Geological evaluation of brown coal reserves at the Hrastnik mine – RTH, Rudnik Trbovlje-Hrastnik

Geološka evalvacija zalog rjavega premoga na območju jame Hrastnik - RTH, Rudnik Trbovlje-Hrastnik

Željko Vukelič[1,*], Bojan Klenovšek[2], Ladislav Placer[1], Vladimir Malenković[3], Evgen Dervarič[1]

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, SI-1000 Ljubljana, Slovenia
[2]RTH, Rudnik Trbovlje – Hrastnik, d. o. o., Trg revolucije 12, SI-1420 Trbovlje, Slovenia
HTZ, I.P., d. o. o., Partizanska 78, 3320 Velenje, Slovenia

*Corresponding author. E-mail: zeljko.vukelic@ntf.uni-lj.si

Received: June 3, 2009 **Accepted:** December 14, 2009

Abstract: As provided by the Act on the gradual closing down of the coalmine Trbovlje-Hrastnik and on the development restructuring of the region, until the end of 2009 Rudnik Trbovlje-Hrastnik (RTH) will continue to supply coal to the thermal power plant Termoelektrarna Trbovlje (TET) in the planned annual volume of 0.6 million tonne. RTH continues to hold significant coal reserves of national importance to Slovenia, which might we worth exploiting at some point in the future. The management of the coalmine has made every effort to ensure continued coalmining at RTH after 2009 at the existing mines Ojstro and Trbovlje (Field III and Field Plesko), at the already closed down mine Hrastnik. This paper provides an overview of the results of the study "The Legitimacy of the Extraction of Remaining Coal Deposits at the Mines Ojstro and Trbovlje After 2009" – Stages 2 and 3, with the emphasis on the evaluation of coal deposits at the mine Hrastnik. The study was undertaken by the Faculty of Natural Sciences and Engineering, Ljubljana, in collaboration with the Economics Institute at the Faculty of Law, Ljubljana, and RTH associates.

Original scientific paper

Izvleček: Rudnik Trbovlje-Hrastnik (RTH) bo skladno z zakonom o postopnem zapiranju in razvojnem prestrukturiranju regije do vključno leta 2009 dobavljal premog Termoelektrarni Trbovlje (TET) v predvideni količini 0,6 mio. ton na leto. RTH še vedno razpolaga z znatnimi in za Slovenijo pomembnimi zalogami premoga, ki jih bo treba v prihodnje smiselno izkoristiti. Vodstvo rudnika si prizadeva, da bi eksploatacijo premoga v RTH nadaljevali tudi po letu 2009, in sicer iz že obstoječih jam Ojstro in Trbovlje (III. polje in Plesko polje) ter iz že zaprte jame Hrastnik. V tem prispevku so predstavljeni rezultati študije: »Upravičenost odkopavanja preostalih zalog premoga v jamah Ojstro in Trbovlje po letu 2009« – 2. in 3. faza, s poudarkom na evalvaciji zalog premoga v jami Hrastnik. Študijo je izdelala Naravoslovnotehniška fakulteta v Ljubljani v sodelovanju z Ekonomskim inštitutom pri Pravni fakulteti v Ljubljani in s sodelavci naročnika RTH.

Key words: brown coal, coal reserves, geological evaluation, research drilling
Ključne besede: rjavi premog, rezerve premoga, geološka evalvacija, raziskovalno vrtanje

Introduction

The geological evaluation of the remaining deposits of brown coal at Hrastnik focused on reviewing the updated brief on the categorisation, classification and calculation of the resources and deposits of brown coal in the RTH mining area as at 31st December 2002 (Mitrevski & Bravec, 2003). It includes the evaluation of the level of observance of geological exploration of the coal deposit using drill holes and the level of observance of results of structural and geological analyses of the Hrastnik coal deposit creation and development from the period of intensive geological explorations between the years 1982 and 1991. In accordance with the Act Regulating Gradual Closure of the Trbovlje-Hrastnik Mine (RTH) and Development Restructuring of the Region (2000), the closing of underground mining facilities began even before some hypotheses on geological structure and coal reserves had been verified. Considering the reassessment of the structural and geological model used in the updated brief on coal reserves as at 31st December 2002, the geological evaluation will give a general assessment of the relevance of further plans for additional geological

exploration and indicate the most optimal direction and level of further exploration, which might result in later preparation of an exploration plan for the new categorisation, classification and calculation of the resources and deposits of brown coal in the Hrastnik area and an assessment of a repeated beginning of brown coal exploitation in this traditionally mining area.

Geological exploration of the coal deposit in the Hrastnik area

Apart from the associates employed by the coalmine's geological department to monitor the preliminary works and surveys carried out at the coalmine on an ongoing basis, vital research over the past fifty years was undertaken by Kuščer (1967) with his core work Zagorje Tertiary, Gregorač (1975) who focused on the hydrogeology of the mine Hrastnik, Kuščer & Mitrevski (1979) who researched the geology of the boundary area between the mines Hrastnik and Dol, Uhan (1991) with his work on the geochemical properties of coal in the central part of the deposit, and Placer who carried out a structural-geological analysis between 1982 and 1991. In the above mentioned period Placer completed an extensive detailed geological mapping of the surface area between Moravče and Laško, and surveyed and mapped the mine facilities and the cores of exploration drill holes. Placer published the major findings of the survey and mapping of the surface area over the mines Hrastnik and Dol in 1987 in the brief "A Geological Structure Survey in the Dol-Hrastnik Area, Part II". In the three-year period (1985–1987), geologists surveyed roughly 3,200 metres of roadways, access tunnels and longwalls, and drilled eleven structural exploration drill holes in the total length of approximately 1,500 m (Uhan, 1987). The geological data obtained in the course of the above mentioned surveying and mapping of mine facilities and exploration drill holes yielded more detailed information on the structure of the "south wing" of the central part of the Hrastnik mine at and under Horizon VII. Building on the results of all previous surveys and having reviewed and processed the entire documentation held by the coalmine, Placer preformed the most comprehensive structural geological analysis until that time, and explained the tectonic development of the coal deposit. When it comes to the evaluation of remaining coal reserves in the Hrastnik area, certain structural geological questions remain unanswered; this primarily refers to the continuation of the coal seam under the hypothetical Hrastnik thrust fault. The other set of debatable questions concern the geological structure of the Eastern Underground Deposit where the continuation of the southern coal seam downwards has been established by exploratory drill holes at Brnica.

Geological structure of the Hrastnik coal deposit

The Zasavje coal-rich tertiary layers (the so-called "Trbovlje layers) sedimented on the Triassic dolomite or pseudozilian slate substrata are composed of lower clastic, predominantly clay, footwall layers, coal and upper, hanging wall marl layers.

The sedimentation of the lower segment of the coal-rich layers begins with clastic sediments in paleo-morphologic depressions. Due to filling of the paleorelief, the thickness of these predominantly clay layers is highly variable, amounting up to 80 m. The upper parts of footwall clay are rich in organic component, and the black clay (the so-called "black footwall") gradually passes into clay coal.

The coal layer in the sedimented thickness of 20–25 m, which can be thinner or thicker due to tectonic repetitions in the form of scales and different inclinations in individual cross-sections, is characterised by the lower part containing more clay, and the upper, cleaner part containing more vitrinite substance. In the medium part, there appear centimetre- and decimetre-thick inserts of volcanic ash, clay and, most often, lime sandstone. With the increasing depth, there occurs an increasing number of decimetre-thick layers of lime sandstone or so-called carbonate inserts, which have, at the point +70 and the descending angle 45–70° southwards, achieved the total thickness even exceeding width across 15 m of the long wall at the field A between the ordinates 4550 and 4800 (Figure 1).

The lower part of coal layer was sedimented in the reduction environment and is mineralised with sulphides. The upper semiterrestic and limnic part is predominantly mineralised with carbonates, and the edge areas of paleo peat bogs passing to the hanging wall marl, it is mineralized with sulphides

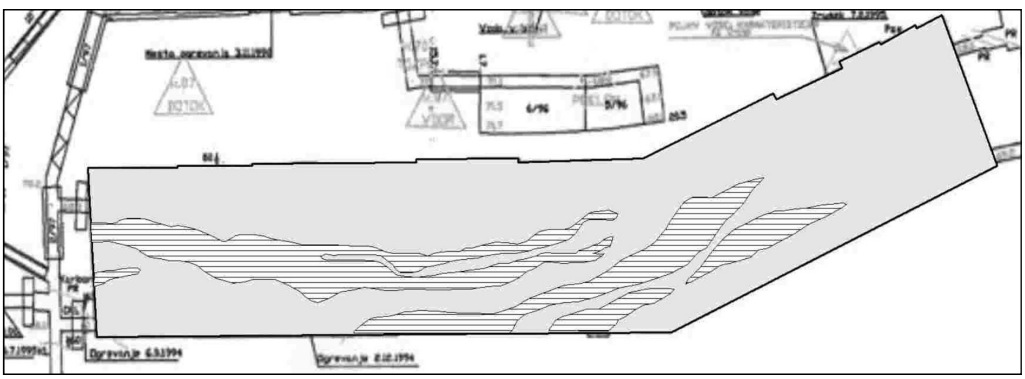

Figure 1. Carbonate layers (hatched) at point +70, Field A, mine Hrastnik

(Uhan, 1991). Depending on the type of mineralisation of final sedimentation sequence of the coal layer, its position in the former sedimentation bed could be presumed. Unfortunately, such explorations have not yet been performed for the Hrastnik coal deposit; however, some data is available on the ratio of mineralization types in the upper part of the coal layer in Trbovlje (Neža) and in the profile approximately 800 m to the east, in the Ojstro mine at the point +135, while some larger distance from the edge of the former sedimentation bed is presumed for the profile at Lopata (ordinates around 2950).

The upper border of the coal layer with the hanging wall marl is more distinctive than the lower one. Where the hanging wall marl contains abundant organic component beside coal, such layers were named "black hanging wall". In the upward direction, this brackish thin-layer marl gradually turns to brown and grey until it borders the Oligocene layers. Similarly to the footwall clay, the hanging wall marl also achieves thicknesses of approximately 80 m. In the marine environment, the Oligocene marine clay ("sivica" in Slovene) gradually sedimented above the hanging wall marl. It is characteristic for being massive, non-layered, marl-like and swellable. The average thickness of this clay sedimentation is 30 m to 50 m, or even more in some locations.

Discordantly on top of the Oligocene marine clay, the sedimentation of Laško layers composed of lithotamnic limestone, marl and sandstone begins in the area of the Hrastnik coal deposit without sandy Govce layers. The thickness of these sediments can measure 100 m or more. On top of the Laško layers, there are discordantly sedimented Sarmatian layers of various thicknesses: conglomerate, sandstone, siltstone and clay completing the sedimentation of the Zasavje tertiary bed.

The coal deposit is shows considerable tectonic deformation. The western part of the coal deposit is characteristic for relatively simple structure of the coal layer of the "southern part", but the eastern part passing into the thrust structure of the Eastern Underground Deposit is more complicated in structure.

In the western part of the coal deposit, an important factor for the estimation of reserves is the structure of the inclined, southwards leaning coal layer anticline. Its northern wing, including its core, is formed of inclined thrust scales that are often parallel to the axis plane of the fault. Tectonic deformations of such type are very rare in the southern wing of the anticline. They are presumed to be located only near the alleged Hrastnik thrust fault indicated by geological data from the drill hole Hj-2/75 and Hj-6/85 as well as the data

obtained in the course geological mapping of the western part of the drift at Horizon VII. The coal in the southern wing of the above mentioned anticline was explored, in the years 1985–87, by ten drill holes, three of which drilled through the tectonically deformed coal layer. The system of youngest tectonic deformations of the Hrastnik region, the Dinaric oriented (NW-SE) and cross-Dinaric oriented (NE-SW) faults is predominant in this area. Dinaric faults usually occur in intervals of 100 m to 150 m, occasionally less, and can be followed in the layout from the footwall to Laško and/or Sarmatian layers. Apparent strike slips along these faults can, in vertical N-S cross sections, exceed 40 m and thus strongly affect the continuity of the thickness of the coal layer under Horizon VII and VIII (Figure 2).

To the east of this location, the coal deposit structure is significantly more complicated, making the assessment of reserves a significantly more demanding task.

In relation with the passing of the Hrastnik structure into the Dol structure, tectonic deformations of the coal layer on the Blato anticline and the Dol syncline play an important role. In general, a steeper and tectonically thinner

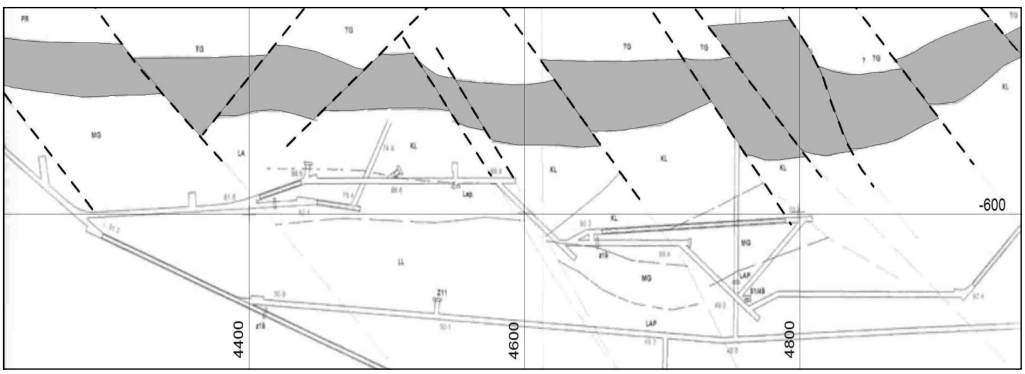

Figure 2. A structural geological prognosis of the coal seam in the southern part of the mine Hrastnik at Horizon VII

Table 1. Off-balance coal reserves at the mine Hrastnik according to the calculations provided in the updated brief on coal reserves as at 31st December 2002

Coal reserve categories	A	B	C_1	C_2	
Southern part	134 000	4 346 000	10 269 000	-	
Corner field	229 000	244 000	72 000	-	
Eastern Corner Field	77 000	455 000	2 378 000	6 272 000	
Total Hrastnik	440 000	5 045 000	12 719 000	6 272 000	24 476 000

coal layer is expected in this part of the coal deposit.

Geology-related problems in coal exploitation can be expected particularly in relation with tectonics-related thinning and discontinuities of the coal layer and increasingly thicker sedimented carbonate barren inserts in the coal layer.

Updated brief on coal reserves as at 31st December 2002

Update of the brief on the categorisation, classification and calculation of the resources and deposits of brown coal in the RTH mining area as at 31st December 2002 is based on the Brief on the coal reserves in the RTH mining area as at 31st December 1997. Changes in the assessment of reserves contained in the above mentioned update are related to the closure process based on the Act Regulating Gradual Closure of the Trbovlje-Hrastnik Mine and Development Restructuring of the Region (Official Gazette of the Republic of Slovenia, No. 61/2000). Within the framework of the 2002 update, all current coal reserves in the Hrastnik mine according to the 1997 brief were assessed as off-balance reserves in categories A, B, C_1 and C_2 (Table 1).

Based on the Rules on classifying the reserves of hard mineral substance in classes and types and on the records thereof (Official Gazette of the SFRY, No 53/79), the Hrastnik mine has been classified in the third group and second sub-group. Individual categories of reserves were calculated pursuant to the prism-method on the basis of parallel geological profiles north-south in the scale 1:2000. For the Hrastnik mine, the volume mass of 1.45 t/m^3 of coal was observed and 25-percent exploitation loss was taken over. When calculating the coal reserves in the Hrastnik mine between the ordinates 4050 and 5350, the occurrence of carbonate inserts in the coal layer, increasing with depth, was considered. The calculated coal reserves have therefore been reduced by 25 percent in this part of the mine. According to the indication in the brief as at 31st December 1997, the parameters of average quality of the reserves are the following: 20.71 percent of moist, 21.17 percent of ash, 2.38 percent of total sulphur and the calorific value of 14.78 MJ/kg of coal. In the coal samples obtained from structure drill holes during the last period of more extensive exploration drilling in the Hrastnik mining area, a slightly lower calorific value was assessed as well as ash contents higher by a few percent.

In the period from 31st December 1997 to the update of the brief on the categorisation, classification and calculation of the deposits as at 31st December 2002, 120 drill holes in total length of 3,421 m were drilled in the Hrastnik mine between the points +45 and 0; however,

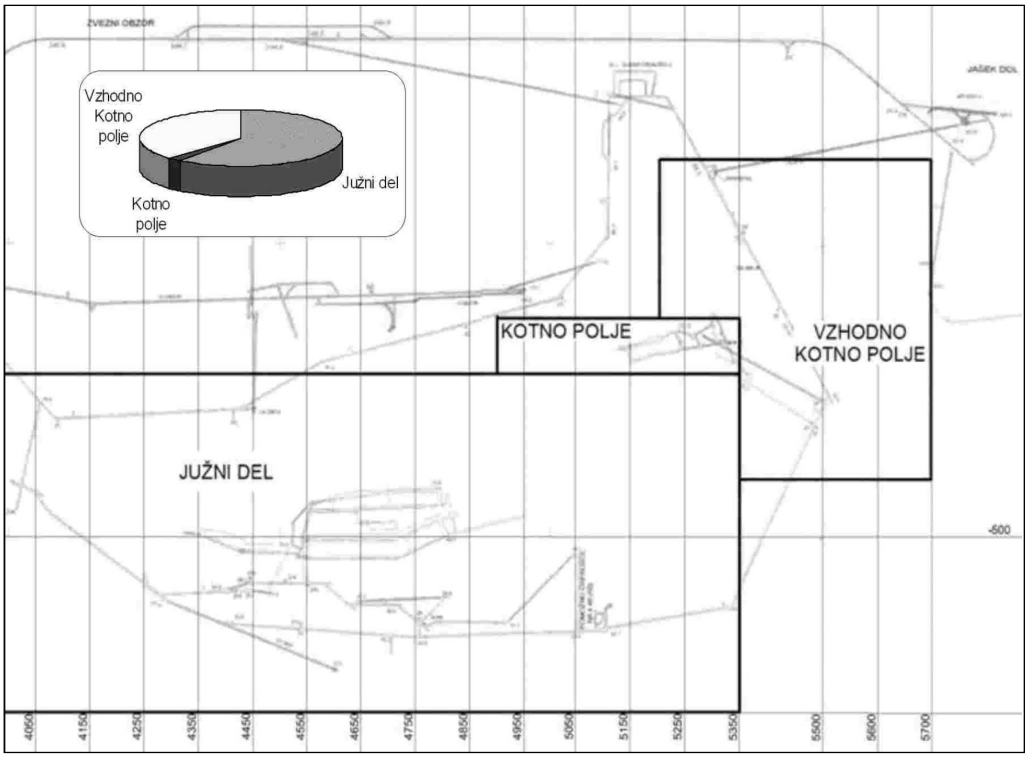

Figure 3. The main mine roadways at the coalmine Hrastnik and a sequence of geological cross-sections N-S used in the updated brief on remaining deposits (2002) for the purpose of determining actual reserves, and the share of deposits at the Southern End, Corner Field and Eastern Corner Field of the mine Hrastnik

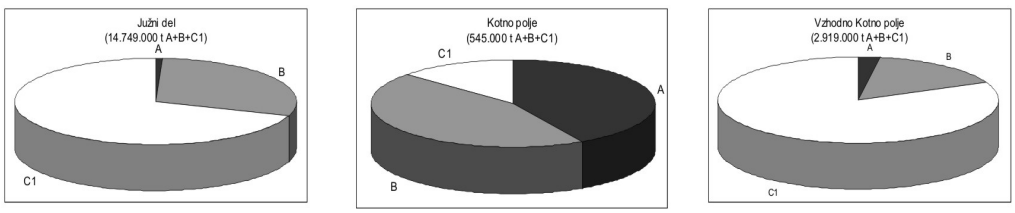

Figure 4. Coal deposits as at 31st December 2002 in the Southern End, Corner Field and Eastern Corner Field of the mine Hrastnik

the purpose of this drilling was predominantly to determine the boundary between coal and the adjacent rock mass to design exploitation levels. In the period between the years 1997 and 2002, there was no structural and geological

drilling, the results of which could influence the calculation of reserves.

The A+B+C_1 coal reserves in the Hrastnik mine (off-balance), the amount of which has not significantly changed since the end of the year 1997, represent precisely one third of the entire (both balance and off-balance) A+B+C1 coal reserves for RTH, the Trbovlje-Hrastnik mine (53,893,000 t). In addition, further sources of the C_2 category (6,272,000 t) have been recorded in the Eastern Corner Field in the mine Hrastnik (Figure 3).

The calculation of coal reserves in the Hrastnik area between the ordinates 3700 and 5350 is based predominantly on the data obtained from exploration mine drilling and mapping of mine roadways between the years 1985 and 1998 and from surface drilling holes in the Brnica area. The reliability level of this largest part of reserves in the Hrastnik mine is high. Exploration drilling for the purpose of recategorisation of C1 reserves to B reserves poses any risks here, but no significant changes in quantity are to be expected. More risk lies in exploration drilling for the purpose of determining the continuation of the coal layer beneath the alleged Hrastnik thrust fault where the cal reserves have not yet been recorded. The exploration risk is also increasing towards east where the coal reserves of the Eastern Corner Field to the ordinate 5700 have been determined on the basis of only a few drill holes and a strongly simplified structural geological model. From the ordinate 4900 towards east, the reliability of the estimation of coal reserves is considerably lower. Exploration drilling in this area could undoubtedly improve the categorisation, but due to current structural geological simplifications in the updated brief on reserves as at 31st December 2002, a reduction in quantity of currently recorded coal deposits and resources is not excluded.

Structural view on the extension of the coal seam in the Hrastnik mine beneath the exploitation level upon the closure of the mine

The opinion on the extension of the coal seam in the Hrastnik mine beneath the exploitation level upon the adoption of the act regulating a gradual beginning of closure of the mines Trbovlje and Hrastnik in the year 2000, was elaborated on the basis of the Preliminary analysis of the structure of Ojstro and Hrastnik (Placer, 1988). Additionally, it includes the data on the structure of the Laško syncline and the reconstruction of the coal deposit in Upper Oligocene (Placer, 1994) and two published articles, one on the structure of the Hrastnik coal deposit (Kuščer & Mitrevski, 1979) and one on the regional structure of the Posavje

folds (Placer, 1999). The last situation in the mine prior to its closure has been derived from the Update of the coal deposits and resources in the Hrastnik mine as at 31st December 2003 (Mitrevski & Bravec, 2003).

The Laško syncline

From the geological point of view, the Zasavje coal mines are situated in the Laško syncline, the upper part of which has been named the Laško tertiary depression with a productive coal seam. In the tectonic sense, the syncline is divided in three large structure blocks separated by the Jug and Hrastnik inclined strike slip fault. The Jug fault lies in the direction SW-NE and runs along the western edge of the coal deposit in Trbovlje and across the town. The Hrastnik fault lies in the direction NW-SE and runs through Hrastnik. The following mines are situated in individual structure blocks: Strahovlje, Loke, Kisovec, Zagorje-Kotredež and Orle in the western block, Trbovlje and Ojstro in the central block between the Jug and Hrastnik fault, and Hrastnik, Dol, Krištandol, Brezno, Huda jama and Mihael in the eastern block.

Local coordinate system

The Zasavje coal mines use the local coordinate system with the reference point at the height point 425.5 above the living quarter of Vode in Trbovlje. The productive area of the Hrastnik coal mine lies between the coordinates y = (+3500 and +5700), presumably extending to 5900 as evident form the projection in Figure 1, and x = (–700 and +200).

Structure of the Hrastnik coal deposit

The structure of the Hrastnik coal deposit is evident from the existing transverse profiles on the coordinate y (abscissa). However, there are two concepts regarding the conditions in the depth and in the eastern part where there is little or no mining activity. The first one was set by Kuščer and Mitrevski (1979) and the other one by Placer (1988). The substantial difference between them lies in three structural questions. The first one is related to the existence of the Hrastnik thrust fault introduced by Placer. According to Placer, the thrust is supposed to have cut off the coal seam, while according to Kuščer and Mitrevski, the coal seam extends in the depth direction. The second question refers to the difference in understanding the extension of the internal thrust panes towards east, and the third one is related to the interpretation of the connection between the Hrastnik and Dol structure, i.e. the relation between the Blato anticline and the Hrastnik and Dol structure.

The significance of different aspects lies in the fact that according to the concept by Kuščer & Mitrevski, the coal deposits and resources are larger than the deposits according to the concept by Plac-

er. The latter model is presented here. In the calculation of updated reserves of 31st December 2003 (Mitrevski in Bravec), the authors took into account the existence of the Hrastnik thrust, while the conditions relating to the second and third point of differences in concepts were as described by Kuščer & Mitrevski. The conditions in the border area between the Hrastnik and Dol structure are therefore strongly simplified and idealised, and probably even incorrect. The above applies to the area of profiles from y = (+5500 to +5700).

The brown coal seam in the area of the Hrastnik coal mine lies in the north-eastern wing of the Hrastnik fault which has cut through the originally uniform seam, separating it in the Ojstro and Hrastnik part. The economically most important part of the Hrastnik coal seam, the so-called main seam, with its medium-steep descent towards south and limited in the north by thrust faults in the direction W-E lying south to the Trbovlje normal fault in the same direction, representing the southern border of the Blato anticline, the core of which contains pseudozilian layers, and to its easternmost point, there lies a preserved, anticlinally sloped and heavily deformed coal seam, approximately 10 m thick and declining in the eastern direction. To the north of the Blato anticline, there lies the heavily compressed and deformed Dol syncline. The southern border of the main coal seam is formed by the Hrastnik thrust, running in the direction W-E. In the central part, the main coal seam is longitudinally cut by the internal thrust panel dividing the seam, which is uniform in the west, in two parts, the so-called "northern" seam and "southern" seam. In the economic sense, the "southern" seam is more significant. The internal thrust panel is sloped in the slip (non-flexive and unbent) anticline, with the crest descending approximately by 25 % in the eastern direction, forming at the same time the upper and the eastern boundary of the "southern" seam and, simultaneously, the lower boundary of the "northern" seam. Kuščer & Mitrevski described the sloped thrust panel as a "barren anticline". The "northern" seam is gradually reduced in the upward direction along one of the thrusts to the south of the Trbovlje fault.

The structure of the Hrastnik coalmine and the coal seam above Horizon VIII at the point +50 m is well known. At this point, coal is almost entirely excavated and the remaining part is well explored. Under this height point, the coal seam was drilled from the standing points at Horizons VII and VIII and from the surface. The level of exploration varies depending of the density of drills. It is higher in the west and lower in the east.

The presumed volume of the "southern" seam is shown in Figure 1, in the

seam projection to the vertical plane in the direction west - east, at the scale of 1 : 5,000. The surface (only in the western half of the projection) and the extension of old excavations are derived from the update of the brief on reserves (Mitrevski & Bravec, 2003). The same goes for the drill holes' drilling points. For the purpose of orientation, the level of Horizon 8 is drawn. The unexploited part of the "southern" seam can be relatively well traced from the transverse profile y = +4200 to the profile y = +5400, i.e. at the length of 1200 m and further to the profile y = +5650 where it has been established at the easternmost point by the drill hole Br. 10. This means that in the most favourable structural and lithological conditions, its length would amount to 1,460 m. In the profile y = +4200, the coal seam extends approximately from the point +90 m to approximately +60 m, and in the profile y = +5400 from approximately +60 m to approximately –220 m in the profile 5700 from approximately –110 m to approximately –290 m. Unlike the profiles y = +4100 in y = +4450, the location of the Hrastnik thrust in the profile y = +5700 has been determined according to interpolation between the drill holes Br. 13 and Br. 10, and therefore very inaccurate. A lower level of accuracy of the thrust's location also applies for the profiles y = +4950 and y = +5390. In the profile y = +5950, the drilling at the hole D 1 was halted in the hanging wall marl, therefore there is no data on the existence of a coal seam in the outermost part in the Hrastnik structure. The thickness of the "southern" seam amounts from 25 m to 40 m. The "width" of the seam on the vertical axis in the projected plane is not correct, it is actually longer by the ratio depending on the inclination of the seam. The value of the ratio to be multiplied with the measured width in the profile is indicated on the profile line for the individual profiles and amounts from 1.05 to 1.25. The western part of the profile reflects the actual situation, but in the eastern direction and in the depth direction, the accuracy level gradually falls lower. This particularly applies to the location of drill points with the coal seam and to the location of the internal thrust panel and the Hrastnik thrust.

According to interpretation as presented here, the "southern" seam is gradually reduced in the eastward direction. However, as it is evident from the following text, the conditions as predicted by Mitrevski & Bravec (2003) should also be taken into consideration.

The unexploited part of the "northern" *seam* can be traced in the mine from the profile y = +5000 to the profile y = +5500 where it has been drilled through by a drill hole from Horizon VIII. Further, towards east, it has only been extrapolated. In Figure 1, the "northern" seam is not shown, as it is

impossible to show its actual volume due to unclarified tectonics. The thickness of the seam amounts to 10 m to 15 m, only occasionally it reaches 20 m. The coal seam in the Blato anticline is not included in this presentation. The longitudinal projection in Figure 1 has been complemented by the orientation profile on the coordinate y = +5400 in Figure 2 at the scale 1 : 5,000 taken from the preliminary analysis of the structure of Ojstro and Hrastnik (Placer, 1988). It shows the structural relation between the "northern" and "southern" seam and the location of the internal thrust panel and the Hrastnik thrust.

The extension of the unexploited part of the coal seam has been determined by mapping of the Horizon VII and VIII of the Hrastnik mine and by drilling from the mine and the surface. Despite numerous data, the existence of all faults and thrusts limiting the coal seam has been determined with more or less probability, as despite everything, a different interpretation is always possible. The least data is available on the location of the Hrastnik thrust fault in the depth. All data sets except one are obtained from the surface drill holes ((Br.12, Br. 2, Br. 12, Br. 13). The only data set obtained from the mine is from the drill hole Hj 19 at Horizon VII in the profile 4350 drilling the coal and the Hrastnik thrust fault; However, this data is of high quality as it proves the coal thrust on the Laško layers, thus the Hrastnik thrust. The internal thrust panel separating the "northern" and the "southern" seam was determined according to the study of mine profiles, while its role was established according to the structural analysis of the deformation dynamics (Kuščer & Mitrevski, 1979; Placer, 1988).

The characteristics of the coal seam in the "northern" and "southern" seam differ from one another. Above all, the "northern" seam is thinner and tectonically much more affected than the "southern" one. Coal in the "northern" seam has been thrust and then horizontally shifted along vertical faults, resulting in formation of scales and thinner layer; both contacts, foot wall and hanging wall, are mostly abnormal and tectonised. The "southern" seam is considerably less damaged. It contains normally developed footwall and hanging wall contact. The barren inserts are less damaged than in the "northern" seam.

The discussion on conditions in the eastern part of the Hrastnik structure and/or on the structure model by Kuščer & Mitrevski on one side, and Placer on the other, is of great significance due to its relation with eventual planning of exploration works. The internal thrust panel occurs in the central part of the coal deposit; in the western part, the coal seam is merely flexurally

bent, and in the eastward direction, the flexure increases and is discontinued in the profile y = +5100. Further towards the east, the size of the discontinuation in the known part of the mine is increasing. The difference between both concepts lies in the prediction by Kuščer & Mitrevski for the eastward shift to gradually reduce again. Therefore, the "northern" and the "southern" seam are reunited into one seam in the profiles from y = (+5500 to +5700) (Mitrevski & Bravec, 2003). Placer allows a possibility that the eastward shift is not reducing, so the seams would remain separated. However, there is no proof to substantiate it.

The southern wing of the Blato anticline is supposed, according to Kuščer & Mitrevski, to represent a normal substrate of the main seam, i.e. the "northern" seam. At its southern side, only the internal thrust panel is supposed to be situated, and the stronger thrust panel should be located in the north. A similar thrust panel should be running into the footwall of the Dol seam. Further towards east, the conditions should be simplified even more, and the coal from the Dol syncline should pass towards south, into the Blato anticline and in its southern wing, into the main coal seam of the Hrastnik coal deposit. In this sense, the profiles from y = +5500 to y = +5700 in the upgrade of the brief on coal reserves by Mitrevski & Bravec (2003) have also been elaborated. Conditions in this part of the coal deposit are represented on the simplified diagram of the profile y = + 5700 from the updated brief. According to Placer (1988), however, conditions are more complicated. Considering the structure of Brezno, Krištandol and Dol, the Blato anticline and the Dol syncline lie in a strongly compressed thrust zone of pseudozilian and coal-rich layers. The connection between the main seam in Hrastnik and the Dol seam is therefore severely deformed by currently vertical thrusts and strike slip faults in the direction W-E.

The original coal deposit

For a complex estimation of the perspective of the coal deposits in Hrastnik, an important role is played by the ratio between the location of the original coal deposit in the time of coal silt sedimentation in the Upper Oligocene and the current location of the Laško syncline lying in the direction west-east, while the direction of the original coal deposit was WSW-ENE. Strahovlje, Loke and Kisovec therefore lie in the southern wing of the syncline, Kotredež and Orle in the southern and partially central part of the syncline, Trbovlje in the central part of the syncline, and Ojstro, Hrastnik, Dol, Brezno, Huda Jama and Mihael in the northern wing of the syncline. Accordingly, the current coal mines are located in various parts of the original Upper-Oligocene coal de-

posit, some in its central part, some at the outermost edge and some in the intermediate area. It is logical to expect the thickest seam in the central part, and the thinnest one at the borders, although the original paleogeographic shape of the swamp might have been different. The above described model is ideal, but fits reasonably well the conditions in the nature. In the central part of the syncline and the original coal deposit, where Trbovlje is situated, the coal seam and the footwall clay layer are the thickest. The coal seam is gradually becoming thinner and poorer in western and eastern direction. The thinnest and economically least important part is situated in Strahovlje in the west and in Mihael near Laško in the east, partially reaching across the Savinja river. The main coal seam in Hrastnik, i.e. the "southern" seam, is situated between the central and border region of the original coal deposit, so it can be expected to become thinner and poorer in the depth and eastern direction. Due to the inclined position of the original coal deposit against the Laško syncline, the erosion has removed a large part of it, possibly even a half of it.

The Hrastnik thrust fault is an important structural element of the Hrastnik structure. It has been proven in the western part of the coal deposit, and in the eastward direction, its existence is not at questionable as its position. Without the Hrastnik thrust, one cannot explain the structure of the southern edge of the Hrastnik structure and the depth extension of the coal seam. In the eastward direction, it is related to the proven southward oriented Kojzica thrust near Šmarjeta. Along the Hrastnik thrust, the northern wing of the Laško syncline overlapped, in the southward direction, its southern wing, with the largest shift along the Hrastnik thrust fault, causing extensive narrowing of the syncline in this area. It can thus be presumed that the cut-off part of the coal seam along the Hrastnik thrust is covered with the mine structure and shifted in the depth direction towards the north. The size if the shift can only be roughly estimated from two aspects: in the first aspect, we add the reduced thickness of the syncline in Hrastnik against its width in Laško and the size of the shift along the thrust in the Kojzica profile. The sum amounts to approximately 1000–1500 m. The shift may not be that extensive, considering the compensations due to bending. Another aspect is an assumption that the covered part of the coal deposit is situated in the prolongation of the Ojstro seam. In such case, the shift would be less extensive. However, it is a theoretical question. The explorations in this sense should be abandoned, as the missing part was situated near the edge of the original coal deposit, therefore resulting in a presumably thinner and poorer seam.

Field exploration and its costs

Given the characteristics of the Hrastnik rock strata and coal seam, and assuming that the investment is economically viable, it would be advisable for initial exploration to focus on the "southern" seam over the Hrastnik thrust, which is only –40 m deep, while the exploration of the "northern" seam should be attempted only in the case of its thickness proving economically viable. The thickness of the "northern" seam is 10–15 m and only occasionally reaches 20 m. Given what we know, any surveys of the coal deposit under the Hrastnik thrust would be pointless

Table 2: Estimated cost of three structural exploration drill holes

DRILLING WORKS **DRILL HOLE V-1** / HOLE DEPTH: 650 m

No.	Type of works	Unit	Quantity	Price (EUR)	Amount (EUR)
1.	Construction of the access road	M	50	50.00	2 500.00
2.	Construction of the platform for the drilling set	m^2	250	10.00	2 500.00
3.	Transportation of the drilling set and equipment, assembly and dismantling	lump-sum			3 000.00
4.	Drilling for the first column without core sampling and column installation	M	12	150.00	1 800.00
5.	Core drilling	M	638	230.00	146 740.00
6.	Core containers (archive)	pcs	130	60.00	7 800.00
8.	Transport of the core to the laboratory	lump-sum			2 000.00
	TOTAL				**166 340.00**

GEOLOGICAL AND LABORATORY ANALYSES **DRILL HOLE V-1**

Type of works	Quantity	Price (EUR)	Amount (EUR)
1. Geological works			13 000.00
Geological mapping of the core			
Sample collection			
Elaboration of the drill hole profile			
Elaboration of the transverse geological cross-section			
2. Laboratory analyses			8 000.00
3. Elaboration of report			3 000.00
TOTAL			**24 000.00**

DRILL HOLE V-1	Price (EUR)
Drilling works	**166 340.00**
Geological and laboratory analyses	**24 000.00**
TOTAL	**190 340.00**

at this point, primarily on account of its extreme depth and costs involved.

On the basis of comprehensive reference points of the geological evaluation of coal reserves, we propose a construction of three structural exploration drill holes from the surface with an average depth of 650 m. Upon acquisition of positive results, one drill hole will be equipped as a piezometer. Estimated costs for the drill hole construction are shown in Table 2 for each individual drill hole.

DRILLING WORKS **DRILL HOLE V-2 /** HOLE DEPTH: 650 m - PIEZOMETER

No.	Type of works	Unit	Quantity	Price (EUR)	Amount (EUR)
1.	Construction of the access road	M	50	50.00	2 500.00
2.	Construction of the platform for the drilling set	m^2	250	10.00	2 500.00
3.	Transportation of the drilling set and equipment, assembly and dismantling	lump-sum			3 000.00
4.	Drilling for the first column without core sampling and column installation	M	12	150.00	1 800.00
5.	Delivery and installation of the piezometer pipe	M	650	100.00	65 000.00
6.	Core drilling	M	638	230.00	146 740.00
7.	Core containers (archive)	pcs	130	60.00	7 800.00
8.	Transport of the core to the laboratory	lump-sum			2 000.00
	TOTAL				**231 340.00**

GEOLOGICAL AND LABORATORY ANALYSES **DRILL HOLE V-2**

Type of works	Quantity	Price (EUR)	Amount (EUR)
1. Geological works			13 000.00
Geological mapping of the core			
Sample collection			
Elaboration of the drill hole profile			
Elaboration of the transverse geological cross-section			
2. Laboratory analyses			8 000.00
3. Elaboration of report			3 000.00
Total			**24 000.00**

DRILL HOLE V-2	Price (EUR)
Drilling works	**166 340.00**
Geological and laboratory analyses	**24 000.00**
TOTAL	**255 340.00**

DRILLING WORKS **DRILL HOLE V-3** / HOLE DEPTH: 650 m

No.	Type of works	Unit	Quantity	Price (EUR)	Amount (EUR)
1.	Construction of the access road	M	50	50.00	2 500.00
2.	Construction of the platform for the drilling set	m^2	250	10.00	2 500.00
3.	Transportation of the drilling set and equipment, assembly and dismantling	lump-sum			3 000.00
4.	Drilling for the first column without core sampling and column installation	M	12	150.00	1 800.00
5.	Core drilling	M	638	230.00	146 740.00
6.	Core containers (archive)	pcs	130	60.00	7 800.00
8.	Transport of the core to the laboratory	lump-sum			2 000.00
	TOTAL				**166 340.00**

GEOLOGICAL AND LABORATORY ANALYSES **DRILL HOLE V-3**

Type of works	Quantity	Price (EUR)	Amount (EUR)
1. Geological works			13 000.00
Geological mapping of the core			
Sample collection			
Elaboration of the drill hole profile			
Elaboration of the transverse geological cross-section			
2. Laboratory analyses			8 000.00
3. Elaboration of report			3 000.00
TOTAL			**24 000.00**

DRILL HOLE V-3	Price (EUR)
Drilling works	**166 340.00**
Geological and laboratory analyses	**24 000.00**
TOTAL	**190 340.00**

TOTAL COSTS FOR THE CONSTRUCTION OF DRILL HOLES V-1, V-2 and V-3	Price (EUR)
DRILL HOLE V-1	**190 340.00**
DRILL HOLE V-2	**255 340.00**
DRILL HOLE V-3	**190 340.00**
TOTAL	**636 020.00**

During the execution of exploration drill holes, a decision on the relevance of the execution of all three drill holes and on the manner of execution of the piezometer would be made, considering the individual data collected from the drill hole V-1. The depths of the drill holes have been estimated, but should not exceed the depth of 650 m.

Conclusion

The off-balance A + B + C_1 coal reserves in the Hrastnik mine, the amount of which has not significantly changed since the end of the year 1997, represent precisely one third of the entire (both balance and off-balance) A+B+C1 coal reserves for RTH, the Trbovlje-Hrastnik mine (53,893,000 t). In addition, further sources of the C2 category (6,272,000 t) have been recorded in the Eastern Corner Field in the mine Hrastnik. The elaborated geological evaluation and the necessary scope of research surface drilling represent a good basis for coal reserve recategorisation. The results of exploration drilling will enable the final confirmation of exploitation reserves of brown coal in the Hrastnik mine.

The purpose of the study "The justifiability of the exploitation of the remaining coal reserves at the mines Ojstro and Trbovlje after the year 2009" – Phases II and III, and the evaluation of coal deposits at the mine Hrastnik was to produce an estimate and identify the necessary scope of activities that would enable the remaining reserves to be determined with a higher degree of precision and subsequently recategorised as actual reserves, and to verify the exploitable coal reserves which, once confirmed, would provide a basis of determining the economic viability of further mining at the coalmine Hrastnik.

Summary

Geological Evaluation of Brown Coal Reserves at Hrastnik Pit - RTH, Rudnik Trbovlje – Hrastnik

The geological evaluation of the remaining deposits of brown coal at Hrastnik focused on reviewing the updated brief on the categorisation, classification and calculation of the resources and deposits of brown coal in the RTH mining area as at 31 December 2002 (Mitrevski and Bravec, 2003).

Apart from the associates employed by the coalmine's geological department to monitor the preliminary works and surveys carried out at the coalmine on an ongoing basis, vital research over the past fifty years was undertaken by Kuščer (1967) with his core work *Zagorje Tertiary*, Gregorač (1975) who focused on the hydrogeology of the mine Hrastnik, Kuščer and Mitrevski (1979) who researched the geology of the bound-

ary area between the mines Hrastnik and Dol, Uhan (1991) with his work on the geochemical properties of coal in the central part of the deposit, and Placer who carried out a structural-geological analysis between 1982 and 1991. In the abovementioned period Placer completed a geological survey and mapping of the surface area between Moravče and Laško, and surveyed and mapped the mine roadways and the cores of exploration drill holes. Placer published the major findings of the survey and mapping of the surface area over the mines Hrastnik and Dol in 1987 in the brief "A Geological Structure Survey in the Dol-Hrastnik Area, Part II". In the three-year period 1985–1987 geologists surveyed roughly 3,200 m of roadways, access tunnels and longwalls, and drilled eleven structural exploration drill holes in the total length of approximately 1,500 m (Uhan, 1987). The geological data obtained in the course of the abovementioned surveying and mapping of mine roadways and exploration drill holes yielded more detailed information on the structure of the "south wing" of the central part of the coalmine Hrastnik at and under Horizon VII. Building on the results of all previous surveys and having reviewed and processed the entire documentation held by the coalmine, Placer preformed the most comprehensive structural geological analysis until that time, and explained the tectonic development of the coal deposit. When it comes to the evaluation of remaining coal reserves in the Hrastnik area, certain structural geological questions remain unanswered; this primarily refers to the continuation of the coal seam under the hypothetical Hrastnik thrust fault. The other set of debatable questions concern the geological structure of the Eastern Underground Deposit where the continuation of the southern coal seam downwards has been established by exploratory drill holes at Brnica.

Given the characteristics of the Hrastnik rock strata and coal seam, and assuming that the investment is economically viable, it would be advisable for initial exploration to focus on the "southern" seam over the Hrastnik thrust, which is only 25–40 m deep, while the exploration of the "northern" seam should be attempted only in the case of its thickness proving economically viable. The thickness of the "northern" seam is 10 m to 15 m and only occasionally reaches 20 m. Given what we know, any surveys of the coal deposit under the Hrastnik thrust would be pointless at this point, primarily on account of its extreme depth and costs involved.

The western end of the "southern" seam has been comparatively well surveyed. However, more detailed surveys of the eastern end should be carried out; this applies in particular to the layout of the Hrastnik thrust.

The question of a direct connection between the "southern" and "northern"

coal seams at the far eastern end of the coal deposit at Hrastnik remains open, as there is always a possibility that the shift along the internal thrust layer in that direction may be diminishing. Should the opening of the "southern" seam be deemed economically viable, however, that possibility should also be explored.

Suitable drilling sites have been identified both on the surface and in the mine. At Horizon 8 (+50 m) the relevant tunnel reaches up to coordinate y = +5350. Access to Level 0 is provided from Horizon 7 (+85 m) downwards. Point 0 is located at cross-section y = +4900. Horizon 8 is more suitable for drilling; the required access tunnel to the far end of the "southern" seam would be at least 600–700 m long and possibly longer with drill holes reaching 200 m to 300 m deep, depending on the layout of the proposed tunnel. The "southern" seam can also be accessed from the surface. The average depth of the proposed drill holes would be about 600 m i.e. between 500 m to 700 m. The cost/benefit analysis would indicate which part should be explored from the mine and which part from the surface.

The most promising point at which the connection between the "southern" and "northern" seams at the eastern end of the coal deposit should be explored would be at cross-section y = +5650 at the location of the existing drill hole Br.10.

Access for the purpose of surveying the "northern" seam from the surface is less favourable.

The far eastern boundary of the Hrastnik coalmine deposit has not been determined. Known findings about the position of the originally identified deposit relative to the Laško synclinal lead us to believe that the uniform or divided main seam is leaning at an angle onto the thrust zone along the northern perimeter of the Laško synclinal. Since we are approaching the outermost boundary of the originally identified deposit in the eastern direction, the potential of this area is limited by that boundary, which translates into a gradual diminishing and thinning of the coal seam.

The proposed surveys at the Hrastnik coalmine deposit should facilitate a recategorisation of reserves and resources, and should focus primarily on the eastern end of the mine. The proposed exploration involves three drill holes to the depth exceeding 650 m. The total cost of drilling would amount to EUR 636,000.

Total actual deposits are expected to be below the figure suggested in the reassessment of resources and reserves carried out in 2003 (Mitrevski and Bravec). The proposed downgrading of reserves applies to the "northern" seam and the transitional area between the Hrastnik

and Dol mines due to the tectonic thrust and shifting tectonic plates, which thinned the original seam and broke it up into individual lens. Due to the lack of field data, the figures presented in the reassessed resources and reserves brief are somewhat idealised.

The purpose of the study "The Legitimacy of the Extraction of Remaining Coal Deposits at the Mines Ojstro and Trbovlje After 2009" – Stages 2 and 3, and the evaluation of coal deposits at the mine Hrastnik was to produce an estimate and identify the necessary scope of activities that would enable the remaining reserves to be determined with a higher degree of precision and subsequently recategorised as actual reserves, and a verification of exploitable coal reserves which, once confirmed, would provide a basis of determining the economic viability of further mining at the coalmine Hrastnik.

References

Dervarič et al. (2008): Upravičenost odkopavanja preostalih zalog premoga v jamah Ojstro in Trbovlje po letu 2009 in zaprtega dela jame Hrastnik – I. faza (*Justifiability of exploitation of the remaining coal reserves in the mines Ojstro and Trbovlje after the year 2009 and the closed-down section of the Hrastnik mine - Phase I*). UL NTF OGTR, September 2008.

Dervarič et al. (2009): Upravičenost odkopavanja preostalih zalog premoga v jamah Ojstro in Trbovlje po letu 2009 in zaprtega dela jame Hrastnik – II. in III. faza (*Justifiability of exploitation of the remaining coal reserves in the mines Ojstro and Trbovlje after the year 2009 and the closed-down section of the Hrastnik mine - Phase II and III*). UL NTF OGTR, March 2009.

Kuščer, D. & Mitrevski, G. (1979): Geologija mejnega območja med jamama Hrastnik in Dol (*Geology of the border area between the mines Hrastnik and Dol*). *Rudarsko-metalurški zbornik 26/2–3*, 167–178, Ljubljana.

Placer, L. (1988): Preliminarna analiza strukture Ojstrega in Hrastnika (*Preliminary analysis of the structure of Ojstro and Hrastnik*). RTH Archive.

Placer, L. et al. (1994): Stratigrafski in tektonski razvoj Laške sinclinale (*Stratigraphic and tectonic development of the Laško synclinal*). RTH Archive.

Placer, L. 1999 (1998): Structural meaning of the Sava folds. *Geologija 41*, 191–221, Ljubljana.

Mitrevski, G. & Bravec, B. (2003): Renovelacija elaborata o kategorizaciji in klasifikaciji izračunanih zalog in virov rjavega premoga na območju pridobivalnega prostora Rudnika Trbovlje-Hrastnik (RTH) s stanjem 31. 12. 2003 (*Update of the brief on the categorisation, classification and calculation of the resources and deposits of brown coal in the RTH mining area as at 31st December 2003*).

RTH Archive.