but soon moved on to purely opencast mining, continuing to mine via a perpendicular shaft. In 1906, it extracted 127,413 tons, in 1907 this was 142,072 tons of coal. During the First World War, after joining Baldauf and Rudolf and until the post-war crisis, it mined 135-182 000 t/year. Around 1930, the mine Jan mined around 160 000 t/year, then mining fell to an average of 50 000 t/year and at the beginning of 1943 its operation was stopped (Kloš et al., 2009).

The Venuše Mine was founded by the Lom coal mining company in 1893. The mining company was established in 1888 as a Consortium founded by Bank Board Mořic Bauer from Vienna, Chamber Council Evžen Gutmann from Berlin and Rail Director Jan Pechar from Prague in order to open coal fields near Lom, where a 30 m thick seam was drilled at a depth of about 400 m. In 1890, the consortium mined 601,035 tons of coal and was the third mining company regarding the yield volume in the mining district after Most and Northen Czech company. Both pits of the Venuše mine were excavated between 1896 and 1897, as the first pits in Austria-Hungary across the quick sand to a depth of 150 m. The mining was stopped in 1947. The Venuše mine operation was restored on 13 October 1955 to test the Viktoria mine. After the end of exploratory breakthroughs, the mine was finally shut down in 1960 (Macůrek, 2004).

The underground mining of the coal seam took place mainly in the middle bench of the coal seam, which contains coal with better technological parameters than the coal from the lower bench. In the course of historical development, the underground mining has experienced qualitative changes in the deposit that have made it possible to use the coal substance more rationally. In terms of time development, the individual mining methods were applied as follows:

- 1879-1915 break-in battery breast to full thickness,
- 1901-1922 board and pillars in berms,
- 1915-1990 panel working with caving system by blasting,
- 1920-1990 bench panel working with caving system (2-5 benches),
- 1942-1989 panel working in the undercut,
- 1949-1950 longwall working system.

Until 1915, the most frequently used mining method was the break-in battery breast to full thickness, which was replaced in the following years by the panel working with caving system by blasting. The next most used method that followed the mining of the minefield to full thickness was panel working in the undercut, which began during World War II. By these mining methods a substantial part of the coal substance obtainable by underground mining methods was mined (Kloš et al., 2009).

2.2 Development of the surface mining

After the end of World War II, the Mine Richard was renamed the Ležáky Mine on 12 July 1945. Based on the nationalization decree dated 24 October 1945, the mine became the property of the state and was incorporated into the national North Bohemian Brown Coal Mines in Most. In 1952, the space of the Evžen underground mine was added to the Ležáky mining field, where mining was stopped and a separate Ležáky open-pit mine was incorporated into the North Bohemian Brown Coal Association.

In 1957, an electrified rail transport with a gauge of 900 mm and the first Z 1200 stacker were used to increase the production at the Ležáky base plant. In 1958 the first K 300

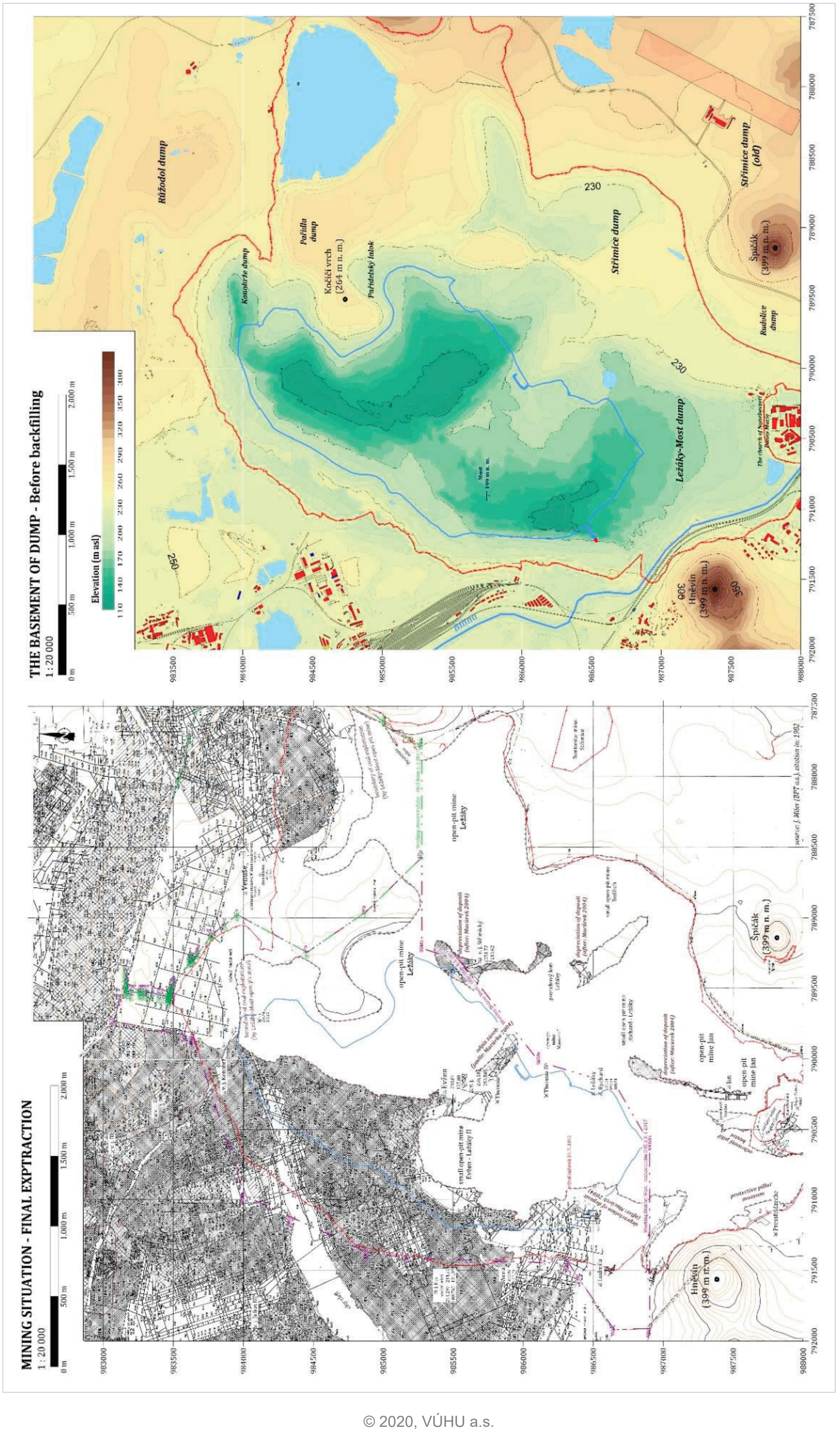

Fig.2: Extent of coal mining and shape of the residual pit.

bucket-wheel excavator was used for coal mining. The complete reconstruction of the mine was completed in 1961. With the new equipment, the mining mine reached the yield of 2.500 to 3.400 million t/year. The protection zone of the village Kopisty, the ash dump in the former Ležáky II mine and the old mines north of the town of Most created the limits of the mine operations. Within such boundaries, the Ležáky mine terminated its activities in this area in 1985.

The continuation of the Ležáky mine became the Most mine, which was being opened for many years in parallel with the mining of the Ležáky basic plant. The destruction of the old part of the city of Most as a result of the opening of this new open-pit mine was already decided by the then Central Committee of the Communist Party in 1962. The overburden mining under the Hněvín hill began in 1970 and coal mining in 1971. The mining lines gradually merged with the Ležáky mine and formed one common mining frontline. As a result of the favourable mining conditions in the Most pillar, coal mining in the 1980s grew to a value exceeding 7 million t/year (maximum extraction of 7.518 million t in 1986).

Before the seam was completely mined in the old town of Most, it was decided to extend the mine to the Kopisty mining field, with deteriorating mining-geological conditions, characterized mainly by a significant increase in the stripping ratio. That is why the mine was equipped in 1983 with the TC2 series with the KU 800 excavator on the mining side and the ZP 6600 stacker on the foundation side. With this equipment, the Most-Kopisty mine, renamed in 1994 to the historical name of Ležáky, was mined until 1995, when the operation of TC2 was stopped as a result of a decision to reduce mining. In 1998, TC2 was put into operation to fill the Konobrže lobe to stabilize the northern slope of the mine (Halíř, 1997). Mining of brown coal at the mine was stopped as of 24 August 1999.

2.3 Preparation of hydric reclamation

One of the main criteria in the decision-making process on reduction were the unit costs (CZK / t) of all operated sites, which clearly showed that the cost of the Ležáky site was 1.5 - 2 times larger than in other sites of MUS a. s. in the first half of the 1990s (Pichler, 2002; Pichler et al., 2002).

The final phase of the planned exploitation of the Ležáky mine was further characterized by the decline of the coal seam in the direction of the process and further increase of the unfavourable stripping ratio (coal-overburden ratio), mining almost exclusively in the caved goaf, where excavation above 30 % of industrial reserves was achieved by previous deep mining.

Based on the assumption of further deterioration of the economy of the Ležáky mine until the originally planned end of the lifetime of the mine, it was decided to liquidate the mine. The technical plan for the liquidation was elaborated by the Department of Mining Development of MUS a. s. in June 1995 and after completion of other conceptual works, its variants were submitted to three independent organizations for opponent evaluation and subsequently approved by the Ministry of Industry and Trade of the Czech Republic on 11st July 1995 (Kloš et al., 2009).

3 Site morphology

The Lake Most is located in the central part of the Most Basin, in an area where the original relief was altered by anthropogenic activity – by a surface mining of brown coal. In a simplified way, the analysed area of the Lake Most can be defined as the area between the hills Hněvín (399 m above sea level) and Špičák (399 m above sea level) surrounding the flooded residual pit from the south and by Růžodol dump and CELIO landfill from the north, further by Venuše sludge pond and body of the Střimice dump in the east and the coal pillar Kopisty and CHEZA site with adjacent ash dumps K1 - K4 in the west (Pletichová et al., 2012; Burda et al., 2015).

The nearest residences are the settlement Most - Kopisty (relict of the former old Most) located about 800 m from the west bank of the lake, the local part of Most Souš about 800 m southwest of the bank of the lake and the relocated Church of the Assumption of the Virgin Mary and the industrial site RICO about 1 km from the south bank of the lake. The village Braňany is 3 km away to the east and Mariánské Radčice is approximately 2.5 km to the north.

According to the geomorphological classification of the Czech Republic (Balatka and Kalvoda, 2006), the whole area belongs to the Podkrušnohorský region of the Krušné hory subprovince and as such is part of the geomorphological unit of the Most Basin. The mapping work took place in the period from March to June 2017 and its aim was to determine the dominant process that led to the emergence of the existing geomorphological shape.

3.1 Geomorphological conditions

The surroundings of the Lake Most are characterized by strictly anthropogenic relief; a geomorphological sketch map is part of Fig. 3. Due to the fact that the lake was formed by flooding of the residual pit of the Most - Ležáky open-pit mine, its banks and adjacent slopes are made of dump soil berms or modified overburden benches. The dump soils form the southern and eastern slopes of the lake. The southern slopes of the lake are formed by the former internal dump of the Most open-pit mine, the slopes have a generally northern exposition with a slope of 5 - 10o, the slope has the character of slightly inclined platforms (up to 2o) with two visible berms 10-15 m high. The area under the hill Hněvín, where the artificial channel of the translated river Bílina is located, there is a clear dump embankment (232-237 m above sea level) 1,200 m long, 250 m wide and 15 m high. Morphologically and hydrologically, it separates the channel of Bílina from the residual pit of the Lake Most. To the east of this embankment, the slope of the inner dump changes smoothly into a vast plain at 250 m above sea level, where the RICO industrial site and the Assumption Cathedral of the Virgin Mary are situated. The plain consists of dump soils and older landfills. Further east in the direction of Rudolice, the dump of the Most mine continues, which rises in several berms to the level of 290 m above sea level. The general plan of the south-facing slope is 1 : 17 (5o). The eastern shore and the adjoining slope of the Lake Most are formed by the soils of Střimice dump (Orlt et al., 1992).

The northern slopes of the residual pit are formed by an earth body of the Konobrže dump with stabilizing and sealing function (Pichler, 1997). The dump body was founded between 1997-1999 in three dump berms. The main objective was to limit the possible seepage of water from the Venuše sludge pond through the chaotically located positions of Quaternary sands and gravel. The general incline of the slope oriented to the southwest is 1 : 8.7, while the steepest part in the Konobrže dump section has an incline of 1 : 5.7. To the south of the Konobrže dump heap, the slopes of the residual pit are formed by the Pařidla lobe around Kočičí vrch (Cat's Hill), which is adjacent to the Pařidla dump from the east (Pichler, 1997). The northern side of the lobe is formed by slopes of a former stone mine with an incline of 1 : 3 to 1 : 5, which are stable but prone to surface erosion processes. Furthermore, the slopes of the Pařidla lobe with an incline of 1 : 4 to 1 : 6 are terraced in sub-basin neovulcanites, which appear to be stable. The degraded pyroclastic was remediated and the slope was retrofitted, maintaining the original incline of 1 : 2 to 1 : 3. The northwest slopes are a relatively safe area consisting mainly of overburden bench of the residual pit. After completion, the slopes were secured mainly by earthworks. General inclination of the north-western slopes reaches 1 : 4.7. The south-western part of the slopes of the residual pit is formed in the lower parts by a body of the inner hopper, partially covered by a dump remediation body, which ensures sealing of permeable sandy locations in the overburden of the seam (Orlt et al., 1992).

The most frequent type of slope deformities detected are landslides (see Fig. 3), where the quasi-homogeneous pelitical environment is an ideal location for their evolution. Most recent landslides were found in the northern slopes and in the Konobrže dump area, the displacement areas occur mostly at the level of 220-250 m above sea level. The majority of the deformations mapped here are (or were) of different depths (usually 5-20 m), rotational or rotationally planar landslides (Dikau 2004), which often change the mechanism of movement (Němčok et al., 1972), from land sliding into flowing, so as a result the deformations often have a characteristic flow-like landslides. Several old large landslides were found during the research, these deformations in the slopes of the Střimice dump and in the western slope area are currently "buried" by dump material. Creeping movements often occur in dumps on sloping ground (Dykast 1983).

Some small regions in the northern part of the area of interest can be considered as a relic of the original proluvial plain, which occupied a significant part of the Most Basin. These remained without significant mining interventions and with minimal impact of declines due to undermining.

4 Site geology

The area of interest is located in the central part of the Most Basin, within easy reach of the delta of the river Bílina (Malkovský et al., 1985).

4.1 Crystalline complex

The deeper subsoil of the basin consists of biotite-muscovite gneisses of the Crystalline complex. These rocks do not come to the surface anywhere in the area of interest. The only exception is the eastern and south-eastern slopes of the Hněvín hill, where a huge block of crystalline rocks was found by drilling and overburden works; it was deposited in this area from deeper layers during intense manifestations of volcanic activity.

4.2 Upper Cretaceous sediments

The surface of crystalline complex contains denuded remains of Cretaceous sediments of marl, clayey marl and limestone character. These sediments reach significant thickness (tens of meters) in the eastern and northern parts of the area of interest (towards the Bílina mine).

4.3 Volcanic formation

The oldest tertiary formation is a complex of volcanic rocks and their weathering products. These rocks have the character of weathered basalt, phonolite volcanic rock, tuffs, tuffites and brightly coloured tuffite clay stones. The complex of rocks of the volcanic formation reaches the thickness of tens of meters and is located in the western and eastern to northern parts of the territory. The most distinctive volcanic elevation is the Hněvín hill, which is made up of phonolite. Most likely it is an eroded magmatic chamber of a Tertiary volcano.

Another significant volcanic elevation in the area of interest is the Kočičí hill (the Cat Hill), located in the northern part of the area of interest. This volcanic elevation was exposed during the mining work at the locality Ležáky. As the volcanic activity subsided, the volcanic rocks were flooded, re-sedimented, forming bedrock. The surface part of the volcanic rock was subjected to intensive weathering resulting in the formation of brightly coloured clays or even clay stones.

4.5 Formation of underlying clays and sands

The period of sedimentation of the bedrock of clays and sands is a period of alignment of the largely rugged relief of the landscape, which was caused by rising elevations of volcanic rock and Cretaceous rocks and gradual deepening of the basin space. The thickness of sediments of bedrock clays and sands is therefore very variable and virtually ranges from 0 to 20 m.

The lower, very varied and locally changeable part of the sediments is made up of shortly deposited, often flooded washes of weathered rocks from rising elevations of volcanic, chalk and possibly crystalline material. On the basis of strata, coarse-grained sandstones to breccias are developed locally. These get gradually smoother with the simultaneous contribution of the clay component. Occasionally, this lower part of the formation has a cyclical character.

The sands were developed mainly in the south-eastern part of the deposit approximately from the Evžen mine area (Ležáky II) towards the southern exit.

However, the basic sediments of the formation are light grey clay stones with an increased proportion of siderite. The sands and sandstones formed a direct subsoil of the coal seam on the part of the deposit. However, it is problematic to determine whether these are sediments belonging to the strata of underlying clays and sands or already to the subset of brown coal seams.

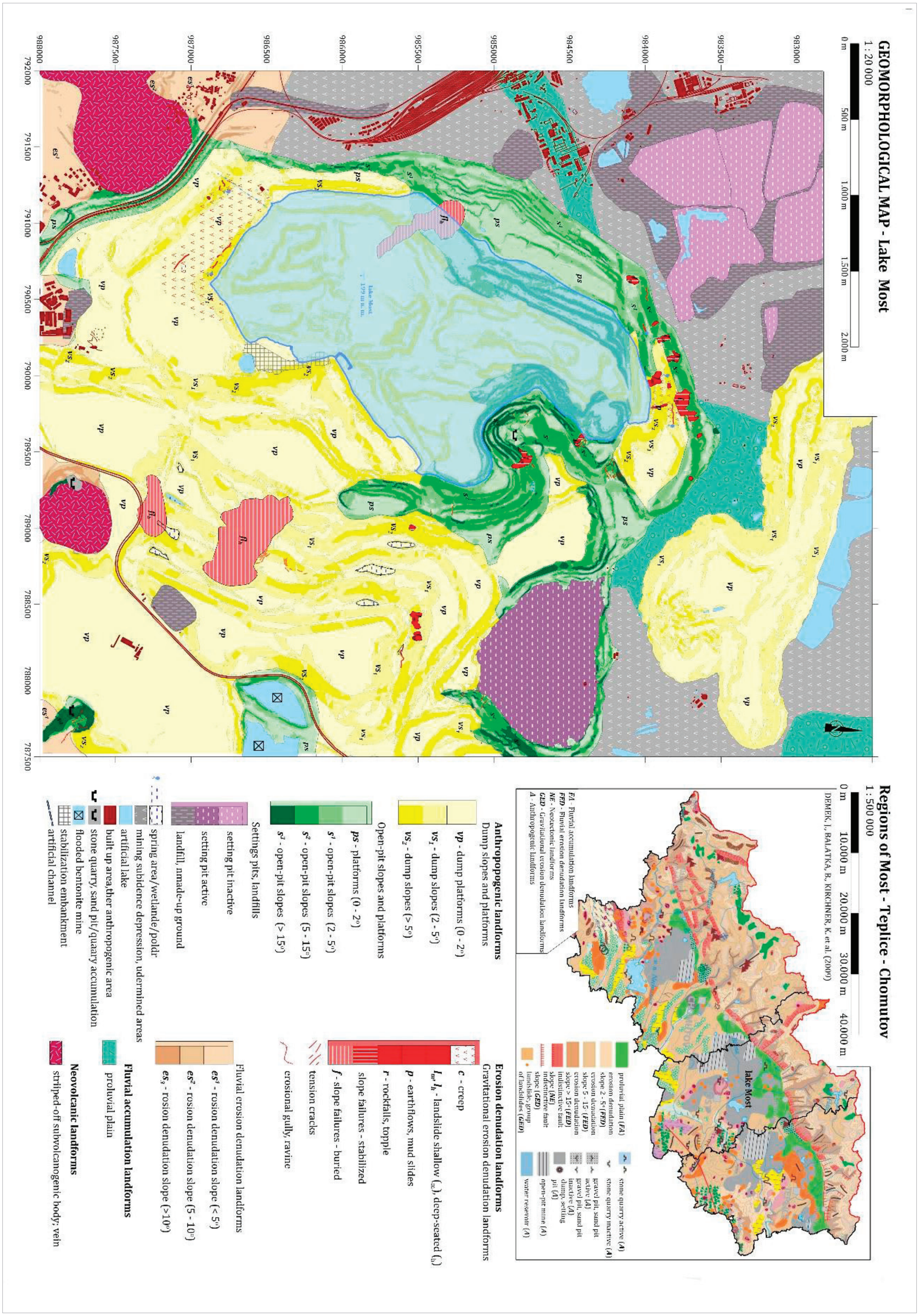

Fig.3: Geomorphological settings of lake Most area.

4.6 Strata of brown coal seams

The strata of underlying clays and sands gradually merge with the increase of organic matter into the strata of brown coal seams.

4.7 Ground coal

The so-called ground coal is developed at the base of the strata of brown coal seams. The ground coal consists of the positions of coal clays and clay stones to coal chips. The quality of the ground coal is poor and only rarely does the ash content fluctuate around 50 %, it is rather around 70 % Ad.

In the surroundings of the former village Kopisty the ground coal has a continuous unified development and reaches a maximum thickness of up to 16.2 m, but mostly the thickness of coal sediments ranked to the ground coal fluctuate at about 7 m. From the Kopisty area towards west, the thickness of the ground coal decreases to about 1 m. To the north, this ground coal shrinks and in a facile way it turns into claystone. In the southern direction, the thickness of the ground coal decreases and it approaches the main seam and its local connection with the main seam can be assumed, but this is not clearly established.

The ground coal is separated from the main seam by clay rocks of thickness ranging from a few meters to tens of meters. Due to its remoteness from the main seam, the ground coal was detected by drilling only accidentally. The MO 843, KP 90 and KP 80 boreholes have clearly demonstrated it.

4.8 The main coal seams

The main coal seam is developed uniformly on the deposit with three detectable benches. Its lower bench has variable ash content and thickness. Usually, the thickness is around 5 m. The sediment coal material was deposited in the environment where other clastic material was transported. The transition between the lower and middle coal bench is smooth and that is due to a significant decrease in ash content of the coal. There is an obvious decrease of ash content towards the ceiling of the lower bench in the vertical development.

The primary clastic component of the lower bench of the coal seam consists mainly of clay rocks, but in the area with sandy development of the underlying rocks, the dust and sandy components also contribute to it.

The coal sediments of the lower part of the lower bench of the coal seam have a very irregular development. This development is given by the shape of the terrain during the sedimentation period. There are sites of relatively stable development in the area that suddenly ends up either by wedging up of seams or by facial transition to clastics. Spatial analysis of the geological development of the bottom bench of the coal seam is very difficult, if not impracticable, due to its irregular development and in relation to its relatively low exploration. The lower bench of the coal seam is defined according to the proportion of the coal component. Towards the under-laying bedrock, there is a more significant occurrence of the coal component, which begins to form coal positions and seams. Towards the overburden the boundary of the middle bench of the coal seam is given to a significant change in the ash content, which drops sharply below 20 % of Ad.

The middle bench of the coal seam represents a period of uninterrupted growth of coal marsh, virtually without a contribution of clastic material. Its thickness is about 18 to 20 m. The middle bench contains several clay bands of several centimetres in thickness, which point to short-term interruptions of coal sediments with the contribution of clay material. Some of these bands have developed throughout the seam area and therefore have become significant correlation horizons on the deposits and also served as guidance for underground mining.

In the middle part of the deposit, the thickness of the middle bench is increasing, but according to the course of bands, this is rather a space with good development of the upper part of the lower bench. Such site occurs around the MO 843 borehole, where the “middle bench” reached 28 m in this development and at the northern edge of the RICO pillar.

Clay sediments with varying proportions of coal material and of a thickness from several decimetres to 2 m are mounted on the ceiling of the middle bench of the coal seam. This position is called „cvišák“ (from German zwischenletten). Above this clay position, there is an upper bench developer with a thickness of about 4 m, max. 14 m. In the upper bench, there is a position of high-quality coal, which was called the upper seam in terms of underground mining. In most parts of the seam, its thickness is stable between 2 and 3 m, maximum 5 m.

From the petrographical point of view, the coal seam consists of detritic-xylitic coal with belts of xylitol, the mineralization is pyritic, and the secondary ash is clayey. The transition types between coal and clay are classified as coal chips or clay chips according to the proportion of clay.

The ash content of the coal seam ranges from 3 to 70 %. Among the pollutants, mainly the sulphur content was monitored. On average, the sulphur content of the dry matter is around 1%. In areas of old quarries, in the lower part of the coal seam, which are already covered by a dump, the sulphur content was up to 6 %. The original water content ranges from 21 to 33 %.

Anomalous development of the coal seam is mainly in the area of the south-western outcrop of the coal seam near Souš, which was affected by sandy sedimentation, which the suppressed coal sedimentation. In these sandy sediments there are positions with enriched coal pulp, up to the positions of coal clays and sandstones. Anomalous development was also detected in the development of the seam in the overburden of the main seam, which in the currently mined space reached the thickness of 20 m and the quality of the main seam.

4.9 Overlaying strata

The overburden of brown coal deposits consisted mainly of clays and clay stones with varying proportion of dust admixtures. Sandy sediments have developed in areas affected by migratory streams during the sedimentation of coal seams and in the area of river delta bodies. Some positions in clay stones are reinforced with carbonate sealant and create solid carbonate positions where lenticular bodies of pelocarbonates can be found.

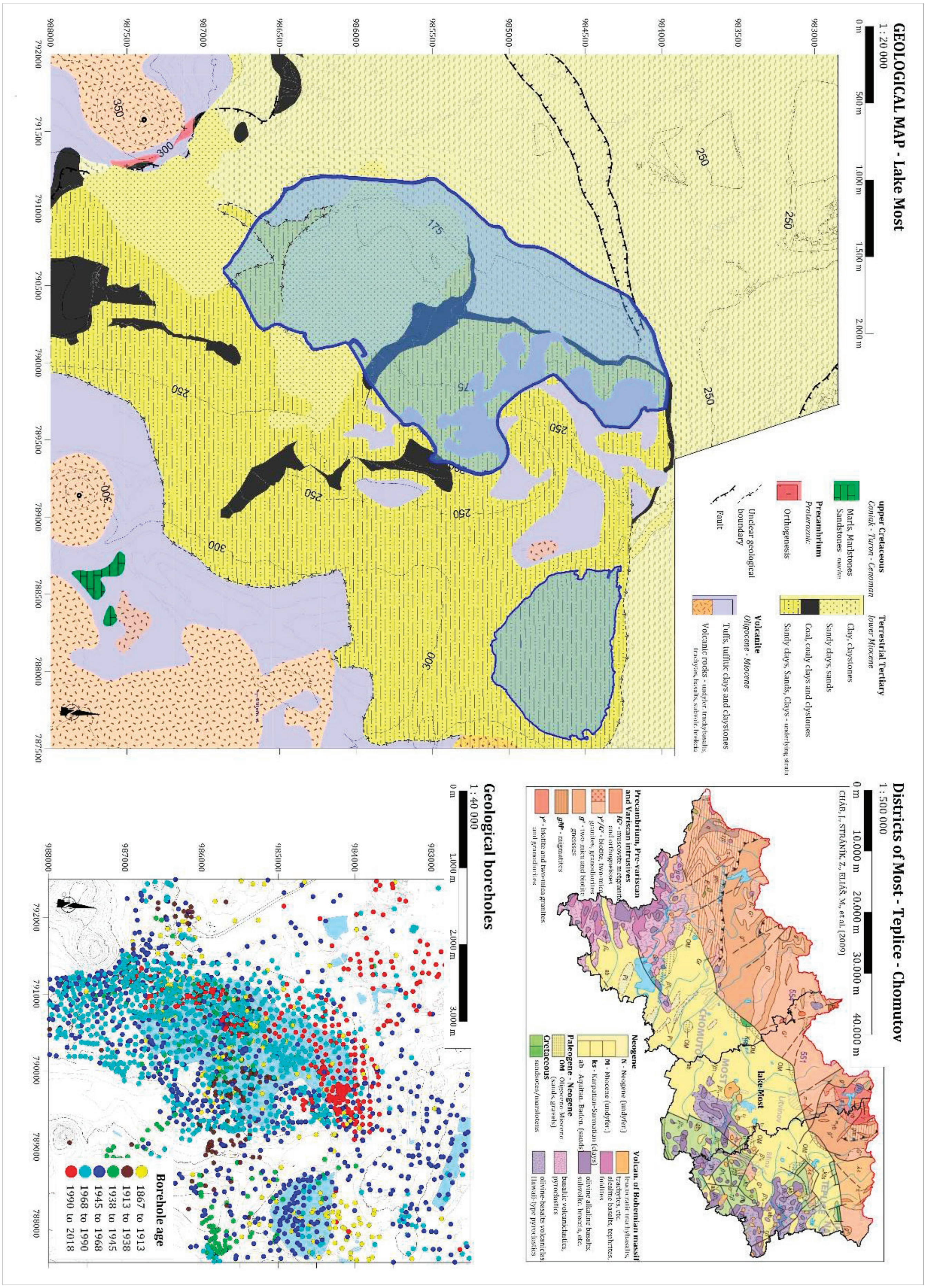

Fig.4: Geological sketch map of lake Most area.

In the overlying clay sediments of the central part of the basin, where the most complete profile of overlying sediments is preserved, two horizons can be defined:

Horizon of solid claystone - it is a light grey laminated dusty claystone with a variable proportion of carbonate admixture (mainly siderite) located above the ceiling of the coal seam. The contact of this horizon with the coal seam is sharp, but the transition of the horizon to the overburden is on the contrary blurred, sometimes lateral. In the horizontal position profile, there are laminae to benches of carbonate (siderite) claystone of centimetre to decimetre thicknesses of large areal distribution, with varying carbonate content. This horizon is bound to the deepest part of the basin and is extended from the mine Czech army to the inundation failure,

Horizon of sandy clays, sands and pelocarbonates - with a very variable petrographic composition (from dusty clay stones to very strong quartz fine-grained sandstones, which were already mined by the Most mine in 1989) with varying proportions of carbonate admixture. This horizon is bounded to the territory within the reach of the delta sedimentation of the Bílina delta, its thickness towards the north and northwest gradually decreases from a maximum of 140 m in the central part around Bílina, and the horizon gradually dies away. The transition to the overburden is quite sharp.

Overlying sands, similar to the underlying sands at the northern edge of the basin, form a one-sided artesian reservoir of groundwater, but on the southern edge of the basin. From the southern outcrop they are slowly falling to the north towards the centre of the Most district, or rather say towards the central depression. Their northern border is approximately on the line Most-Mariánské Radčice-Duchcov.

At first, this area was designated as a sedimentation area at the head of the delta when describing cyclic sedimentation of uncovering of the mines of M. Gorkij in Braňany and Bílina (Hurník-Luft 1959). Hurník (1961) defined them as the Bílina and Žatec delta facies in connection with the research of paleo floristic areas in the overlying stratum (according to the stratigraphic division of the time).

They are mostly irregular bodies of sand and sandy clays forming several converged positions at different levels above the seam. These bodies are very large in area (several km^2) and thick from a few centimetres to tens of meters, while the total thickness of sands can reach up to 70 m.

The most important and best studied is the large area of quicksand between Most, Duchcov and Bílina - the so-called břešťansko-braňanská quicksand basin. The location of quick-sand here reaches an average of 20-30 meters in thickness. At the southern edge, the sands reached up to the surface, forming an ideal infiltration area. In the direction towards the basin, the thickness of quicksand decreases until they gradually disappear.

4.10 Quaternary

The quaternary sediments are represented by clays, gravel, gravel sands, slope debris and in small amount loess clays. The oldest sediments are slope debris that is largely clayey. Their thickness fluctuates in the order of the first meters and they occur especially at the foot of the Hněvín hill. Gravel and gravel sands are formed by alluvial deposits of former surface brooks (Bílý brook and Mračný brook) and these are made of boulders of quartz and gneiss with sandy or loamy-sandy fillings. Loess is one of the typical yellow-brown loess, which are made of fine sand, with scattered carbonates and tiny hard loess nodules.

Quaternary sediments, overlying strata sediments and sediments of the brown coal seams were removed by mining activities in a substantial part of the area of interest in the past.

5 Hydrological and hydrogeological conditions

5.1 Hydrological conditions

The main watercourse draining the wider area of the Lake Most is the river Bílina (catchment number 1-12-01-001). The Lake Most is an endorheic depression with an orographic catchment area of 1,050 ha. The surrounding catchments are then formed by left-side tributaries of the river Bílina – the Mračný brook and in the northern part by the residual river bed of the Bílý brook. The predominant direction of flows was from northwest to southeast. In connection with the construction of the dump body, the beds of Divoký, Mračný and Bílý brooks were relocated by their diversion under the southwest foot of the Růžodol dump, while the bed of the Radčice brook remained unchanged.

The catchment of the present Lake Most used be the location of several water bodies in the history. These were mostly nameless water areas, some of which were created gradually, as a result of the flooding of the descending original terrain due to ongoing underground mining.

North-east of the former village of Růžodol, a spring was mapped in the past approximately on the contour line with an altitude of 285 m above sea level. Its discharge was detected in September 1968 and evaluated at approx. 0,2 l.s^{-1}.

The hydrological situation ascertained in connection with the implementation of evaluation of RIBC Plc., who evaluated the complex situation of the dump at then, assesses the situation in the southern part of the dump, where a large number of drains were realized, especially in the areas prepared for landfill storage. The main slip areas at that time were also mapped.

5.2 Hydrogeological conditions

From the hydrogeological point of view, the area of interest is currently a very complicated whole. The watering of the dump bodies is very complicated due to their geological structure. The drilling exploration detected water bodies of sands and coal evacuations in the dump bodies. Their mutual interaction in the area of interest cannot be excluded or confirmed on the basis of the research done so far. However, it is assumed that these are separate closed aquifers without the possibility of wider interaction with the surrounding soils.

In the past, the most significant aquifers included underlying sands, coal seam, overlying sands (quick sand) and quaternary sediments.

Underlying sands

The underlying sands form a closed artesian structure that falls towards the NW. The underlying sands are mostly medium

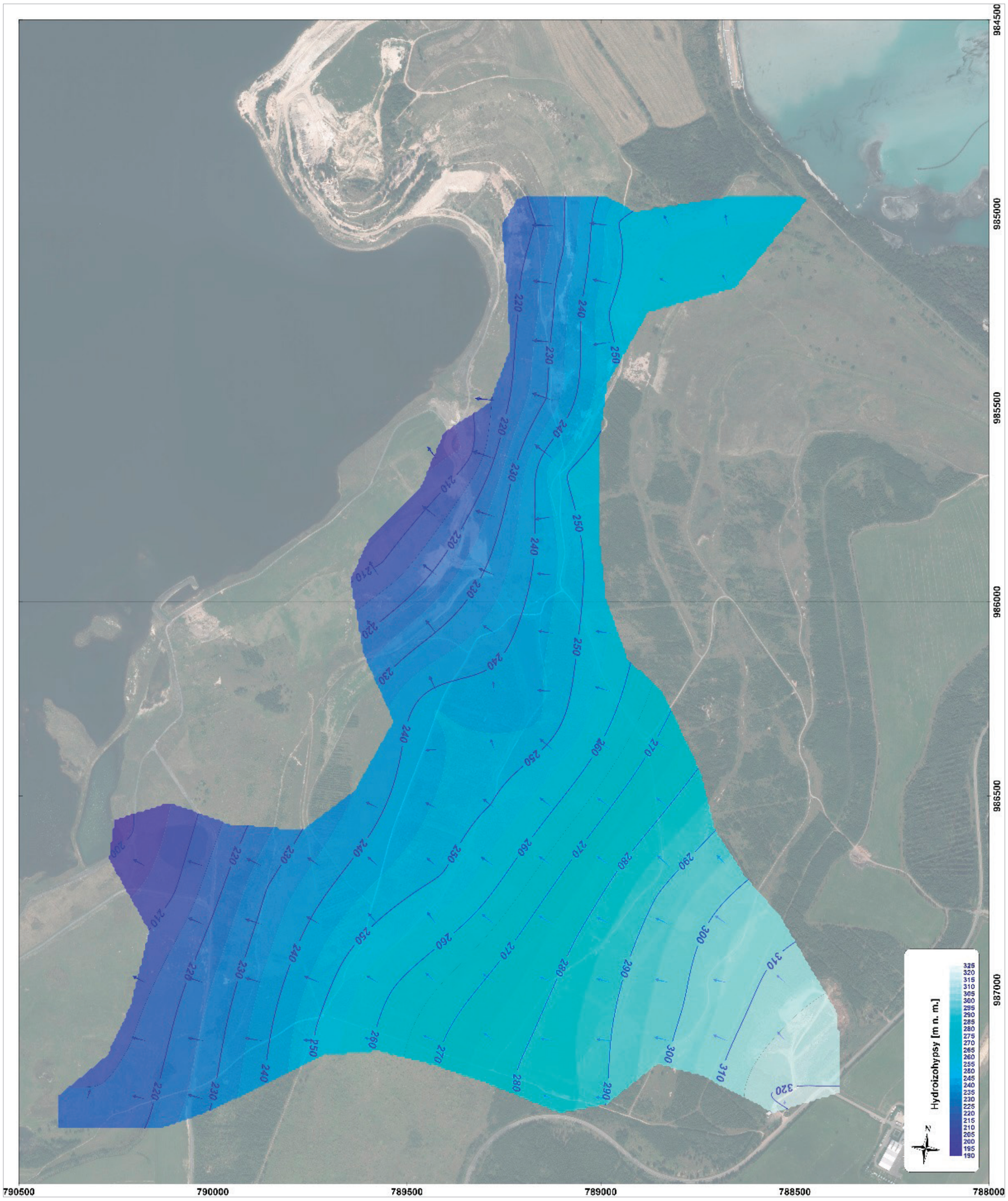

Fig. 5: Shallow groundwater flow in the body of Střimice dump.

to coarse-grained and are divided by sandy clays into several positions. Hydrogeological and hydraulic relation to coal seam is problematic. Some wells of hydrogeological survey from 1979 to 1980 showed differences in the pressure levels, while on other wells some pressure continuity of both aquifers was detected. According to the results of pumping tests, the volume rate of the underlying sands aquifer increased proportionally with the increasing thickness from 1.0 up to 17,2 $l.s^{-1}$. After a proper pumping test, the borehole level did not return to its original level, indicating the static nature of the water supply in the underlying sands aquifer.

The underlying sands were drained by pumping wells until the end of 1985. Since 1980, a total of 550,152 m^3 of water has been pumped out of this hydro geologically isolated structure by means of five pumping wells. The water level was successfully lowered by 40 m from the original level of approx. 183 m above sea level so the danger of a possible rush of water to the bottom of the mine was eliminated.

Coal seam and overburden sands

The coal seam can be considered as a significant aquifer. Its main infiltration area is the outcrop at the foot of Ressl, Hněvín, Kočičí and Červený hill. The original fracture permeability of the coal seam was relatively low and the water movement was slow. The hydrogeological situation has completely changed by underground mining of the coal seam.

Original relatively low, mostly fracture permeability of coal seam, which filtration coefficient fluctuates in the values of $k = n \cdot 10^{-5}$ to $n \cdot 10^{-6}$ $m.s^{-1}$ was significantly increased by mining activity, according to unique hydrodynamic tests, the filtration coefficient in the old-age aquifer was within the range of $n.10^{-2}$ až $n.10^{-4}$ $m.s^{-1}$.

Underground mining created open spaces (corridors and chambers) in the coal seam that were subsequently filled with a caving mixture of coal and overburden clay. Depending on the used method of underground mining, some of the cavities formed were not sealed. Overall, there was an increase in the volume of free space and thus increased permeability of the part of coal seam affected by underground mining. However, apart from some exemptions, the lower bench of the coal seam was not affected by underground mining, and the original fracture permeability was preserved.

The flow of water in the old materials is determined by the slope of the coal seam base, especially the excavated parts and corridors. In the area of interest there is a general slope of the coal seam from southwest to northeast.

In addition to the north-eastern part of the former village of Konobrže, the coal seam is deeply reworked. It was drained gravitationally northwest by a pumping station at the Evžen pit and at the Anna pit. After both the close down of both stations in 1969 and 1975, the water flowed out gravitationally to the pumping station at the M.J. Hus mine.

Specific problems with groundwater arose in the area of the Gothic church, which was moved from the old Most to the remaining pillar of the seam near its outcrop; in close proximity to the buried surface mine Segen Gottes.

Prior to the commencement of coal mining, there were two hydraulically connected aquifers in the area - coal seam and Bílina alluvial deposits. Their groundwater interacted with the water in the Bílina River. Mining activity primarily increased the low permeability of the coal seam by an order of magnitude and after the opening of surface quarries the water level of the connected aquifers decreased to the lower part of the coal seam.

In the first half of the 1970s the upper edge of the overburden of the Most mine advanced up to 65 m from the newly placed church. On the lower coal section, constant inflows of water were recorded, which flowed to the main pumping station of the mine. At the time of the church's transfer in 1975, the groundwater level was safely below the level of the newly built foundation structure. Subsequent up-swelling of the groundwater level was not foreseen and the foundation drainage project was not prepared.

The Venuše water reservoir, which is used for storing ash and other wastes mainly from UNIPETROL, a.s., was built in the first half of the 1970s and was put into operation in December 1976. Originally, the coal seam of Ležáky - the Venuše section - was mined here. In the east and west it is bounded by phonolite igneous rocks, the hills Cat's back and Červený hill together with accompanying impermeable tufitic clays and tuffites. In the south, it is bounded by the Střimice dump consisting of mixed, mostly clayey, but partly sandy soils. The northern boundary consists of coal seam (a pillar in which the seam was mined in the past by underground mining via chambering to controlled caving) and partly overburden clays in which two aquifers of fine-grained sands and sandstones are stored.

The described geological conditions point to a relatively varied mining and hydrogeological situation. From this point of view, the subsoil of the coal seam is not problematic, that is, those parts of the residual pit that are constructed via impermeable volcanic and underlying tufitic clay stones. From a hydrogeological point of view, the coal seam and overlying sands have the properties of aquifer layers. In the past, the coal seam was mined underground (mainly by chambering to controlled caving). In addition to the caved goafs left here after underground mining a network of unburied mine corridors remains there, many of which reached into the area of the remaining pit in the untouched lower parts of the coal seam. These corridors can represent potential routes for water interaction with the surrounding area. The stratum of overlying sands is enclosed in an overlying layer of impermeable clays and clay stones. These are two layers of sand with a relatively complicated location and possessing a quick sand character. Their total thickness is 4 to 8 meters and the individual sub-layers are connected with a not completely flat course. The overlying sands base on the adjacent perimeter of the Venuše pit was very suitable for infiltration of contaminants from the reservoir.

Some mining and hydro-geological operational problems have been already anticipated during the construction of the water reservoir due to the location of the residual pit situated in the vicinity of the closed underground mine Venuše, which is interconnected with the Kohinoor II mines and the mine Mír (Masaryk) that was still in operation at that time.

Since the abandoned residuals of the closed Venuše mine after chambering at controlled caving were together with its transport corridor leading directly into the residual pit; the corridors were closed via so called outer circle of concrete anti-penetrable dykes and the coal seam, uncovered in sections in the northern slope of the mine, was nearly at its entire (overreaching its ceiling) covered by clay dump soils. This way a layer at least 2 meters thick was formed, which created isolation against the seepage of water from the water reservoir into the coal seam, old abandoned mine and corridors in the coal seam. This measure was supposed to eliminate the risk of leaking uncontrolled amounts of water from the fly ash tanks into the closed Venuše mine and further after the Kohinoor II seam collapse.

During the water treatment of the ash fly, there was leakage of water from the water reservoir to the surrounding rock environment. Although, the coal seam was covered with a clay screen in the residual pit, water leakages from the water reservoir into the old Venuše mine and the Kohinoor II mine were not completely prevented, and the pumped amount of seam water from the Kohinoor II mine was increased. These leaks apparently culminated in the 1980s. With the gradual consolidation of the sealing screen, the leaks decreased and in 1989 they practically disappeared. On the other hand, more significant leaks from the water reservoir to the overlying sands started to occur in the same decade. On the basis of monitoring boreholes, a rise of underground water level of more than 30 meters was recorded in this horizon.

Measures were taken to minimize water leaks from the water reservoir to the Venuše mine through overlying sands, based on experience with the operation of the water reservoir in the Ležáky II mine - Evžen section, based on suitable water treatment of fly ash technology. If it is floated so that an ash beach forms at the walls of the reservoir, where sand outlets are formed, it is very likely that the leaks will decrease and that the colmatation based on the fly ash-sand contact will be substantially applied.

Quaternary sediments

Quaternary sediments in the area of interest represented the most extensive water saturated aquifer. Their water saturation depends on the grain composition, thickness, their clay content and input from atmospheric precipitation. The permeability of Quaternary sediments is variable and depends mainly on the above-mentioned facts. Gravel and alluvial sediments have good permeability ($k = n.10^{-4}$ $m.s^{-1}$). Gravel sand, sandy clay and clay have permeability in wide range ($k = n.10^{-4} – 10^{-6}$ $m.s^{-1}$). The degree of saturation of the Quaternary sediments, expressed and documented by the water level in the monitoring wells, is more or less constant. Unlike other aquifers (subsoil aquifers, coal bed, etc.), where the long-term downward trend of water level is apparent (drainage effect of near mine), the level of the Quaternary aquifer depends solely on the input from atmospheric precipitation.

Groundwater flow in Střimice dump

Grey to grey-brown clays and clay stones (occasionally sandy stones), fine-grained sands, gravel, clearance coal, cinder, ash and burnt clays were stored in the Střimice dump. The deposit of the above-mentioned rocks is more or less chaotic. In the years 2013 - 2017, a hydrogeological survey was carried out in the area of interest, within which 34 wells marked with MS and HVV were realized. The results of this survey showed that the positive aquification mainly concerns clearance soils (coal, ash, and soot), sandy soils, gravel and burnt clays.

In terms of geological structure, only the upper part of the Střimice dump body was drilled. Moreover, the individual wells are so far apart that in terms of the possible use of a mathematical model, it is not possible to determine basic hydro-stratigraphic units (layers of aquifers and impermeable beds) in the territory. It is not possible to carry out an adequate correlation of the individual hydrogeological layers from the geological profiles of the aforementioned wells. These units represent the basic data for the creation of the initial computing network. Another important input is the hydrodynamic parameters of the detected aquifers, but these are insufficient for the needs of the hydrogeological model. Without this information, model discretization and subsequent calibration and validation of a possible model cannot be performed.

The shallow groundwater flow in the upper part of the Střimice dump can be modelled by modelling long-term monitoring of water levels from observation wells. The results of this monitoring revealed long-term, average values of the level of shallow groundwater in the dump, which were subsequently correlated with each other. Based on these input data, a groundwater flow model was created in the upper part of the Střimice dump body. The level gradient and groundwater flow directions are shown in Fig. 5.

From the resulting model, it is apparent that the vast majority of shallow groundwater from the area of the Střimice dump body flows to the west in the area of the Lake Most.

6 Monitoring of groundwater and surface water chemistry

6.1 pH

The pH value significantly affects chemical and biochemical processes in waters and toxic effect of substances on aquatic organisms. It makes it possible to distinguish various forms of occurrence of some elements in water, it is one of the criteria for assessing water aggressiveness and it affects the efficiency of chemical, physical-chemical and biological processes used in water treatment and purification.

In pure natural (surface and underground) waters the pH is within the range of 4.5 to 8.3. A drop in water pH below 4.5 is due to the presence of inorganic and organic free acids (e.g. humic substances). Waters with a pH above 8.3 probably contain CO_3^{2-} or OH^-.ions.

Analysis of surface water samples

From the data obtained from long-term monitoring of the locality, it was found that the pH values of the sampling points were absolutely satisfactory with the exception of one sampling point. The unsatisfactory pH values were reached by the sampling point marked JM5, where the pH reaches an average value of 3.33. This is a sampling point, which dump surfaces from the wider surroundings are covered by deposition of clearance soils.

Analysis of groundwater samples

The analysis of groundwater samples revealed that most sampling sites had satisfactory pH values. The only exception is the sampling sites designated HVV9, MS10, MS29 and MS36, where the average pH values range between 5.50-5.80. Absolutely unsatisfactory are groundwater taken from well MS35, where the long-term average pH value = 3.60.

6.2 Dissolved substances (DS)

Natural waters contain a number of dissolved inorganic and organic substances. Some substances are absorbed by the water already in the atmosphere, but their main enrichment with dissolved substances occurs during soil and rock infiltration.

Analysis of surface water samples

Analysis of samples from surface water sampling sites revealed that the limit values of dissolved substances were exceeded at nine sampling sites (JM4, JM5, JM8, JM13, JM16, JM17, JM18 and JM19). The highest mean concentration of dissolved substances was found at the sampling site JM13 (4 584 $mg.l^{-1}$). At other sampling points, situated mostly at the banks of the Lake Most, the concentrations of dissolved substances are absolutely satisfactory (units of $mg.l^{-1}$).

Analysis of groundwater samples

From the data obtained from the analysis of groundwater samples it is apparent that the vast majority of samples exceed the concentration limit values for dissolved substances. Only two sampling points (JM21 and JM32) were satisfactory. The average concentrations of dissolved substances from all other sampling sites reach values in the order of thousands of $mg.l^{-1}$.

6.3 Iron (Fe^{II}, Fe^{III})

Iron occurs in waters in divalent or trivalent form. In the anoxic reduction environment of groundwater and in surface waters at the bottom of reservoirs and lakes, iron occurs in oxidation stage II. In waters containing dissolved oxygen, iron in oxidation stage III is the most stable form of occurrence. The sources of iron in waters are minerals such as pyrite (FeS_2), hematite (Fe_2O_3), siderite ($FeCO_3$) and others.

In small concentrations, iron is a common part of water. In surface waters it usually occurs in hundredths to tenths of $mg.l^{-1}$. In reservoirs and lakes, the iron content is stratified. During the period of summer and winter stagnation, dissolved and undissolved forms of iron accumulate in the lower layers of water at the bottom (in hypolimnion) in concentrations reaching sometimes tens of $mg.l^{-1}$, although only hundredths of $mg.l^{-1}$ can be found in the upper layer (epilimnion). At the bottom of water reservoirs, reduction processes occur, forming Fe^{II}. During spring and autumn circulation, Fe^{II} is scattered throughout the water and oxidized at the surface by contact with dissolved oxygen and then hydrolysed.

In groundwater not containing dissolved oxygen, dissolved iron in the oxidation stage II occurs in concentrations up to tens of $mg.l^{-1}$.

Analysis of surface water samples

From the results of analysis of FeIII concentrations it is evident that from all sampling points, there are 4 sites that exceed the permitted limit value. The average concentration of Fe^{III} ions at sampling sites JM8 and JM17 is 1.20 or rather say 1.54 $mg.l^{-1}$. The average concentration of iron at the JM5 sampling site is 6.13 $mg.l^{-1}$. The increased concentration of iron ions at this sampling point completely correlates with the pH value and is caused by the properties of soils located in the wider surroundings. The highest mean concentration was found at the sampling site JM13 (20.41 $mg.l^{-1}$). It is an area with a small thickness of the dump with a relic of a coal seam underneath it.

Analysis of groundwater samples

Groundwater in the area of the Střimice dump is heavily affected by the presence of trivalent iron ions. The analysed samples were found to reach tens to hundreds of $mg.l^{-1}$. The presence of trivalent iron is mainly due to the fact that the monitored sites are stored with clearance coal or clays with the addition of iron-rich minerals to monitor the auriferous layers of the dump.

6.4 Nitrates (NO_3^-)

Nitrates are found in water mainly in a simple ionic form as NO_3^-. In groundwater and surface waters, nitrate nitrogen is usually found in concentrations in unit of $mg.l^{-1}$. The high nitrate content is likely to be related to the breakdown of organic nitrogen substances in water and soil and to the excessive use of fertilizers.

In natural waters, nitrate concentrations vary depending on the growing season. Their maximum concentrations are found in groundwater in the winter, i.e. out of vegetation period. On the other hand, in summer, they are used up from the water by vegetation.

Analysis of surface water samples

Nitrate concentrations in surface water samples were significantly exceeded at three sampling sites (JM9, JM 19 and JM30). Mean nitrate concentrations ranging from 54.77 to 175.00 $mg.l^{-1}$ were found at these sites. The average values of nitrate concentrations of the other samples are in the order of units of 10 $mg.l^{-1}$, the value of 10 10 $mg.l^{-1}$ is exceptionally exceeded. As described in the theoretical section, nitrate concentrations vary depending on the growing season. The results of the analysed samples show that the limit values are not exceeded at sampling points, which are in the vicinity of sufficiently grown vegetation (e.g. Střimice dump).

Analysis of groundwater samples

Regarding the groundwater sampling sites, nitrate concentrations were significantly exceeded at three sites (JM23, JM32 and MS23). The average concentration values of nitrates at sampling points are in the hundreds of $mg.l^{-1}$. Such high nitrate concentrations are likely to be caused by organic matter in decomposition, but the certain source of nitrate is currently unknown.

6.5 Manganese (Mn)

Increased iron content in waters is usually accompanied by increased manganese content, the concentration of which is usually lower than that of iron, but there is also groundwater with inverse ratio. Due to the limited solubility of manganese oxides, its concentration in water rarely exceeds 20 $mg.l^{-1}$. For example, mine waters may be an exception. Manganese concentrations in groundwater are higher than in surface waters where oxidation processes take place.

Analysis of surface water samples

Limit values of manganese concentration were exceeded in the area of interest at a total of five sampling points. At three of these sites, the average concentrations are up to 0,6 $mg.l^{-1}$. The highest average concentration of manganese was recorded at the JM5 sampling site, similarly as for trivalent iron ions. The causes of such a high concentration are the same as for F Fe^{III} ions.

Analysis of groundwater samples

Groundwater, especially in the area of the Střimice dump, is heavily affected with presence of manganese. The limit values were exceeded for all analysed samples, with some exceptions. The average concentrations of manganese are in the order of tens of $mg.l^{-1}$. Due to the fact that in the Most Basin, there is not known massive occurrence of mineral, which would contain a higher concentration of manganese, it can be assumed that the origin of this element was bound to its oxides and hydroxides, which filled cracks in tertiary clays and clay stones. By disrupting the original integrity of these rocks and their introduction into the dump, this element got gradually leached into the aquatic environment.

6.6 Sulphates (SO_4^{2-})

Sulphates occur mainly in the weathering zone. The main minerals are gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$). Sulphates are also formed by oxidation of sulphide ores, which is the reason for their high concentrations in mine waters.

In low- and medium-mineralized waters, sulphates tend to occur predominantly in the form of a single SO_4^{2-} ion. Ionic associates may also be present in waters with a high concentration of sulphates. In surface waters, sulphates usually occur in concentrations of units up to tens of $mg.l^{-1}$. In general groundwater, their concentration values are usually tens to hundreds of $mg.l^{-1}$.

Analysis of surface water samples

Analysis of surface water samples revealed that the vast majority of these samples exceeded the limit value. The average concentrations of the above samples are in the order of hundreds to thousands of $mg.l^{-1}$. The cause of such high concentrations is mainly soils containing coal material. Soils from areas of coal outcrops, which are characterized by higher sulphur and ash content, are most affected.

Analysis of groundwater samples

The groundwater samples analysed are highly affected with sulphates. The limit values in the order of hundreds to thousands of $mg.l^{-1}$ were exceeded at all sampling points. The highest average concentration of SO_4^{2-} occurs at sampling sites MS5 and MS 35. The average concentration of SO_4^{2-} - at these sites is around 5.0 - 5.5 $g.l^{-1}$.

6.7 Ammonium ions (NH_4^+)

Ammonium ions are very volatile in natural waters under oxidizing conditions. By biochemical oxidation (nitrification) it is converted to nitrites or even nitrates. Ammonium ions are very important from a hygienic point of view because they are one of the primary decomposition products of organic nitrogen compounds. They are therefore also an important chemical indicator of groundwater pollution by animal waste.

The concentrations of $N(NH_3+NH_4)$ in groundwater and pure surface water are up to about 0.1 $mg.l^{-1}$. Organically contaminated surface water may contain ammonium ions even in the amount of several units of $mg.l^{-1}$.

Analysis of surface water samples

The analysis of surface water samples revealed that the limit value of the concentration of ammonium ions was exceeded at six sampling sites. At three of these sites, the average NH_4^+ concentrations reached values in the order of units of $mg.l^{-1}$. The cause of these recorded concentrations is probably contamination of sampling points with organic material.

Analysis of groundwater samples

Groundwater in the wider area of the Střimice dump is affected with NH_4^+ ions. At most sampling sites, average concentrations of ammonium ions in the order of tens of $mg.l^{-1}$ were recorded. Extreme values were detected at the sampling site JM21, where the concentration of ammonium ions reached the value of 138.00 $mg.l^{-1}$. The origin of the pollution at most of the sampling points is notcurrently known; however, on the top of the Střimice dump there is a landfill for technical and municipal waste, which may (in case of leakage through the subsoil of the landfill) represent this source. However, this presumption has never been confirmed or refuted.

6.8 Results of surface and groundwater chemist

The analysis of physical-chemical parameters of surface waters shows that the site is heavily affected with SO_4^{2-} ions. Given the nature of deposited soils, this fact is not exceptional. This is a normal situation in other localities in the Most Basin. For other parameters, the limit values were exceeded rather exceptionally (according to Government Regulation No. 23/2011 Coll.). The most exposed is the offshore area, located southeast of Kočičí vrch (sampling point JM5) and also the area around the sampling point JM13.

It is recommended to replace the soils in the vicinity of the sampling point JM5 with suitable reclaimable soils, or replace the existing soils with a continuous layer of calcareous soils (marl, marlstone, etc.). In view of the long-term development of physical-chemical parameters, it can be assumed that spontaneous improvement of the above-mentioned indicators is likely to occur within 20-25 years, assuming the current climate.

The analysed groundwater samples are considerably affected by the presence of undesirable ions and elements, several times exceeding the limit values. This is mainly due to the fact that soils with a high content of these substances were found in the exploration works. The results of the monitoring show that most of the pollutants gradually decrease their concentration in the given environment. Thus, there is a gradual elution from the auriferous layer of the given location. Determining the time at which acceptable concentrations will be reached is very difficult in such a heterogeneous environment. On the basis of existing data, it can be assumed that this could happen in the next 30 years, with some indicators up to 50 years.

The problematic area is the wider area around the MS30 and MS31 sampling points. In these places, the groundwater spills over to the terrain and this water flows to the shore line of the Lake Most. The solution can be a perfect sealing of the well with the active overflow and its wider surroundings, or eventual pumping of the water springing outside of the lake area. To improve the physical-chemical parameters of surface waters around this site, it is recommended to apply calcareous soil drainage ditches to the existing surface.

7 Climatic conditions

Apart from the geographical location, the climatic conditions of the Lake Most are also determined by the leeward position in the precipitation shadow of the Krušné Mountains. The area is located in the warm climatological area T2 (Quitt 1971), which is characterized by the average temperature of the warmest month reaching 18-19 °C, average temperatures of the coldest month below 0 °C, average temperature in April 8-9 °C and average temperature in October 7-9 °C. The average monthly temperatures in the Most Basin are evident from Fig. 6, where long-term temperature averages of individual months from the

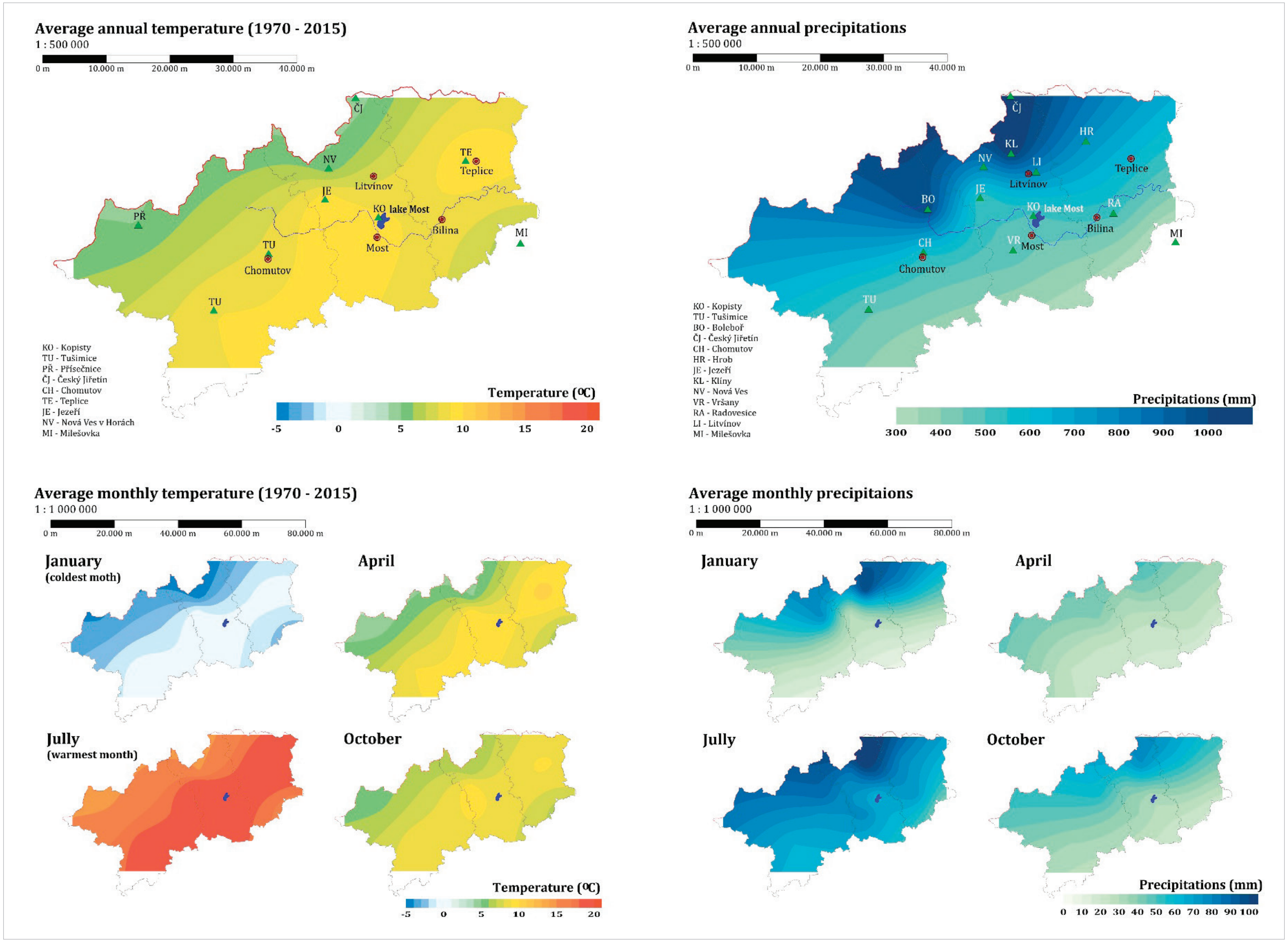

Fig.6: Basic climatological characteristics of the Most basin.

nearest meteorological stations of CHMI are stated including the Kopisty station (240 m above sea level). This station is situated in the immediate vicinity of the Lake Most and the measurements are available from 1970. The annual mean temperature in the basin region is around 9 °C, which is above the national average (CHMI 2005). For comparison the annual average temperature in the plain region of the Krušné Mountains oscillates around 5 °C. The measured temperature difference of the hottest month (July) reaches up to 3.9 °C, while the temperature difference of the coldest month (January) exceeds 5.5 °C.

An interesting phenomenon is the increase in average monthly temperatures by approximately 1 °C in the second half of the 20th century in Kopisty station. In the period 1901-1950, the average monthly temperatures in the first eight months were 0.8-1.3 °C lower (Bárta et al. 1973) than in the period 1971-2016. The average monthly temperatures of the remaining four months differ considerably less (-0.1 to +0.7 °C) in both periods. The cause may be a combination of several anthropogenic effects - drying of large water bodies, regulation of the originally streaming Bílina and its mountain tributaries, widespread deforestation due to the development of surface mining causing air overheating in spring and summer months (Marek, 2006), but certainly also general evolution of climate at regional or global level. The warming trend of more than 1.5 °C compared to the long-term mean average has been apparent since 2014, so the period 2014-2016 represents the most significant thermal anomaly since the year 1981.

The annual precipitation volume varies depending on the altitude, or better say on the station's exposure in relation to the Krušné Mountains barrier. In the area of the Most Basin, the influence of the precipitation shadow is applied and therefore the total precipitation volume is up to 50 % lower than in the mountain area of the Krušné Mountains. Also, the proportion of summer precipitation is increasing (59-63 %). Part of the Most region, represented by the weather stations Kopisty (457 mm), Tušimice (439 mm) and the former station Ervěnice (463 mm), is one of the driest areas of the Czech Republic. In peak areas and on the slopes of the Krušné Mountains, the annual precipitation is 800-1,000 mm. Thanks to the Atlantic circulation, the annual precipitation is balanced (52 - 54 % of the summer precipitation).

The precipitation deficit (approx. 25 % of the total precipitation volume for the period 1981 to 2010), which started to show in the whole Czech Republic since the beginning of 2015, caused by the presence of high pressure systems over most of the Euro-Atlantic area, i.e., the absence of low pressure systems and associated fronts (CHMI, 2016), did not manifest itself in the central part of the Most Basin. Unlike the areas on the edge of the Most Basin (e.g. the settlement Hrob) or in the Krušné Mountains, no negative precipitation anomalies occurred in the precipitation in Kopisty, Tušimice and Chomutov. Therefore, the drought period in 2015/2016 was not primarily due to precipitation deficit, but mainly due to high above-average temperatures and thus high evaporation.

The opposite scenario is then the drought of 2018, when January demonstrated normal to above-normal precipitation and temperature above-normal. However, the months of February and March were already above averge in terms of temperature and also below-normal in terms of precipitation, especially in the mountain areas of the Krušné Mountains. Since April the temperature prevails to above average to extremely above average weather, and on the other hand, precipitation is below-normal to extremely below-normal. The total precipitation volume reaches 70% and at some stations even 60 % of the long-term average 1981-2010, while the average monthly temperatures are almost 2 °C higher than the long-term average and spring and summer months (April-August) are warmer even by 1.9-3.9 °C. The drought during the year 2018 was due to a combination of low total precipitation and high evaporation due to extremely above-average monthly temperatures.

7 Flora and fauna

The animals were monitored as part of the project "Impacts on the microclimate, air quality, water and soil ecosystems in the framework of hydric reclamation" in the years 2011-2014 (Šafářová, 2014). For a more complete overview of the development of avifauna in relation to the gradually changing conditions of the flooding lake, data from 2009-2010 were taken to complete the information in the final report of the project.

During the monitored years 2009-2014, a total of 149 bird species were detected in the locality of the Lake Most and its surroundings (Šafářová, 2014). In terms of the number of monitored species, the overall data from the monitored years document that the lake is one of the most important ornithological localities. Species composition of birds is very rich and there are numerous species that occur in the rest of the Czech Republic only rarely and in small numbers. These findings are due to the very varied habitat conditions of this area, which is typical of emerging ecosystems in anthropogenically affected areas.

There are species that are commonly and quite abundant in the Czech Republic, with a more or less constant population (greylag goose, mallard, gadwall, common pochard, marsh harrier or water rail. Birds from the oscine suborder include the whinchat, the sedge warbler, reed warbler, marsh warbler, white-spotted blue throat, reed bunting. The fact that there is a relatively significant number of species high in abundance in this territory, but receding or few numbered regarding the rest of the country is very interesting. These include the great crested grebe, black-necked grebe, little grebe, tufted duck, black coot, northern lapwing from the family of lapwings and the great warbler from the oscine suborder. For some of these species, nesting has not yet been detected at the site, but is highly likely to occur in terms of the nature of the environment.

Of the aquatic and wetland bird species recorded during the breeding season, however only those not expected to be nesting, the following species have occurred: northern shoveler, Eurasian green-winged teal, garganey, red-crested pochard, common moorhen, common snipe, green sandpiper, common redshank, and common sandpiper.

The great cormorant, great egret, grey heron, Caspian gull or black-headed gull belong to species that appear at the territory the whole year but do not nest here.

In the period of spring and autumn thrust and in winter period there are mainly taiga bean goose, goldeneye duck, common merganser and various kinds of seagulls. Individual species stay on the site for various lengths of time, from individual days to almost months.

The common buzzard and the common kestrel rang among the commonly occurring birds of prey. Occasionally, the occurrence of black kite and red kite, hen harrier, rough-legged buzzard, European honey buzzard, Eurasian hobby perch and peregrine falcon was found here.

In addition, seven amphibian species and two reptile species were identified on the lake and in its immediate vicinity (smooth newt and warty newt, the fire-bellied toad, the large toad and the green toad, marsh frog, agile frog, the sand lizard, the grass snake). In all cases the species were specially protected under the Act on Nature and Landscape Protection No. 114/1992 Coll.

In 2013, only 6 species of molluscs were found on the simultaneously flooded Lake Most (ap-prox. 0.5 m before full flooding). Most of the detected species occurred in very low numbers and their populations in most localities were so far not very numerous. The exception was the zebra mussel. Its occurrence can be described as very numerous to mass and in some localities, it exceeded even 80 individuals per 10 cm^2. This species also occurred in 9 of the 11 sites studied.

A relatively large number of very rare (3) and rare (13) species were found in spider material (about 5.5 thousand ex and 143 species). These are predominantly drier and warm habitat species, but in some cases also species with broader valency and wetland species.

One of the most important fauna findings was the species of the spider Enoplognatha mor-dax, known only from one to two findings regarding the Czech Republic (the surroundings of Hradec Králové, NNR Nesyt –Moravia). This species is abundant on the seashore - dunes, rocky habitats, etc. Although the spider Cheiracanthium punctorium is mentioned as a species generally very rare, in the vicinity of Most and some other towns in the Most Basin area under the Krušné Mountains (Teplice, Ústí n. L.) the species is widespread. The presence of this species has been associated with a danger to humans (see Czech taxonomy carrying the name „poisonous“ for this spider). Bite cases are rare, but can lead to temporary paralysis of, for example, a limb. In addition, bites are very painful.

In the material of ground beetles (up to now approximately 1800 ex and 103 species of ground beetles have been determined), almost a balanced proportion of species characteristic of disturbed and weakly disturbed environments was found. In contrast to the evaluation with the help of the classification of spiders, there were no species that would indicate cli-max habitats, or rather say conditions similar to these habitats.

Of the occasionally observed arthropod species, 12 species were particularly protected in the category "Endangered" according to the Decree of the Ministry of the Environment No. 395/1992 Coll. All these species belong to relatively common species of various non-forest communities and forest margins; they are also common in ruderalized communities with heavily disturbed soils. However, P. machaon and O. funesta were rarely observed at the site of interest. One of the more important ones is the observation of The Silver-studded Blue and Ides Blue, species that are rapidly disappearing from today's nature. However, as we have seen through observations at several sites in the wider area, they may occur more frequently at secondary dumps sites. However, determining their occurrence in the field is difficult and targeted catches were only occasionally performed.

7.1 Vascular plant species

The studied area included its own water reservoir, its banks, wetlands in the immediate vicinity and slopes above it. The tree species planted as part of the reclamation process were recorded only in a facultative way. In total, 380 vascular plant taxa were found in the monitored area.

Among the specially protected and endangered species from the locality of the Lake Most we mention the following: Atriplex oblongifolia (C4a), Bolboschoenus maritimus s. str. (C3), Bromus commutatus (C2), Bromus japonicus (C4a), Carex bohemica (C4a), Carex otrubae (C4a), Carex pseudocyperus (C4a), Carex secalina (C2), Centaurium erythraea (C4a), Eleocharis mamillata subsp. mamillata (C4a), Erysimum crepidifolium (C3), Filago arvensis (C3), Galeopsis angustifolia (C3), Hieracium glomeratum (C4a), Juncus ranarius (C3) Lathyrus hir-sutus (C1), Libanotis pyrenaica (C4a), Melica transsilvanica (C4a), Papaver argemone (C4a), Papaver confine (C3), Papaver dubium (C4a), Populus nigra (C2), Potentilla recta (C4a), Pyrus nivalis (C2), Pyrus pyraster (C4a), Rumex stenophyllus (C1), Salsola kali subspecies rosacea (C3), Schonoplectus tabernaemontani (C2), Stellaria pallida (C2), Tetragonolobus maritimus (C3), Typha laxmannii (C1), Ulmus laevis (C4a).

The occurrence of Schoenoplectus tabernaemontani was detected on the Lake Most and other hydrologically reclaimed brown coal quarries. This species, listed in the Black and Red List of Vascular Plants of the Czech Republic as strongly endangered (C2), has the highest con-centration of localities in the Podkrušnohoří region in the Czech Republic. A specialized map of the distribution of the selected taxa was prepared based on the results of our own field survey. The collection of phytosociological images shows the types of vegetation in which the species occurs in the area.

8 Geotechnical problems

8.1 Basic units of geotechnical model

The basic geotechnical model of the Lake Most locality was elaborated according to the methodology described in Read and Stacey (2009), taking into account all four main parts of the basic geotechnical model: geology, hydrogeological model, material model and structural model (in this case represented by the mining model; Fig. 7).

Similarly to the majority of mining sites in the Most Basin, it is possible to define two basic types of slopes in the area of the Lake Most i) open-pit slopes: created by shaping the original relief in the soils in-situ due to mining ii) dump slopes: resulting from excavation of the overburden soils and their reloading into the dump bodies, which created a completely new relief with a chaotic and incoherent composition of soils, dependent purely on the nature and method of foundation of the dump.

Open-pit and dump slopes have their specifics and hydrogeological regime, and therefore we understand them as two basic units of the geotechnical model.

8.2 Area of open-pit slopes

The basic and dominant types of soil in the Most Basin are overlying light grey Miocene clays (Řehoř and Schmidt, 2015). Uncovering tens, in places more than hundreds of meters of overlying layers naturally causes stress-strain changes inside the massif, or rather say inside the newly formed slopes. Clearly, in such cases, a significant change in the relative height and incline of the slope plays a crucial role in terms of slope stability. According to Pichler (1998), taking the weight off of the foot of the slope and the associated change in stress inside the slope weakens the passive shearing forces, and thus the slope can be destabilized.

In connection with the presence of coal seam, it is necessary to consider the specifics that do not apply to other (meaning non-coal) slopes. It is mainly a small specific weight (γ_n) of coal compared to e.g. soils. As a result, the buoyancy of the groundwater on the overlying strata has a greater effect than in other cases. Furthermore, it is the low shear strength (τ_f) of coal clays, which is lower than that of other rocks. Záruba and Mencl (1987) even state that shear deformation occurs at a pressure that corresponds to 20-40 % of the shear strength of other rocks.

Other phenomena negatively affecting slope stability are fault planes and systems of large and small cracks that pervade overlying dusty clay stones (Rybář and Dudek, 1976). Overall, the basin filler has a quasi-homogeneous discontinuous character in which anisotropy is applied.

Another important factor is the fact that the strength and deformation characteristics of overlying clay stones vary in the vertical direction. Rybář and Dudek (1976) observed that due to diagenetic reinforcement their strength increases with depth, while to the depth of 30-40 m (regelation zone) clay stones have very low strength characteristics. At this depth there is a geotechnical interface.

As Pichler (1998) states, since mining activity is always risky, slope movements in the large opencast mines of the Most Basin are a widespread and de facto natural phenomenon.

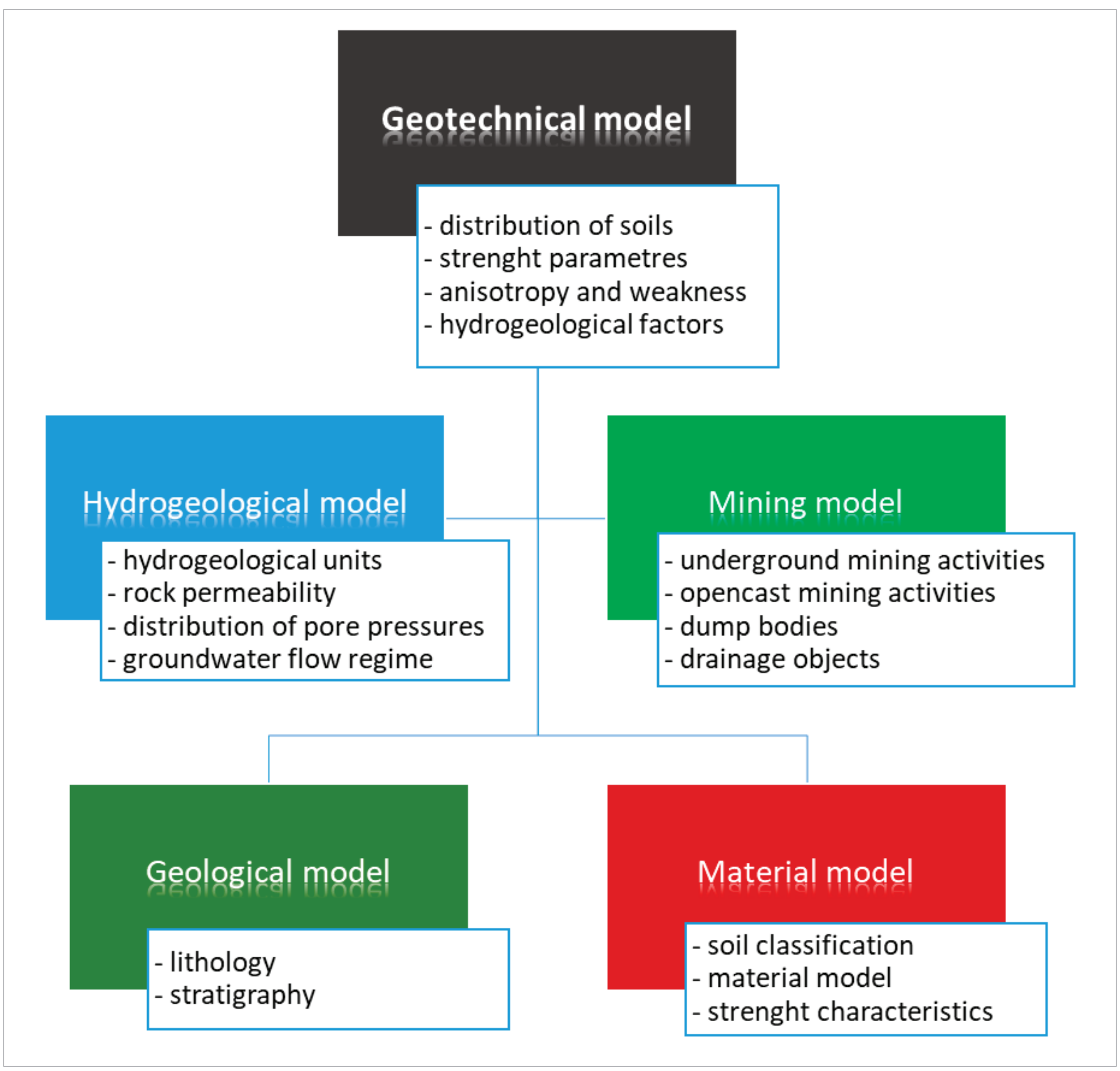

Fig. 7: Basic overview of the parts that enter the geotechnical model of Lake Most (modified according to: Read a Stacey, 2009).

Furthermore, sliding as well as flowing and creep can be encountered in this area.

In the area of interest, there is a progressive disruption of slopes, which is typical of plastic over consolidated soils (Bjerrum, 1973).

The shear stress of soils decreases sharply to residual value after reaching peak values with further deformation (Fig. 9). When changing the stress state of the soil, the pulling stress develops, which increases to the maximum as the x-coordinate increases. This pulling force causes the disruption of cohesive soil (creating cracks in the ground block) and the subsequent shift of the plane, which according to Pichler (1998) occurs in anisotropic environment on rheologically and lithologically predisposed areas, where the shear strength is lower. At the same time, stresses are concentrated on these planes and deformations occur within the slope, which is a frequent cause of overall movements. An unfavourable accompanying phenomenon is the increase in moisture at these areas. Händl and Kurka (2010) put this in connection with increasing permeability during loosening as a result of the dilatable behaviour of soils on the shear plane. In the observation wells, the shear plane manifests itself as an area of negative porous pressures - due to the increase in volume, a suction level is created here, or, on the contrary, in the case of contractancy it is manifested by high porous pressures (200 kPa). This behaviour is typical of brittle rock mass disruption.

Fig. 8: Poorly clear boundary of the Quaternary and Tertiary, where in addition the locally applied sloping fault surfaces and other areas of discontinuity (Photo: J. Burda).

In deep-seated landslides, a source of high deformation is associated with the rise in pressure stress inside the slope, associated with the formation of shear planes. Based on high--pressure shear tests carried out in the 1990s, Pichler (2009) concludes that these deformations occur at a pressure stress of 0.4-0.8 MPa and that the higher the ratio τ_f/τ_c (i.e. primarily above the geotechnical interface), the more progressive they are.

On the other hand, such high pressures cause a reduction in volume (soil contraction) and cause formation of new shear planes which may not be bound to the anisotropy planes. The disruption of the clay structure begins when the shear stress reaches about 60 % of the shear strength, i.e. peak shear strength cannot be utilized in the contractual nature of the shear stress. At the foot of the slope, this supple disturbance is usually manifested by a thin sliding surface, inside the slope by a sliding zone, in the separation areas a perfectly smoothed shear plane is typical (Fig. 10).

Geotechnical properties of rocks and soils in the locality of the Lake Most

Overlaying clays – these are predominantly siderite-kaolin-illitic clay stones with a minimum content of organic matter (max. 5 %), the proportion of clay particles smaller than 0.002 mm is greater than 50 %. Plasticity index Ip > 20 %, apparent density of solids 2 600 kg.m^{-3} (Řehoř and Schmidt, 2015). In 1997, 5 exploratory drill holes were carried out, from which rock samples were taken for testing their usability as sealing clays.

A total of 54 samples were taken that determined the basic characteristics of overlying clays. These are heavily sandy loess loam (in some places coarse sandy with quartz and gneiss Ø 5 – 10 mm). The results are presented in unpublshed report „MUS a. s. závod Hrabák – testing of the clays – locality Ležáky“.

A comprehensive overview of the results of permeability testing and expert determination of filtration coefficients show very low permeability values for almost all samples. These are mostly valuing below 4.10^{-10} m.s^{-1}, in most samples they are in the order of 10^{-11} m.s^{-1}. Occasionally, values of higher filtration coefficients were determined (in 4 samples - sample no. 980/97, 981/97, 991/97 and 1003/97) - in the order of 10^{-9} m.s^{-1} with permeability through preferential paths of compacted lump materials of harder consistency. However, permeability results in the order of 10^{-9} m.s^{-1} still fall within the range of impermeable materials.

Material (geotechnical) types of geotechnical model

As part of the elaboration of the geotechnical model of the locality, a search of geotechnical materials was carried out. The results of a further 76 laboratory analyses were processed for this study (Schmidt, 1997).

Based on the vertical variability of the results, for the needs of the geotechnical model, three geotechnical types which can be pervaded by anisotropic planes with residual strength (Weakening c_{res} = 8 kPa, φ_{res} = 8,5°) were defined in the overburden clays of the Libkovice Members in Most Formation.

Jil$_1$ – characterizing the control zone soils that were degraded during the Pleistocene period. The position of this zone is clear from Fig. 11 and the characteristic (most frequent) values are φ = 9,5°, c = 57 kPa and I_p = 40. Characteristically, these are grey-brown kaolinite-illitic clay stones with a weak dusty admixture, i.e. soils F7 (MH) to F8 (CH), loam and clays of high plasticity, slaking and with significant presence of the sloping fault planes, intermittent stratification areas and systems of large and small fissures. This position is partially fissure permeable, especially in the vertical direction.

Soils of the geotechnical type Jil_1 form the dominant part of the northern and western slopes of the lake. They are partially covered by soils of the dump below the space of the sealing wall (see the basic schematic geotechnical model in Fig. 11). In the area of the Konobrže lobe, they are then partially covered by the Konobrže sealing body. The Jil_1 / Jil_2 geotechnical interface is slightly rising northwards from the level of 205 m above sea level to the spot height of approximately 225 m above sea level in the area of the Konobrže Lobe.

Jil_2 – the position consists of grey to grey-brown clay stones. Again, the soils are F7 (MH) to F8 (CH), loam and clays with high plasticity, which are characterized by the values φ = 17°, c = 93 kPa and I_p = 40. Geotechnical type can be characterized as a solid clay stone environment of semi-rock character, where the cohesiveness increases with depth due to diagenetic strengthening. The environment acts as a perfect insulator. However, the soil strength parameters within

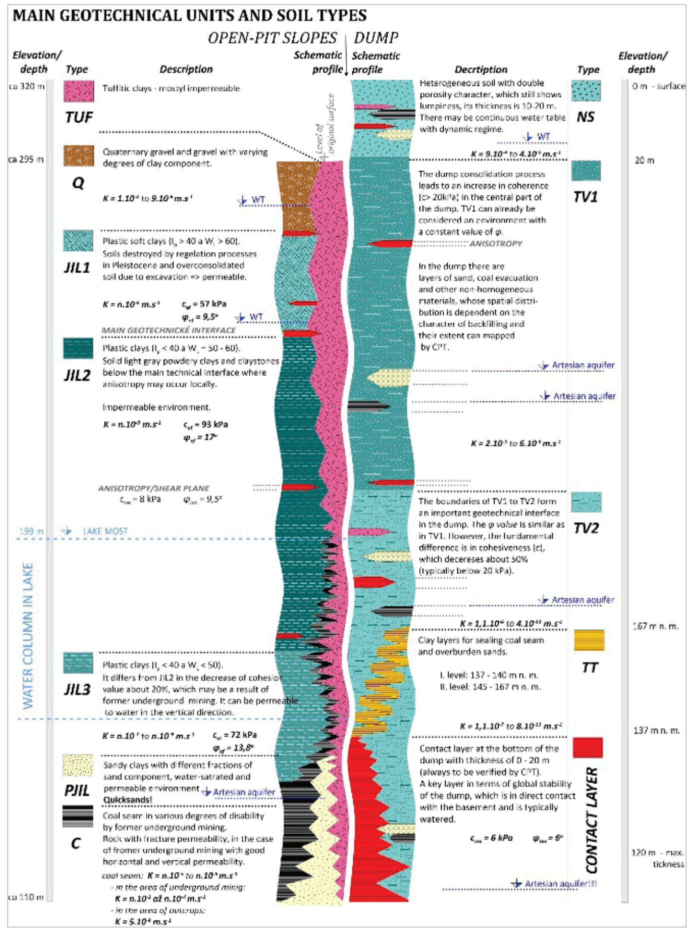

Fig. 11: Schematic vertical geotechnical model of the Most lake locality depicting the vertical structure of material types of the two main geotechnical units of the model: i) open-pit slopes, ii) dump area.

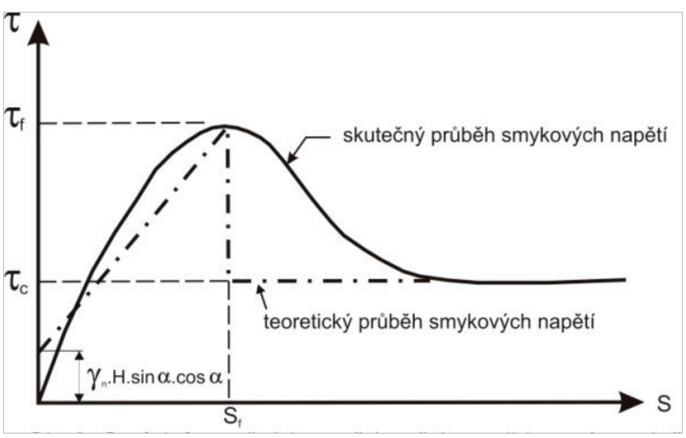

Fig. 9: Deformation stress graph in overconsolidated soil τf - peak strength, τf - residual strength (Pichler, 2009).

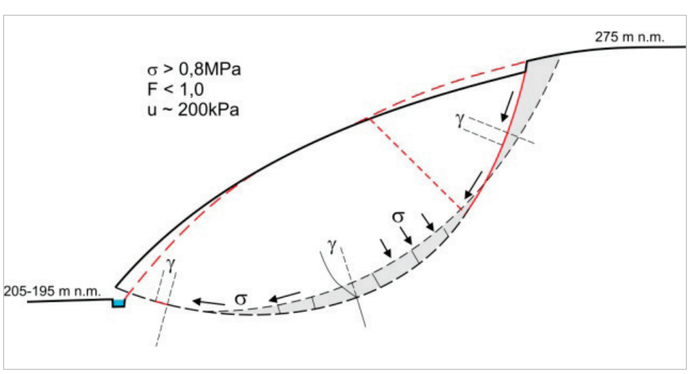

Fig. 10 Example of supple slope destruction with progression, σ - normal stress, F - degree of safety, u - pore pressure (Pichler, 2009).

the range of the former mining technology could be negatively affected by over-consolidation (they may be close to Jil_1 values).

Similar to the Jil_1 type, this geotechnical type occurs predominantly in the western and northern slopes of the lake, where it is completely covered by the material of the inner Most-Ležáky dump or by Konobrže dump body. They only reach the surface below the lake water sur-face level in a short section of the western side slopes.

Jil_3 – Despite the increasing depth of deposition of these clays, the cohesive value does not increase, but on the contrary, the overall shear strength decreases by about 20% (c = 72 kPa, φ = 13,6°). This decrease occurs abruptly at depths of 80-120 m, i.e. always with clays that are in the overburden of coal seam up to approx. 20 m. In the area of the central part of the Most Basin, this is a relatively untypical phenomenon, because clays at these depths are of a semi-rock to rocky character with an average value of strength in a simple pressure of 4.2 MPa or more (FNM CR no. 00489-2002-240-S-2633). This geotechnical type is interpreted as clays with strength characteristics secondly influenced by the earlier intensive under-ground activity. It is not possible to rule out fracture permeability here, especially in the vertical direction. In any case, it is a geotechnical type that is present in the model to a minimal extend. These are positions that were

Tab. 2: Average geomechanically-physical properties of overlay complex clays.

Parameter		Placement depth [m]			
		0-25	25-40	40-70	>70
Natural moisture	W_n (%)	28,1	19,4	19,0	16,9
Fluidity limits	W_l (%)	64,4	57,7	56,6	49,8
Volumetric weight	γ_n [kN.m^{-3}]	19,5	20,8	21,2	21,5
Degree of consistency	I_c	1,02	1,17	1,16	1,18
Internal friction angle	φ [°]	17,0	18,6	18,6	17,5
Cohesion	c [kPa]	40,0	88,0	162,0	253,0

either mined in the past or are now completely covered by a dump. They are below the lake water surface level and do not create any side slopes or bottom of the lake at all.
In addition to the aforementioned basic geotechnical types, which are dominant in the locality, we define a few other geotechnical soil types that may partially affect the stability analysis.

Q – The quaternary is represented by quartet gravel and gravel sand (S4 to G4) with varying degrees of loam, which represent a relic of the original rock cover. Genetically, these are various relics of the prouvial, fluvial and eolitic sediments.
From the point of view of stability analysis, they represent a thin top layer, which does not have a significant influence on stability, but is important from the point of view of groundwater flow and its inflow to the assessed slopes. Strength characteristics and permeability are inconsistent and for the specification of the geotechnical model, we recommend to carry out an additional engineering-geological survey.
Continuous relicts of the Quaternary are left almost all around the lake, with the exception of the Kočičí Hill and Střimice area, where they were almost completely mined.
The following geotechnical soil types are part of the model, but are understood as its bases, i.e. the level beyond the reach of possible slope deformations.

TUF –Tertiary volcanic rocks, most often of the character of tuffite clays, which act as an insulator. The unweathered volcanic rocks, which are deposited deeper, have the character of rock to semi-rock with possible fissure permeability. Tuffite clays are spatially present in the geotechnical model. They form a large part of the lake slope at the Kočičí Hill.

PJIL – underlying sandy clays and clay stones of Miocene age and C - coal, coal seam, or rather say its relict. It is affected by earlier underground mining to a varying degree and it represents a basal geotechnical type of model. PJIL are pulled up to the surface in the area of the Kočičí Hill and the Hněvín Hill and directly form the slope of the lake.

8.3 Dump slopes

Characteristic properties of slopes from clay dump material

The geo-mechanical properties of clay dump material differ significantly from the initial soil properties in the original overburden. This is caused by stress-strain changes during which the originally compacted soil is first transformed into a loose material. At first, the dump material has relatively loose position of individual pieces (lumps). Later, due to the increase in normal stresses and the associated consolidation processes, it gradually turns into compact clay of varying consistency, depending on the moisture conditions. Due to the long-term influence of stress and water, the clayfill dump material transforms back into more homogeneous soil and its most important feature is their double porosity (Mašín et al. 2005). The stress-strain changes take place gradually and are influenced by (Dykast 1993):

- before the excavation of the overburden by gradual lightening of the massif (change of geostatic stress),
- during the excavation by a sudden change of the structure,
- during transport from the excavator to the stacker by temperature and humidity changes, vibration, turning and spreading,
- during the loading the influence of different technological processes, different fall energies, etc. is applied,
- after loading into the dump due to moisture and stress changes over time.

The freshly poured clay dump material is characterized by a lumpy structure. Other characteristics of dump materials result from this basic characteristic:

- high compressibility
- variability of geo-mechanical properties over time and in dependence on changes (Dykast, 1994):
  - normal pressure
  - moisture

The lumpy character of the dump material means that, in addition to the porosity of the grown pieces (lumps) in the range of n = 20-40 %, the dump material also has a similarly large void space m = 20-40 % (ratio of the volume of gaps between lumps to total volume of dump material). With increasing thickness, first the number of voids gradually decreases. At this stage, the lumps are wedged, twisted, and crushed. Up to a thickness of 40 to 50 m, the fresh dump material is permeable. It is therefore prone to settling. The settling rate in this initial phase is considerably more dependent on changes in humidity, for example due to atmospheric precipitation, rather than time. Only after minimizing the voids at depths of > 50 m does the process of classical filter consolidation occur also with the reduction of porosity. This process is strongly time-dependent. It gradually slows down at a constant level of normal load (Dykast, 1994).

Changes in properties of dump materials during transport

During transport by conveyor belt transport, the strength parameters of transported dump soils are reduced. The shear tests showed mainly a decrease in the cohesion values (by 50 % on average) and a slight decrease in the intergranular angle of internal friction. However, this decrease of shear parameters occurs only in those transported soils, which were primarily destroyed while still in a mature state as a result of belonging to the so-called regelation zone (the upper part of the overlying clays, which underwent intensive regelation processes during the Pleistocene period and is chemically and mechanically damaged). Claystone with a high degree of diagenetic hardening is subject to these changes only exceptionally.

Other unfavourable properties of the transported clay dump materials may be adhesiveness and slaking. Both properties can have a very negative effect on the transport performance of rail as well as belt transport. Sometimes the adhesiveness of soils leads to clogging of dumps and heaps and also to a forced shutdown of the whole technological unit (excavator - long-distance belt conveyor - stacker).

The susceptibility of clays to adhesiveness is most dependent on the petrographic type of clay and the plasticity index. Sticking occurs when the so-called critical clay moisture is reached (Dykast, 1993).

Lumpiness of dump material

The lumpiness of the dump material depends mainly on the natural disintegration of the compacted soil according to the separation planes and on the method of disintegration. It depends, for example, on the shape of the buckets and the thickness of the chip to be removed. On the first overburden sections, the lumpiness is minimal with the length of the edges of individual pieces exceptionally up to 400 mm. On the contrary, on deeper overburden sections, it is often necessary to modify the lumpiness with rounders or crushers (the occurrence of pieces over 1 000 mm).

Shear strength of dump material

The value of shear strength of clayey dump materials cannot be derived from shear strength determined on compact samples. This finding manifests itself especially in the cohesion investigation, when not only the values themselves are often found to be divergent, but also the other dependencies on other variables. For example, in general it can be stated that: the more cohesive the mature soil of the overburden, the less cohesive its dump debris.

The dump debris from the overburden bench of the northern part of the Jan Šverma and the ČSA mining fields (that means from central part of the Most Basin) showed for example a maximum cohesive value of 40-50 kPa usually when they came from a claystone from an original depth of up to 40 m (depth of the so-called geotechnical horizon).

The minimum cohesive values of 15-20 kPa were measured in the case of claystone dump material with the original deposition at a depth of around 100 m.

On the contrary, the values of the internal friction angle in the tested dump material approximated the values determined even at the intact compact samples. Both, the peak and residual values showed quite apparent dependency on the depth of the original deposition. The peak values φ increased with this depth from 14° to 32°, the residual values φ_r were from 5° do 20°.

The shear tests of clayey dump materials under normal pressure up to 3 MPa brought new results. After exceeding the normal stress in the shearers 1-1.5 MPa (depending on the type of soil), which corresponds to geostatic pressure at depths of 50 to 75 m, there is a collapse of their structure.

This phenomenon is accompanied by a decrease of cohesiveness up to twice the amount. This phenomenon is observable in clayey dump materials with a maximum moisture content of 25-30% (in dry matter). If the humidity (natural or additionally gained) is higher, the described phenomenon shifts to a lower pressure range or alternatively disappears completely. To induce this behavioural change of the dump material, a 5-7 % moisture increase in the sample is sufficient. In the whole investigated range of normal stress 0 to 3 MPa the dump material then shows low values of the internal friction angle, within the range of only 2-6°.

The difficulty of the laboratory investigation of shear strength of clayey dump material arises from behavioural changes at high values of normal stress. At low stress the dump material is loosy, the total shear strength parameters are practically identical to the effective ones (Dykast, 1993). When increasing the normal stress to a certain limit (1-1.5 MPa), there seems to be an appearance and then increase of the porous pressure of air and water. At the moment of the next load, after the disappearance of all the voids in the dump material, the whole increment in the normal stress is only induced by water in the pores. The shear stress capable of mobility in the loose material practically no longer increases (Dykast, 1993).

Changes of characteristics of dump material in time, after loading the dump

The volume mass of dump material immediately after loading into the dump is around 1.500 kg.m^{-3}, with voids volume within the range from 20-40 %. Depending on the normal load the volume mass increases. When the base of the dump is 150 m thick, the volume mass of the dump is about 2.000 kg.m^{-3}. Thus, the loosening values resulting from the ratio of volume mass of the soils in the mature and poured state can range from 1.40 to 1.05 (Dykast, 1993). The average loosening coefficient of the current dumps in the Most Basin is about 1.15.

Moisture changes

The moisture of the clayey dump material gradually increases after loading into the dump body. It is desirable that the moisture build-up should be as low as possible since it is directly related to the gradual degradation of shear strength. Laboratory tests with samples of moisture dump material clearly showed up to 50 % reduction of shear strength if their moisture content was artificially increased by 5 to 7 % (Dykast, 1993). The reason for the gradual progress of soil moisture in the dump is not only the infiltration of atmospheric precipitation. The lump-like structure of the dump soils with an initial volume of voids of about 30% is an environment permeable not only for water but

Tab. 3: Ranges of filter coefficient values (Dykast, 1993).

Origin of loose material	Filtration coefficient
On the surface of dumps	$9 \times 10^{-4} – 4 \times 10^{-5}$ m.s^{-1}
In depth 10-50 m (in boreholes)	$2 \times 10^{-5} – 6 \times 10^{-6}$ m.s^{-1}
In greater depth (laboratory simulaion)	$1 \times 10^{-6} – 4 \times 10^{-11}$ m.$^{s-1}$

also for air. It can then, especially in the summer months, precipitate its moisture on the surfaces of relatively cooler pieces of soil. Barometric pressure changes have been detected in macro pores of dump material down to 30-50 m from the surface of the dumps (Dykast, 1993).

Another cause of the increase in moisture in the dumps may be underwater in the subsoil layers that were not drained beforehand. After loading the dump, water can be pushed vertically upwards into the dump body. Crevice water (especially in the case of internal dumps) may have a similar effect. At that time, it is suitable to continuously drain the dump at the base - by drainage, underground pumping station, etc. Drainage is required until the dump body that is in contact with the inflows becomes impermeable to water.

The surface layer of dumps is exposed to the greatest variation of humidity and temperature conditions. Therefore, there are also noticeable changes in volume that are not related to consolidation. This relates to the surface layer of the dump to a depth of about 5 m. Changes are not only dependent on random (immediate) meteorological conditions, but their regular periodicity was also detected (daily, annually). E.g. the measured annual amplitude of the volume changes was ± 4 mm in diameter (Dykast ,1994).

Changes in permeability

The permeability of the dump soils is manifested by the infiltration and capture properties of the dump surface. Dumps freshly poured or only few years old usually manage to accumulate most of the precipitation. This is due to a large volume of voids, as well as negative pore pressure (vacuum) of fresh clay stones, caused by a sudden relief from the original geostatic stress in the overburden (Dykast ,1993).

Older dumps usually possess already reduced infiltration capacity. However, in this case, drilling surveys have revealed several groundwater horizons (aquifers), very often with buoyancy effect. This phenomenon is caused by the obvious inhomogeneity of the dump, especially in the vertical direction. The main causes are time intervals in the construction of individual dump berms. The surface of the previously dumped berm usually has an interface of low permeability as a result of weathering, eventually compacting caused by travels of mining technology. Practically impermeable are also the kneaded positions of the dump along the former shear planes. On the other hand, the positions of sand, seams, burnt clays, etc. are well permeable.

The coefficients of filtering of clayey loose material in the natural deposit on dumps are determined in situ by infiltration testing, in a laboratory using a permeameter.

The value of the coefficients of filtering 1.10^{-6} m.s^{-1} is generally considered to be the limit of the technical (gravitational) drain ability of the dump. If the loose material is still permeable for water, it can also have the settling ability. During the tests of settling ability in edometers, the detected value of settling ability for the hardest claystone in CSA open-cast mine was 4.5-6.5 (for δ =1,0 MPa). At normal pressures of 2.5 and 3.5 MPa, the loose material was already impermeable, hence unable to settle. Swelling was also detected in the same type of material and was only registered at a low pressure of δ =0.2 MPa when it was 1.6 %.

Changes in deformation characteristics

The settling of the dump surface is a summarized exterior manifestation of various deformation processes taking place inside the dump body, possibly even in a certain layer of the subsoil. Deformation changes begin at the start of the pouring of the first berm on the subsoil. The first berm is first compressed by itself only due to its own gravity, later gradually from the burden of the gravity of other berms. Other stages show similar development.

During the gradual increase in thickness of the dump, its individual elements (lumps) under-go significant changes. The changes are time dependent, but their size and speed depend largely on the possibility of water saturation. The freshly formed claystone lumps have a firm to solid consistency. As a result of lightening during mining, the pores of the lumps carry a negative pore pressure that is why the lumps absorb moisture easily. Initially, a loose material with considerable voids (up to 40%) becomes almost impermeable to water and air at higher normal pressures (1-1.5 MPa). The time immediately before this happens is decisive in terms of the following properties of the loose material. If the deformation processes are carried out under a limited supply of water, they are caused by crushing the lumps on the contacts and after further decrease of voids, the air gets locked in the remaining voids. Such cemented material is already very impermeable for water. There is no significant deterioration in the strength and deformation characteristics of the soil in this case.

Conversely, the worst properties, the loose material can gain, is when all the voids are filled with water. In the case of dry loose material, the danger comes from the external water, as the loose material is initially very permeable. If the loose material has increased moisture already during loading into the dump, then usually the water gradually forced out of the lumps is sufficient to fill the voids. Although, gradual kneading will homogenize the soil, but as a rule at the cost of obtaining a soft and porridge-like consistency. Dump soils with such altered properties do not allow further increase of the dump thickness. At the moment of another berm being loaded, all of the increment of the normal load is transferred by the porous water with zero shear strength. The dump thus becomes unstable due to the rapid increase of active forces with simultaneous stagnation of passive forces. Most of the dump collapses were caused by this effect in the past.

The settlement of the surface of dumps with a predominance of soils with soft to porridge-like consistency can be less than usual, but only if the soil is prevented from expanding later-ally.

This special case can only occur at the internal dump, located in a definitely angled mine (Dykast, 1993).

Material (geotechnical) types of the geotechnical model

The dump loose material is a complicated heterogeneous environment that cannot be reliably modelled. For this reason, for the stable calculations of large spoil heap slopes, the division of the loose material into several separate geo-technical units is used, reflecting the basic geo-technical properties and laws of the loose material depending on its material composition and depth of deposition.

Due to the fact that in the recent past, there has been no detailed geo-technical survey of dump sites carried out, the individual geo-technical units were determined on the basis of analogy from other dump sites of the Most Basin.

NS – a non-consolidated dump material which partially retains its pseudo-gravel character (double porosity soil), resulting in relatively high internal friction angle values. This approximately 10-20 m thick part of the dump is permeable with a dynamic regime of groundwater, which leads to permanent weakening of the intergranular bonds of shear strength decrease in permanent aquifers. In general, the NS dumps of the Most Basin can be characterized by values of φ 20° (which may, however, significantly decrease in permanent aquifers) with a highly variable value of c.

TV1 – the dump body 1, generally considered as a stable ump material, which is not influenced by climate factors, it is at a certain stage of consolidation and can be considered as an impermeable environment. In general, the TV1 dumps of the Most and Sokolov Basins can be characterized by an increase in the c value with depth. The c values determined by the CPT method are 20 kPa.

TV2 – both of these subtypes of TV1 and TV2 show very similar values of the internal friction angle (depending on the origin and type of soil), but TV2 exhibits a relatively significant decrease in the c value. The c values detected by the CPT method are 20 kPa, and also often fall far below 15 kPa. The continuous thickness of both TV1 and TV2 is disturbed by various weaknesses - inserts of heterogeneous materials, which may be aquifers (often with tense water surface levels), but may also mix with one another.

Anisotropy – positions, which appear to be randomly located in the loose material, are a con-sequence of the manner and nature of soil loading during the construction of the dump. The thickness of these weaknesses can be in the order of dm to the first meters. The CPT method is a reliable way to identify them. Strength parameters are usually close to residual values, and the material is also usually auriferous at these positions, which create anisotropy areas and represent potential predisposed shear areas (Dykast 1993).

TT –the position of the sealing bodies at the bottom of the pit. These are relatively low-strength bodies that were laid on the bottom of the pit to seal it. These clays have been shown to be impermeable with $k = 1.10^{-7}$ to 8.10^{-11} $m.s^{-1}$. In terms of volume, these are negligible bodies, but their impact on HPV may be significant, so that is why they were included in the model. A specific feature is the Konobrže sealing body, which, however, has an enormous thickness and from the perspective of the model is on the border of TT and TV1 / 2.

Contact – with the weakest strength at the base of the dump, where the soil strength decreases to the level of residual parameters in almost the entire area. Soils are in permanent contact with water flowing on the ground. In places where the thickness of dump soils reach-es 80-100 m, their structure could have collapsed. The extent and depth of soil degradation shall be verified by the CPT method (Šípek and Burda, 2015).

The above-described model is schematic, in real environment, the individual layers alternate, and even their order can be reversed in several repeating sequences. To create a credible model, we recommend that you follow this classification, only adjust it to the actual dump structure. The only way to determine the internal structure, including any potentially degraded soils, is CPT. Since the results of the comprehensive CPT survey are not available at present, the model is based on a general analogy valid for the dumps of the central part of the Most Basin and Sokolov Basin (Šípek and Burda, 2015).

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