

Pseudosocka Beds with Coal in Borehole Tdp-1/84 Trobni Dol (Eastern Sava Folds, Slovenia)

Psevdosoteške plasti s premogom v vrtini Tdp-1/84 Trobni Dol (vzhodne Posavske gube)

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Key-words: coal, chemistry, stratigraphy, tectonics, Upper Oligocene, Miocene, eastern Sava Folds, Slovenia

Ključne besede: premog, kemična sestava, stratigrafija, tektonika, zgornji oligocen, miocen, vzhodne Posavske gube, Slovenija

Abstract

The sedimentary succession with coal in the Trobni Dol area was studied in detail. The coal district lies east of Laško and belongs to the eastern part of the Sava folds. Every attention was given to the stratigraphic problems of the Egerian succession as well as to the coal, its stratigraphic position and age. The Pseudosocka beds are subdivided into the lower Pseudosocka beds, the coal horizon and the upper Pseudosocka beds. The coal seams of the Trobni Dol sedimentary succession were formed in the Upper Oligocene, the Lower Egerian respectively. Finally, the correlation of the Pseudosocka beds from Trobni Dol and western Laško synclinalorium area was performed.

Kratka vsebina

Na območju Trobnega Dola smo podrobno raziskali zaporedje sedimentnih kamnin z vložki premoga in piroklastitov. Trobnodolski premogovni bazen leži vzhodno od Laškega na ozemlju, ki geotektonsko pripada vzhodnim Posavskim gubam. Glavno pozornost smo posvetili stratigrafskim problemom egerijskega sedimentacijskega zaporedja, zlasti pa premogu, njegovi stratigrafski legi in starosti. Psevdosoteške plasti smo razčlenili v spodnje Psevdosoteške plasti, premogovni horizont in zgornje Psevdosoteške plasti. Sloji premoga v trobnodolskem sedimentnem zaporedju so se oblikovali v zgornjem oligocenu oziroma spodnjem egeriju.

Introduction

Geologic investigations in the Trobni Dol area were carried out in the frame of the coal exploration programme in Slovenia. The scope of these investigations was to study the geology of the abandoned Trobni Dol and Pojerje coal mines as well as the area between Trobni dol, Breze and Pojerje (Fig. 1). With this purpose about 16 km² of the terrain among Breze, Trobni Dol and Pojerje was mapped in detail (Petrica,

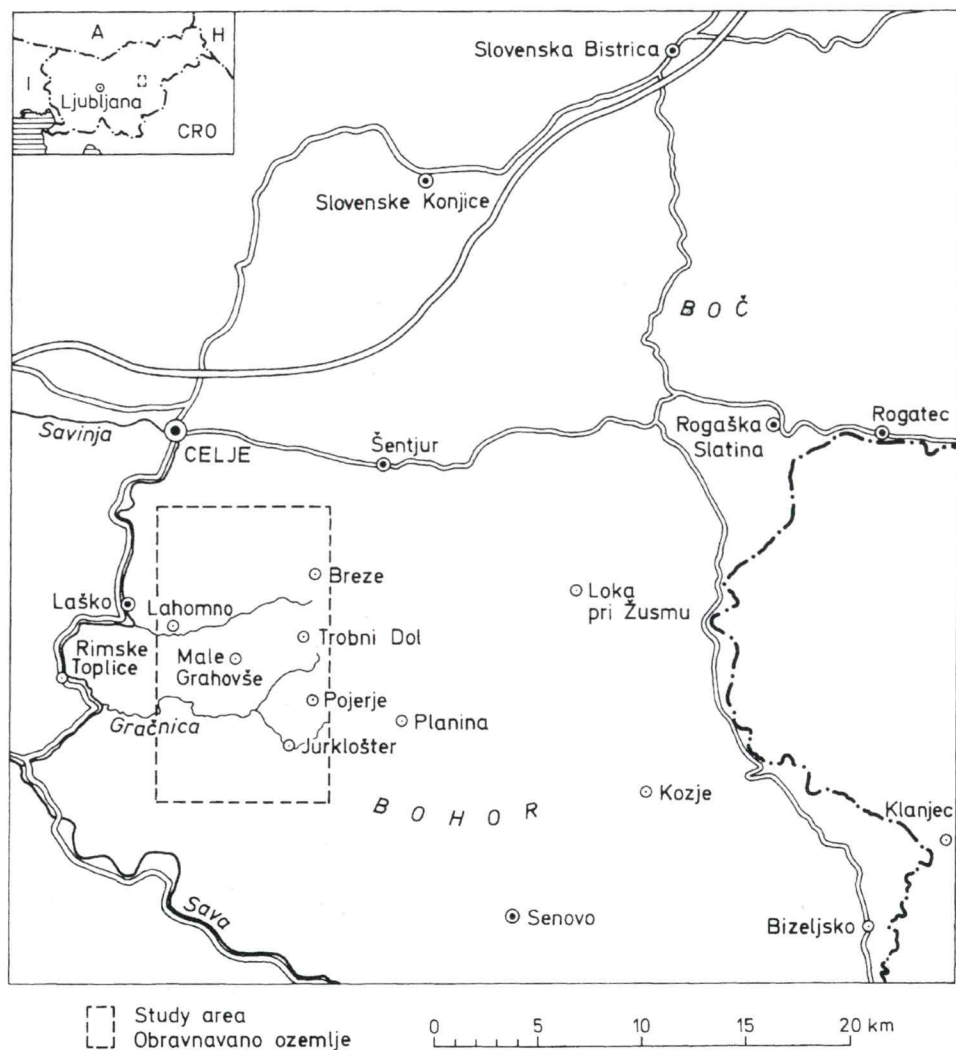


Fig.1. Location sketch map

Sl. 1. Položajna karta

1984). In the year 1984 two deep exploration boreholes were bored west and north of the abandoned coal mine Trobni Dol. For understanding the lithostratigraphic conditions of the wider area the borehole Tdp-1/84 with the depth of 385 metres reaching the Tertiary basement is important. Due to tectonic conditions the second borehole (Tdp-2/84), being bored up to 400 m, did not reach the Pre-Tertiary basement.

Further on, the area between Lahomno and Grahovo was reconnoitred for the scope of underground gas storage construction by S. Dozet, P. Mioč, M. Žnidarčič, B. Stojanovič and M. Demšar (Mioč et al., 1983). The Rudnica anticlinal area was explored for the same purpose by S. Dozet and B. Stojanovič (Dozet, 1985).

Simultaneously with the geological mapping the sampling of the Tertiary rocks and coal was performed. The Tertiary microfauna was determined by Rijavec (1983, 1984a, b, c). Petrographic analysis of the Oligocene and Miocene rocks was carried out by Orehek and Kovič (1984). X-ray analysis was done by Mišič (1984). Chemical analysis of the coal samples was executed in the laboratory of REK Trbovlje by T. Žuža. The Tertiary macrofauna was revised by V. Mikuž.

Previous investigations

In the past the wider area of Trobni Dol was investigated many times owing to the coal and other mineral resources. A great number of printed and manual works exist on these investigations. The Zollikofer's description of the Tertiary beds among Konjiška gora, Macelj, Sotla and Savinja was one of the first and most important geological works. This work was the basis for the Bittner's and other subdivisions of the Tertiary in this area. Zollikofer (1861) ranged the coal-bearing beds at Zagorje and Trbovlje as well as their continuation to the east of Laško to the oldest Neogene. Stur (1871) described the Neogene beds of the wider area. As Socka beds he considered all continental strata of the region Socka-Trbovlje-Zagorje lying between the Triassic basement and the Marine marly clay. He noticed that the Socka beds of Laško originated in the fresh-water environment and that towards the east a brackish and a marine fauna prevails. Bittner (1884) divided the Tertiary beds between Laško and Zagorje into the "Socka" beds with coal, the marine Miocene beds (Marine clay and green sands, the lower Leitha limestone, the Laško marl and the upper Leitha limestone) as well as the brackish Sarmatian beds. Granigg (1910) noticed that the coal mine Trobni Dol lies in the southern limb of the Laško synclorium. He mentioned a 72 cm thick coal seam which contains a 37 cm thick clay interbed. He ranged the beds with coal into the Govce beds.

In the period between both wars the study area was explored by A. Winkler, M. Munda and W. Petrascheck. Petrascheck (1926/29) distinguished two horizons of coal: a) – older, from the limnic and brackish "Socka" beds and b) – younger from the Aquitanian marine beds. Munda (1939, 1942, 1953) correlated the "Socka" beds of Senovo, Trobni Dol, Zagorje, Medvode and Bohinj. He mentioned that the Trobni Dol coal formation, can not be of Miocene age taking into account its fossil contents.

The period of most intensive geological investigations occurs after the Second World War with appearance of the following researchers: M. Hamrla, M. Munda, K. Grad, A. Nosan, D. Kuščer, L. Rijavec and others. Hamrla (1954, 1955, 1987) observed that the Laško Tertiary coal seam was getting thinner in the west-east direction. He considered that simultaneously with the predominant marine developments of the Oligocene beds in the east direction, conditions for formation of coal

were less favourable. In short brackish intervals only thin coal seams can be formed. Grad (1962, 1967) gave a geologic outline of the Kozje area. Among Tertiary beds he mentioned the Oligocene, Badenian and Sarmatian ones. He considered the main folding in the area to be Post-Pannonian. Nosan (1956) distinguished three facial types of the "Socka" beds:

- a) – the "Socka" beds at Zagorje-Hrastnik-Trbovlje,
- b) – the "Socka" beds in the Senovo basin and,
- c) – the "Socka" beds between Pohorje and Bohor.

Kuščer (1962, 1967) ascertained that in the Laško-Zagorje synclinalorium occurs only one coal seam in the "Socka" beds. The coal passes downwards into a black shaly clay (black footwall) and upwards gradually into the light brown marly limestone and shale with sandy intercalations. Rijavec (1959, 1965, 1974, 1983, 1984 a, b, c, 1986) determined the Tertiary microfauna in the following areas: Rudnica and Boč, Loka at Žusem, Šmarje at Jelše as well as the Trobni Dol and its wider surroundings. She determined the microfauna from the surface and both boreholes of Trobni Dol.

The detailed investigations for the Geological map of Slovenia, the map sheet Celje on the scale of 1:100 000 with corresponding explanatory text written by Buser (1979) are of great importance. The author combined the results of the geological mapping and reconnaissance in the Celje map sheet area a detailed description of the mapping units. He attributed the main folding of the study region to Helvetian.

Lately, R. Petrica et al., P. Mioč et al., S. Orehek et al., P. Kovič, M. Mišič, S. Dozet et al., G.S. Odin et al. and M. Jelen et al. contributed to the interpretation and explanation of geologic problematics of the area. Mioč et al. (1983) reported on results of geological and geophysical explorations in the Šmarjeta-Lahomno area. Mišič (1984) analysed with X-ray method the volcanic succession from the borehole Tdp-1/84 in the hanging wall of the "Socka" beds. Jelen (1984) examined palinologically samples of the Oligocene marine clay and the "Socka" beds from the borehole Tdp-1/84. Dozet (1985) and Dozet et al. (1994) reported on results of the geological investigations in the Rudnica anticline area. Dozet and Rijavec (1994) described geological conditions in the area of Šentjur-Planina-Trobni Dol-Loka at Žusem. Kovič (1984, 1985) described and systematically classified Tertiary rocks of the Trobni Dol area by means of microscopic examination of thin sections. Jelen et al. (1990) described changes of the Oligocene microfossil assemblages in the Zagorje region. Jelen et al. (1992, 1994) established that the "Socka" beds in the southern Karavanke and Socka area are of Middle and Upper Eocene age. Since the beds with coal in the area between Laško and Zagorje are of Oligocene age, they considered the Socka beds as Pseudosocka beds. Odin et al. (1994) presented the results of geochronological analysis of pyroclastic interbeds in the coal from Neža (Trbovlje). The analytical results indicate that the plagioclase samples were erupted at 25 ± 1.0 Ma (2 σ), therefore the Pseudosocka volcanoclastic layers containing the plagioclase were deposited during the Late Chattian. Petrica et al. (1995) described stratigraphy of the Upper Oligocene and Miocene beds in the Trobni Dol area.

Geographic setting

The Trobni Dol and Pojerje coal mine areas are situated in the eastern Sava folds 10 km east of Laško and 8 km south of Šentjur. This is the area of up to 800 metres

high narrow elevations of west-east direction as well as of steep and narrow valleys being formed by faulting and stream erosion. The access to the investigated area is possible through the Lahomnica valley from the Laško direction, along the Gračnica valley (Jurklošter, Marof) from the Rimske Toplice direction, as well as from the Šentjur direction passing across Breze.

Geology of the area Pre-Tertiary basement

The Pre-Tertiary basement is exposed only along contacts with the Tertiary succession. Most of Tertiary overlies erosively and discordantly the Permo-Carboniferous micaceous shales, quartz sandstones and conglomerates. South of V. Grahovše and in the close vicinity of the abandoned Trobni Dol coal mine crop out Permo-Carboniferous rocks and Triassic dolomite underlying the Tertiary beds. The other part of the Pre-Tertiary basement is probably built up from the Permian sandstones, Middle Triassic Pseudozilian shales and keratophyre tuff as well as the Triassic dolomite, which are in tectonic contact with the Tertiary rocks at northern and southern edge of the investigated area.

Stratigraphic and tectonic relationships of the Pre-Tertiary rocks were not studied by us.

Tertiary

In the investigated area the Tertiary succession begins with the Upper Oligocene Pseudosocka beds, which lie discordantly upon the Triassic dolomite. Upwards follow grayish green Marine marly clay, green dacitic tuff and repeatedly clayey beds belonging to Egerian and passing upwards into the Govce beds. Discordantly upon the Govce beds rests the Badenian (Tortonian) succession which is discordantly overlain by the Sarmatian sediments. The complete development of the Tertiary beds is similar to the Tertiary developments in other parts of the Laško synclinorium.

Upper Oligocene

In the study area the Oligocene comprises the Pseudosocka beds, grayish green Marine marly clay and dacitic tuff. In this paper the Pseudosocka beds from the borehole Tdp-1/84 are considered in detail.

According to Stur (1871) the beds at Socka (north of Celje) and the coal-bearing beds between Zagorje and Trbovlje are described as Socka beds. Kuščer (1967), who studied the Tertiary area at Zagorje, used the name Socka beds dividing them into the lower and upper Socka beds. These beds are separated by the main coal seam. The lower Socka beds (footwall) are composed of clay, sand and locally gravel. The upper Socka beds are represented by marl, marly limestone and quartz shale. Upon the Socka beds lies conformably the bluish Marine marly clay with a rich microfauna. Recently, Jelen et al. (1992, 1994) established that the Socka beds from southern Karavanke are of Middle and Upper Eocene age. Since the beds with coal between Laško and Zagorje are of Oligocene age Jelen et al. (1992) as well as Odin et al. (1994) considered the up to that time Socka beds as Pseudosocka beds.

Pseudosocka beds-Lower Egerian

According to the data of the borehole Tdp-1/84 (Fig. 2) the oldest Tertiary rocks of the Trobni Dol area have a similar development as it can be seen between Zagorje and Laško where it is divided into the lower and upper Socka beds (Kuščer, 1967). In the eastern part of the Laško synclinorium there is few data about the Oligocene beds, owing to erosion of cover by younger sediments.

The **lower Pseudosocka beds** in the borehole Tdp-1/84 consist of brownish and gray massive clay, individual regular lenses of fine gravel (up to 1 cm thick) and of rare coal veinlets. The thickness of the lower Pseudosocka beds attains 14.85 metres.

Approximately in the middle of the clay, which by analogy with the Laško synclinorium can be nominated the footwall clay, about 5.50 m above the Triassic dolomite, occurs the first, about 30 cm thick coal seam that passes upwards into a 30 cm thick layer of clayey coal. The coal has the calorific value 20.36 MJ/kg (as received basis, a.r.b.), whereas the clayey coal reaches 4.29 MJ/kg (a.r.b.) only. In the borehole Tdp-1 the coal is overlain by an about 8.75 m thick grayish clay. Immediately above the footwall clay lies a 40 cm thick second coal seam. The core from the borehole was crushed, so it is possible that the coal is thicker. The calorific value of the coal is 15.94 MJ/kg (a.r.b.). According to the stratigraphic position this coal seam can be correlated with the coal seam exploited in the Laško synclinorium between Laško and Zagorje.

The **upper Pseudosocka beds** start with a 26.85 m thick succession of the hanging wall marl. It consists of fine laminated grayish and yellowish marl, limy marl and marly limestone. In the upper part of the marl, approximately 3 metres under the boundary of the succession, a 30 cm thick coal seam of good quality occurs, resembling at first sight to anthracite. The calorific value of this coal is relatively high, 22.50 MJ/kg (a.r.b.).

The hanging wall marl was formed in a shallow, calm and predominantly brackish environment. It is laminated in the lower part, and it shows the signs of flaser-bedding in the upper part. Above the hanging wall marl in the borehole Tdp-1/84 follows upwards a 42 m thick succession composed of rhythmic alternation of dark gray sandstone and siltstone characterised by organic admixture and bioturbation. This succession starts with a 2.15 m thick horizon of a black clay and claystone containing numerous small pelecypods with thin shells. Upwards lie conformably the following beds:

- Black claystone. Thickness 2,1 metres.
- Grayish, fine-grained sandstone alternating with siltstone. Thickness 1.6 metres.
- Gray, fine to medium-grained, massive sandstone. Thickness 5.8 metres.
- Dark gray flaser bedded siltstone. Thickness 0.40 metres.
- Gray to yellowish gray sandstone with carbonate admixture, and white up to 2 cm thick calcite veins. Thickness 2.3 metres.
- Dark gray, here and there flaser-bedded siltstone containing rare thin pelecypod shells. Thickness 3.4 metres.
- Gray, massive, medium-grained, bioturbated carbonate sandstone. Thickness 3.4 metres.
- Gray, massive, medium-grained bioturbated carbonate sandstone. Thickness 4.0 metres.
- Thin-bedded, fine-grained, laminated sandstone and siltstone alternating with dark gray shale. Thickness 2.8 metres.

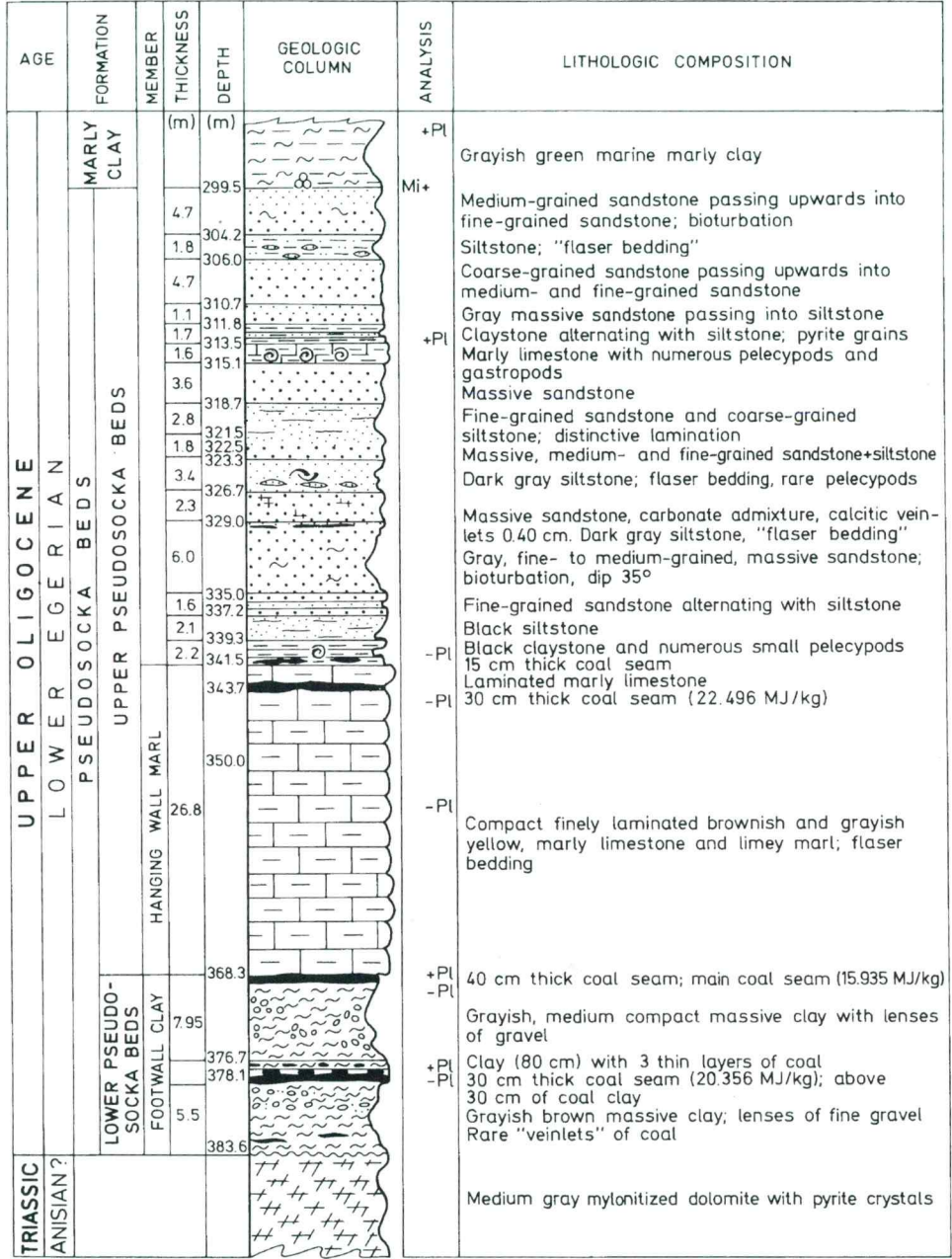


Fig. 2. Geologic column of the Pseudosocka Beds with coal seams in the Tdp-1/84 borehole at Trobni Dol

Sl. 2. Geološki stolpec pseudosoteških plasti s premogom v vrtini Tdp-1/84, Trobni Dol

- Gray, massive sandstone. Thickness 3.6 metres.
- Fossiliferous, bedded, yellowish gray marly limestone containing numerous pelecypods and gastropods. Thickness 1.6 metres.
- Dark gray claystone alternating with a gray siltstone containing rare small pyrite grains. Thickness 1.7 metres.
- Gray, massive sandstone passing gradually into a siltstone. Thickness 1.1 metres.
- Coarse grained sandstone passing upwards into a siltstone. Thickness 4.2 metres.
- Gray, clayey, here and there flaser-bedded siltstone. Thickness 2.3 metres.
- Gray quartz sandstone with bioturbation. The grain thickness diminishes from bottom to top. The passage into the overlying Marine clay ("sivica" in Slovene) is gradual and fast. Thickness 4.7 metres.

Coal

Basic data on the Trobni Dol and Pojerje coal seams

The abandoned Trobni Dol and Pojerje coal mines have been known for a long time. Their geology was already studied in the last century. The first data about the Trobni Dol area were presented by Zollikofer (1861), who studied the stratigraphic position of the productive formation. Granigg (1910) noted that in the Martin pit a lenslike, about 60 cm thick coal seam was mined. South of Martin pit there was another pit with a 70 cm thick coal seam containing a 37 cm thick sterile interlayer. In the hanging wall Petrascheck (1926/29) found a shale with *Cyrena* and a clay upon the shale. The exploited coal seam was 0.6–1 metres thick. He mentioned a shale with *Cyrena* in the hanging wall and a 40 cm thick bed of limnic limestone in the footwall. Under the limnic limestone he noticed an other 20 cm thick coal seam.

According to the exploration borehole Tdp-1/84 data in the Trobni Dol area three thin coal seams occur in the Pseudosocka beds:

The first coal seam is 30 cm thick. It lies in the footwall clay, 5.50 m above the Pre-Tertiary basement that is composed of the Triassic dolomite.

The second coal seam with the thickness of 40 cm is situated at the contact between the footwall clay and the hanging wall marl. By its stratigraphic position this coal is correlative with the coal excavated in the coal mines of the Laško synclitorium between Zagorje and Laško. We supposed that this coal was mined in the Trobni Dol area although, according to the Petrascheck's description (1926/29), it is not possible with certainty to conclude.

The highest, 30 cm thick coal seam is situated in the uppermost part of the hanging wall marl and has the highest calorific value according to chemical analysis. The coal quality was estimated on the basis of the coal analyses from the borehole Tdp-1/84 and from the surface. Owing to limited possibilities of sampling in the borehole the results of analyses have a limited value.

Chemical composition of the Trobni Dol coal seams

The results of the proximate and ultimate analyses of the coal from the borehole Tdp-1/84 and from the surface in the Trobni Dol area have been obtained. On the

surface the Pseudosocka beds were only partly exposed, therefore the connections of individual samples with coal horizons are not certain.

The coal sample No 47 has been collected east of the road Aškerc-Trobni Dol. The 20 cm thick coal outcrop is situated under the beds of the upper Socka limy marl. The results of the proximate and ultimate coal analyses from the surface are the following (table 1).

Table 1. The chemical composition of the coal sample No 47

Tabela 1. Kemična sestava vzorca premoga št. 47

Sample:		Trobni Dol – 351/82			
Vzorec:		Outcrop No: 47			
		Izdanek št. 47			
Proximate analysis			As received basis	Dry basis	Dry ash-free basis
Osnovna analiza			V dostavljenem stanju	(at 105°C)	Brez vlage in pepela
				V suhem stanju	
Total moisture					
Celotna vlaga		%	19.57	–	–
Ash – Pepel		%	10.22	12.77	–
Combustible matters					
Gorljive snovi		%	70.21	87.29	100.00
Coke – Koks		%	46.89	58.30	–
Volatile matter					
Hlapne snovi		%	33.54	41.70	47.77
C-fix – C fiks		%	36.67	45.59	52.23
S total					
Celotno žveplo		%	2.54	3.16	–
S in ash					
Žveplo v pepelu		%	0.35	0.43	–
S combustible					
Gorljivo žveplo		%	2.19	2.73	3.13
Calorific value					
Kurilnost	MJ/kg		19.6026	24.9784	28.6168
Ultimate analysis					
Elementarna analiza					
Carbon – Ogljik	C	%	48.94	60.85	59.71
Hydrogen – Vodik	H	%	3.68	4.57	5.24
Sulphur – Žveplo	S	%	2.19	2.73	3.13
Oxygen + Nitrogen					
Kisik + Dušik	O+N	%	15.39	19.13	21.92

The results of the coal analyses of the samples from the borehole Tdp-1/84 on the “as received basis” are the following (table 2).

Table 2. The chemical analysis of the coal samples from the borehole Tdp-1/84

Tabela 2. Kemična analiza vzorcev premoga iz vrtine Tdp-1/84

Proximate analysis Osnovna analiza	1	2	3
Total moisture Skupna vlaga	9.93	9.16	11.92
Ash – Pepel	19.07	29.47	9.99
Combustible matter Gorljive snovi	71.00	61.37	78.09
Coke – Koks	58.50	64.02	51.10
C-fix – C-fiks	39.43	34.55	41.11
Volatile matter Hlapne snovi	31.57	26.82	36.98
S total Celotno žveplo	1.10	0.98	2.32
S in ash Žveplo v pepelu	0.06	0.26	0.09
S combustible Gorljivo žveplo	1.04	0.72	2.23
Calorific value MJ/kg Kurilnost	20.356	15.935	22.496

Sample 1 – the coal within the footwall clay; depth 377.80–378.10 metres

Sample 2 – the coal between the footwall clay and the hanging wall marl; depth 368.30– 368.70 metres

Sample 3 – the coal from the upper part of the hanging wall marl; depth 343.40–343.70 metres

Hamrla (1987) examined the mean random huminite-vitrinite reflectance of the coal from the borehole Tdp-1/84 at the depth of 368 m. This coal horizon is situated along the contact between the footwall clay and the hanging wall marl. By its stratigraphic position and maturation it is comparable with the coal seam in the Laško synclinorium. It is known that the maturation of the organic substance in a sediment is reflected in change of chemical and physical parameters. The attained stadium of transformation is named the stage of maturation or rank. The Trobni Dol coal was characterized by Hamrla (1987) as a brilliant brown coal (“Glanzbraunkohle”) with the following values of the coal rank parameters: mean random vitrinite reflectance 0.60 %, carbon content 69 % (dry ash-free basis; d.a.f.), volatile matter 47.8 % (d.a.f.) and the total moisture content 25 %. The maximal depth of burial was estimated to 800 metres. The rank of the Trobni Dol coal is relatively high with respect to the coals

westward of the studied area. In Laško the coal rank amounts to 0.32 % and in Zagorje and Trbovlje 0.30 %. H a m r l a (1987) explained the anomalous rank of coal from the Trobni Dol area with possible thermal influence of andesite-dacite volcanism in the coal hanging wall. Petrascheck (1926/29) concluded that the higher maturity of the coal is caused by influences of marine environment after the formation of peat.

Fossils and age of coal-bearing beds

The age of coal was defined on the basis of macro and microfauna. S t u r (1871a,b) studied the rich macrofauna from the hanging wall beds and established their brackish character on the basis of certain marine species. In the yellowish white limestone from the Trobni Dol area he determined the following fossils:

Natica helicina Brocchi
Tympanotonus margaritaceum var. *marginatum* Grateloup
Pirenella plicata var. *papillata* Sandberger
Pirenella plicata var. *pustulata* Al. Brogniart
Cerithium rahtii Al. Brogniart
Littorinella acuta Al. Brogniart
Melania cf. *falcicostata* Hofmann
Cytherea incrassata var. *styriaca* Rolle
Cyrena semistriata Deshayes

In the dark gray sandy shale, which is most probably equivalent of the silty and sandy succession above the hanging wall marl, S t u r (1871) mentioned the following fossils:

Brotia escheri Brogniart
Brotia sotzkanensis Stur
Unio eibiswaldensis Stur
Chara sp.

S t u r (1871a,b) considered that the sediments from the Trobni Dol are the brackish and partly marine equivalent of the lacustrine "Socka" beds of Trbovlje. He correlated the brackish "Socka" beds with the Upper Oligocene beds and Cyrena marl in Siebenbürgen and Upper Bavaria. Granigg (1910) ranged the Trobni Dol coal beds into the Lower Miocene Govce beds. Petrascheck (1926/29) also mentioned the lacustrine limestone from the footwall of the main coal seam. According to the borehole Tdp-1/84 data the hanging wall limestone and marl are developed only in the footwall of the third coal seam. From the hanging wall marl, which is usually 60 cm thick, Petrascheck (1926/29) quoted beside above-enumerated also some other fossils, namely:

Congerina basteroti Deshayes
Cardium thunense (?) Mayer
Cerithium galeotti Nyst
Neritina picta Ferrusac

Beside brackish forms Stur (1871a,b) found in the waste material a dark gray sandy coal shale containing lacustrine fossils. The author could not define the position of these beds considering them brackish and marine. Munda (1939) tried repeatedly to determine the macrofauna of the coal-bearing succession, but the gathered material from the dump was not good enough to get new data and to permit conclusions. He considered the "Socka" beds to be of the Chattian age.

On the basis of determined microfossils Rijavec (1983, 1984a,c) concluded on the Oligocene age of the Trobni Dol coal horizons. At the depth 309.00 m to 326.00 m the washouts from the borehole Tdp-1/84 contain rare foraminifera *Cyclamina* sp., *Quinqueloculina* sp., Ostracoda as well as imprints and calcitic cores of gastropod tests. In this interval, at the depth to 313.10 m to 315.10 m, an interlayer of marly limestone in the sandy and silty succession was found. It is interesting that in the marly limestone, the richest fossiliferous layer in the whole borehole Tdp-1/84, numerous undeterminable gastropods and pelecypods have been found. We do not know with certainty whether Stur, Petrascheck, Munda and others found the macrofauna in a bed corresponding to this horizon, but it is very probable. In the borehole we found another horizon with less macrofauna in the immediate hanging wall marl at the basis of the sandy-silty succession.

Jelen (1984) examined 15 samples from the borehole Tdp-1/84 and examined 30 thin sections of the Pseudosocka beds and Oligocene Marine clay. In positive samples the palynological contents was poorly preserved. In the clayey coal at the depth 376.80 m Jelen (1984) determined the following palynologic species:

Spores: *Verrucatosporites favus favus* Thomson & Pflug

Verrucatosporites sp.

Laevigatosporites sp.

Pollen: *Monocolpopollenites tranquillus tranquillus* Thomson & Pflug

Inaperturopollenites hiatus Thomson & Pflug

In the sample of silt at the depth 312.80 m Jelen (1984) determined the following palynological contents:

Spores: *Verrucatosporites favus favus* Thomson & Pflug

Polypodiaceosporites sp.

Pollen: *Inaperturopollenites hiatus* Thomson & Pflug

Engelhardtoidites microcoryphaeus verus Thomson & Pflug

Monocolpopollenites sp.

Jelen concluded that in the lower part of the borehole Tdp-1/84 as well as in the "Socka" beds of the Zagorje coal basin undistinct similarities of the palynological spectrum can be shown. Similarities are also observed in the upper "Socka" beds of both areas.

Grayish Green Marine Marly Clay and Tuff – Lower Egerian

At the depth of 299.50 metres in the borehole Tdp-1/84 (Fig. 3) rests without discordance upon a sandstone the grayish green Marine marly clay. In the clay a foraminiferal fauna appears already 50 cm above the underlying sandstone. The

microfauna occurs upwards in numerous samples of the clay up to 159.40 metres. At that point begins a sedimentary succession composed of alternating dacite-andesitic fine-grained tuff, lapilli tuff and pyroclastic breccia. This succession goes on continually upwards as far as to the point of 28.50 metres where the grayish green Marine marly clay reappears, alternating with tuffs to up to 12.50 metres, the base of the overlying alluvial deposits. In the grayish Marine marly clay above the tuffs Rijavec (1984a,c) found similar microfauna as under the tuffs. On the basis of microfauna from the interval 16.7 m to 27 m Rijavec ascertained the probable Lower Egerian age of the beds. Beside numerous foraminifera *Almaena osnabrugensis* also foraminifer *Anomaloides granosus* is present. In numerous samples of the Marine marly clay between 158.30 m and 299 m Rijavec (1984a,c) determined the following Upper Oligocene (Egerian) foraminifera: *Glomospira charoides* (Parker & Jones), *Cyclammina acutidorsata* (Hantken), *Spiroplectammina carinata* (d'Orbigny), *Martinottiella communis* (d'Orbigny), *Cyclogyra polygyra* (Reuss), *Nodosaria longiscata* d'Orbigny, *Vaginulinopsis gladius* (Phillippi), *Vaginulinopsis pseudodecorata* Hagn, *Glandulina laevigata* d'Orbigny, *Sphaeroidina bulloides* d'Orbigny, *Stainforthia schreibersiana* (Czjzek), *Uvigerina* cf. *farinosa* Hantken, *Siphonina reticulata* (Czjzek), *Cibicides lobatulus* (Walker & Jacob), *Pullenia bulloides* (d'Orbigny), *Gyroidina soldanii* d'Orbigny, *Anomalina affinis* (Hantken), *Cibicidoides ungerianus* (d'Orbigny), *Hanzawaia boueana* (d'Orbigny), *Melonis soldanii* (d'Orbigny), *Almaena osnabrugensis* (Roemer), *Hoeglundina elegans* (d'Orbigny), *Bathysiphon filiformis* Sars, *Haplophragmoides* sp., *Textularia* sp., *Gaudryina* sp., *Karreriella* sp., *Nodosaria* sp., *Lenticulina* sp., *Guttulina* sp., *Uvigerina* sp., *Chilostomella* sp., *Gyroidina* sp., *Heterolepa* sp., *Melonis* sp., *Miliolidae*.

In the Marine marly clay above the dacite-andesitic pyroclastic succession at the depth from 28.50 m to 12.50 m Rijavec (1984a, c) determined the following foraminifera: *Glomospira charoides* (Parker & Jones), *Martinottiella communis* (d'Orbigny), *Glandulina laevigata* d'Orbigny, *Sphaeroidina bulloides* d'Orbigny, *Uvigerina hantkeni* Cushman & Edwards, *Pullenia bulloides* (d'Orbigny), *Gyroidina soldanii* d'Orbigny, *Anomalina affinis* (Hantken), *Anomaloides granosus* (Hantken), *Cibicidoides ungerianus* (d'Orbigny), *Heterolepa dutemplei* (d'Orbigny), *Melonis soldanii* (d'Orbigny), *Almaena osnabrugensis* (Roemer), *Globigerina* div. sp., *Textularia* sp., *Cyclogyra* sp., *Lenticulina* sp., *Guttulina* sp., *Uvigerina* sp., *Heterolepa* sp., *Miliolidae*.

Beside foraminifera in the Marine marly clay fish teeth, echinoid spines as well as limonitized and pyritized gastropod cores also occur.

For the Lower Egerian age are still characteristic numerous Paleogene foraminifera *Vaginulinopsis pseudodecorata*, *Vaginulinopsis gladius* and *Uvigerina hantkeni*. In the Lower Egerian beds estward and westward of Trobni Dol beside the above enumerated foraminifera also species *Tritaxia (Clavulinoides) szaboi* and *Planularia kubinyii* are found. The grayish Marine marly clay is the most characteristic and regional wide-extended Oligocene sediment in the Laško synclinorium, Gorenjska and the Savinja valley area. If andesitic tuffs occur, they usually lie in the hanging wall of the Marine marly clay. However, the Marine marly clay resembles very much to the Kiscell clay in Hungary. Opinions about the more precise age of the Marine marly clay and underlying Pseudosocka beds are still very different. A group of researchers (Kuščer, 1967; Buser, 1977, 1979; Cimerman, 1979; Pavšič, 1985; Jelen et al., 1990) attributed them the Middle Oligocene (Rupelian). Pavšič proved the age by means of nanoplankton. Jelen's statements about the Middle Oligocene

repose on palynological research. On the basis of several ten years of investigations of foraminifera in Slovenia Rijavec (1984a, b, c) and Rijavec & Pleničar (1979), arrived at a decision that the Marine marly clay is of Egerian age. In favour of this age also speak the results of investigations of miogypsins and lepidocyclins at Zagorje (Papp, 1954).

Lately, the results of absolute age datation on the basis of plagioclase from the volcanoclastic layers within the coal seam at Zagorje caused a great sensation (Odin et al., 1994). The analytical results indicate that the plagioclase samples were erupted at 25.0 ± 1.0 Ma (2 σ), therefore the volcanoclastic layers (Pseudosocka beds) containing the plagioclase were deposited during the Late Chattian. The precise age corresponds to the Lower Egerian, accurately to Late Chattian. The grayish green Marine marly clay lies directly upon the Pseudosocka beds with coal: according to this their Lower Egerian age is confirmed. Regarding numerous unsolved questions it will be necessary to continue systematic research of individual Oligocene basins in Slovenia. This research is also interesting and important for adjacent regions i.e. for the whole sedimentary area of the former Paratethys. Indications exist that from Hungary across Slovenia to Italy there was a relatively uniform sedimentary basin.

Oligo-Miocene and Miocene beds

Over the andesitic tuff lie the beds which were deposited between the Upper Oligocene and the Lower Miocene, and which can not be subdivided either by fauna or lithologically. Accordingly, the grayish green to brownish sandy clay as well as the beds of sandy clay sandstone and sand are ranged into the Upper Egerian (Petrica et al., 1995). According to lithologic and paleontologic characteristics the sandy-clayey beds, which in other parts of the Laško synclinorium overlie the Marine marly clay, correspond to the lower Govce beds. In the Trobni Dol area the upper Govce beds (Eggenburgian), Laško beds (Badenian) and incomplete Sarmatian beds are developed, too. The enumerated beds area already described in detail (see: Dozet & Rijavec, 1994; Petrica et al., 1995).

Structural relations

The investigated area is a part of the eastern continuation of the Tertiary belt which appears at Moravče and passes through Zagorje, Trbovlje, Hrastnik, Laško and east of Savinja. The entire Tertiary belt belongs to the Sava folds tectonic unit. Kuščer (1967) denominated the belt as Laško synclinorium, whereas other authors use the name Laško syncline.

The Tertiary beds of the investigated area were subjected to two types of deformations:

- 1) The deformations originated during the Tertiary sedimentation, manifested as erosional and tectonical-erosional discordances between the Pseudosocka beds and Pre-Tertiary basement, the Lower Miocene and Badenian (Tortonian) beds as well as the Badenian and Sarmatian ones.

- 2) The deformations occurred after the deposition of the Sarmatian beds. They were caused by orogenic activity which folded the Tertiary beds of the whole area. Kuščer (1967) found that the main orogenic phase in the Sava folds, which caused

the folding of the Tertiary beds and influenced the origin of structures, was the Attic orogenic phase that was active in the Lower Pliocene. Forces which caused the folding were acting from the north to the south. To the second type of tectonic deformations two synclines (Laško, Planina) and the anticline Rudnica between them are ranged.

During and after the folding came to a faulting and deformation of the folded structures. Fault systems with directions NW-SE, SW-NE, N-S and W-E originated. The strongest fault systems were those with the NW-SE and W-E direction. In the Laško syncline the synform was preserved undisturbed. Deformations arose at the northern flank where along the W-E fault at Podgorje one part of this limb sank, so that in the northern flank area the andesitic tuff came in tectonic contact with the Pre-Tertiary rocks. However, in the northern flank a normal succession of beds without any essential changes is observed. The synclinal core is built of Laško marl strata.

The southern limb of the Laško syncline is also deformed. The preserved part of northern syncline and the core are somewhat sunk along the W-E fault regarding the southern limb which in the central part of investigated area strongly turned to the NE.

Between Resje and Matizel the southern limb of the syncline is divided in some smaller local synforms and antiforms. Only in the western part of the investigated area the southern limb preserved his shape. The limb was deformed along NW-SE, W-E and N-S faults. In the southern limb of the Laško syncline the upper Pseudosocka beds, Oligocene Marine clay, Govce beds and Laško beds are developed.

The crest of the Rudnica anticline is deformed similarly as the southern limb of the Laško syncline. It turns to the NE and becomes divided between Matizel and Resje in several smaller folds, synforms and antiforms respectively. Because of predominantly clayey sediments and consequently a small density of measured dips it is not possible to define everywhere the crest of the anticline. The anticlinal crest passes through the grayish green marly clay in the western part of the investigated area, and east of the road Mala Breza-Trobni Dol it is totally invisible.

The southern Planina syncline is also strongly deformed, especially its southern limb which is overthrust by the beds of the Pre-Tertiary basement. In the northern limb there are the same sediments as in the Laško syncline, with distinction that the Upper Oligocene sandy beds and Pseudosocka beds do not outcrop there. In the eastern part of the mapped area the northern limb continues up to Matizel. The sandy clayey Egerian beds outcrop there, whereas in the western part of the mapped area the grayish green Egerian clay is to be found. Upwards in the northern limb the normal Tertiary succession follows. In the synclinal core there are Sarmatian sandy marly clays and Sarmatian conglomerate, belonging according Winkler (1924) to the Cynthetic Delta. The anticlinal axis has a direction SE-NE. The southern limb between Globoko and Mirni Dol is strongly tectonically deformed. In this area the Pre-Tertiary basement lies over the southern limb of the Planina syncline. For that reason the Sarmatian and Egerian beds are in inverse position. Consequently, between Mirni Dol and Globoko the Planina syncline passes to a plunging fold. Inside of the plunging southern limb of the syncline it also came to thrusting of Tertiary beds (Sarmatian and Egerian beds). In the eastern part of the area between Pojerje and Blatni Vrh it came to folding and smaller overthrusting. Also in the southern part of the Planina syncline the development of beds is normal from the Upper Oligocene to the Middle Sarmatian, but they are owing to strong tectonic deformations very thinned.

In the mapped area the most expressive fault system has the NW-SE direction.

Faults of this system transverse the whole area. It came to horizontal movements along the faults. Along the faults N-S and W-E especially the latter, occurred larger and stronger vertical movements of the studied area. For example, at Podgorje the northern limb of the syncline sank along the W-E fault. On the other hand, the faults in SW-NE direction did not essentially influence the geological structure of the mapped area.

Suggestion for further investigations

The most perspective area for investigation with exploration boring, regarding the results of detailed geological mappings and the boreholes, is the southern limb area of the Laško syncline. Especially perspective is the southern limb, from the road Trobni dol-Breze towards the west in the continuation of the Trobni Dol Oto coal field. In this part of the limb an about 30 cm thick coal seam outcrops. The coal lies between clastic and marly sediments corresponding to the Pseudosocka beds. The western part of the southern limb is not deformed so much that it would come to folding within the southern limb; in such a manner this part of fold preserved its shape. The beds in the southern limb area dip 25° to 35° towards NW. Regarding all these conditions we believe that this area is favourable for further investigation with exploration drilling.

The northern limb of the Laško syncline at Podgorje, can also be prospective for further coal investigation with drilling since these beds are not tectonically deformed except along the contact with the Pre-Tertiary basement. If taking into account the thickness of individual lithostratigraphic members found out by detailed geological mapping we expect there a coal seam at the depth about 300–350 metres. Less prospective is the area of the Planina syncline and eastern part of the southern limb of the Laško syncline. In this part of the investigated area, in Egerian outcrops and along the contact with the Pre-Tertiary basement, there are no Pseudosocka or analogous beds, because towards the north they wedged out. Over the Pre-Tertiary basement lie sandy-clayey beds containing coal lenses. In the beds of gray to white sand and sandstone at Laška Vas we found several about 10–20 cm thick outcrops of coal. This syncline is also strongly tectonically affected. Its southern part is overthrust so that the Pre-Tertiary rocks are overthrust upon the Tertiary ones.

In the Planina syncline area of some interest is the Pojerje locality where before the Second World War an up to 4 metres thick coal seam was excavated. For this area it would be necessary to find out whether the coal seam appears also in the north-eastern continuation of the abandoned Pojerje coal-mine; therefore, the area is prospective for investigation with drilling. The eastern part of the southern limb of the Laško syncline is divided along the faults into several smaller folds with steep limbs. At present stage of investigations of the terrain this part is not suitable for exploration by drilling.

Summary

In the Trobni Dol area lie discordantly over the Pre-Tertiary basement Oligocene Pseudosocka beds intercalated with thinner seams of brown coal. They are comparable with the productive Pseudosocka beds in the wider Laško synclinorium area

towards the west, between Laško and Zagorje, where economically more important coal field and coal mines are situated.

In the Trobni Dol area, 8 km east of Laško, the brown coal was excavated in the past, and carried away by narrow-gauged railway. The beds with coal at Trobni Dol are exposed in a deformed anticline. The anticline is better expressed in the Rudnica area where in the anticlinal core prevalently the Triassic rocks came to light. At the depth of 385.00 m in the structural borehole Trobni Dol Tdp-1/84 lies discordantly upon the Triassic dolomite a 14.85 m thick footwall clay. Upon the footwall clay rests conformably a 40 cm thick brown coal seam which is by its stratigraphic position comparable with the productive coal seam in the area between Laško and Zagorje.

Upon the coal lies a 26.85 m thick succession of fine stratified marly limestone. It is called the hanging wall marl, and this is also a very typical horizon in the area between Laško and Zagorje.

Continuously over the marly limestone lies the 42 m thick succession of rhythmic alternating siltstone and sandstone which end the sedimentation of the Pseudosocka beds. At the depth of 299.50 metres starts without any visible discordance about a 140 m thick succession of bluish gray Marine marly clay known by the name "Sivica" and mostly containing rich microfauna which indicate the lower part of Egerian. Upwards, upon the Marine clay, at the depth 159.40 m, starts a cca 131 m thick pyroclastic succession. Above the Marine clay, from the depth 28.50 m, alternate a pelitic tuff and Marine marly clay with the Lower Egerian microfauna. The Marine clay is the typical Oligocene sediment in the wider area of central and eastern Slovenia. By its lithologic development it is comparable with the Kiscell clay from Hungary. Pyroclastic rocks are products of high silica dacite magma belonging to ignimbrites. Their characteristics indicate submarine pyroclastic streams. Pyroclastic rocks in the Trobni Dol area are the extreme westerly exposed larger outcrops of volcanic rocks in the Laško synclinorium. East of Trobni Dol we found them at Žusem in the Rudnica area. Towards the west the volcanic rocks occur in the form of thinner interbeds in the coal and Marine marly clay.

Discussion and Conclusions

The Pseudosocka beds at Trobni Dol show certain litostratigraphic differences in the upper part regarding their development towards the west. Namely, the Pseudosocka beds between Laško and Zagorje end with the hanging wall marl. At Zagorje Kuščer (1967) mentioned a special development of the upper Pseudosocka beds that are composed of grayish brown shale which often contains leaf imprints. There are several interlayers of sand within the shale succession resembling the Govce sand. East of the Kotredež brook there are clastic quartz sediments within the shale. Kuščer (1967) considered them the hanging wall. The Oligocene Marine clay with foraminifera at Potoška vas near Zagorje lies concordantly upon the shale. A similar stratigraphic position can be seen in the Trobni Dol borehole where the Marine clay lies concordantly upon the quartz sandstone and siltstone. It is necessary to emphasize that the alternation of sandstone and siltstone above the hanging wall marl in the borehole Tdp-1/84 does not represent any lateral equivalent in the area of the Laško synclinorium. The Pseudosocka beds of the area studied are divisible into the lower Pseudosocka beds, the main coal horizon, and the upper Pseudosocka beds. In the borehole Tdp-1/84 three coal seams occur. On the other hand, in the mapped

area some other very thin (up to 1 cm) coal seams are to be found in the uppermost part of the Pseudosocka succession. Determined macro- and microfauna indicates that the Trobni Dol coal is of the Upper Oligocene age.

The characteristics of the footwall, main coal horizon and hanging wall sediments indicate the following chronology of the geologic events:

1. Supply of continental waters which filled the depression with clay and sandy material, and deposition of the footwall clay.
2. Periodical ingressions of the sea caused mixing of the marine, brackish and limnic sedimentation and fauna.
3. The gathered fauna indicates predominantly brackish and limnic character of the coal-bearing beds. Limnic are probably the lower Pseudosocka beds under the main coal horizon.
4. The hanging wall marl is mostly a brackish sediment formed in a shallow lagoon. After the formation of the hanging wall marl owing to the intensive shallowing of the sea repeated filling up with sandy material occurred.
5. After the deposition of the hanging wall marls it came in the lagoon to a stronger continental water supply which filled up the lagoon with sandy material. In a brackish environment a vegetation reappeared, what is proved by lenselike coal seams and charred plant remains in the Upper Pseudosocka beds.
6. The sinking of the investigated area was intensified and the lagoon was flooded with the sea water; in a new somewhat deeper environment the marine Upper Oligocene grayish green limy clay was deposited what is proved by a rich foraminiferal fauna.

Acknowledgements

We are greatly indebted to Prof. Dr. Vasja Mikuž for revision of macrofauna from the Pseudosocka beds according to data of Stur, Petrascheck and Munda. For technical assistance in drafting and typing we would like to thank Ms. Metka Karer and Ms. Marjeta Oman.

Pseudosoteške plasti s premogom v vrtini Tdp-1/84 Trobni Dol (vzhodne Posavske gube)

Cilj članka je podrobneje prikazati zaporedje in razvoj oligocenske skladovnice Trobnega Dola in ga primerjati z razvojem zahodnejše v Laškem sinklinoriju. V okviru raziskav premoga na območju Trobnega Dola vzhodno od Laškega sta bili poleg geološkega kartiranja površine na območju premogovnika Trobni Dol izvrtani raziskovalni vrtini Tdp-1/84 globine 385 m in Tdp-2/84 globine 400 m. Za preučevanje litostratigrafskih razmer je pomembnejša vrtina Tdp-1/84, ker je prevrtala normalno zaporedje oligocenskih plasti in dosegla predterciarno podlago. Vrtina Tdp-2/84 zaradi tektonskih razmer ni dosegla produktivnih plasti s premogom.

Na sl. 2 in sl. 3 je prikazan razvoj oligocenskih plasti Trobnega Dola, ki jih po mikropaleontoloških raziskavah foraminifer prištevamo k zgornjemu oligocenu oz. spodnjemu egeriju. Pseudosoteške plasti so limnično-brakične. Pričenjajo se s talno glino in z vložkom premoga. Na talni glini je v vrtini 40 cm debela plast svetlega rjavega premoga. V krovni premoga je 27 m debela skladovnica drobnoplastovitega krovnega lapornega apnenca. Krovni lapor je prekrit z 42 m debelim sedimentnim zaporedjem, ki ga sestavlja ritmično menjavanje peščenjaka in meljevca. Te plasti prehajajo brez diskordance v 140 m debelo lapornato glino, bogato s foraminiferami, ki kažejo na spodnji egerij. Ta glina je zelo razširjena v osrednji Sloveniji, podobna pa je Kiscelski glini na Madžarskem. V normalnem zaporedju leži na laporasti glini 131 m debela piroklastična skladovnica, ki je produkt visoko silicijske dacitne magme. Piroklastiti prehajajo navzgor v laporasto glino s podobno foraminiferno mikrofavno, kakršna je v njihovi talnini.

Večino litostratigrafskih členov iz Trobnega Dola moremo primerjati z razmerami zahodnejše v Laškem sinklinoriju, kjer je razvit premogov sloj, ki ga odkopavajo v več premogovnikih. Spodnji produktivni del v Trobnem Dolu prištevamo k Pseudosoteškim plastem. Te so bile doslej obravnavane kot Soteške plasti. Omenili smo že, da se pseudosoteška skladovnica Trobnega Dola pričenja s talno glino, ki vsebuje tanke vložke drobnega proda in 30 cm debel vložek premoga in da talni glini sledi v vrtini 40 cm debela plast rjavega premoga. Slednjega primerjamo po legi in glede na značaj talnine in krovne s produktivnim premogovim slojem med Laškim in Zagorjem. Premog pripada svetlemu rjavemu premogu in ima odsevnost 0,60 % Ro, ki je najvišja med oligocenskimi vrstami premoga Laškega sinklinorija. Visoko odsevnost premoga je mogoče razložiti s termičnim vplivom vulkanizma pri Trobnem Dolu.

S korelacijo litostratigrafskih členov smo ugotovili, da v krovni laporja ležeča 42 m debela skladovnica Trobnega Dola, ki jo sestavlja ritmično menjavanje peščenjaka in meljevca, ni značilna za Pseudosoteške plasti proti zahodu.

Piroklastiti so v Laškem sinklinoriju razkriti v večjem obsegu le na območju Rudnice; zahodno od Trobnega Dola pa se v lapornati glini pojavljajo samo tanjši vložki tufov in tufitov.

References

- Bittner, A. 1884: Die Tertiär-Ablagerungen von Trifail und Sagor. – Jb. Geol. R.-A., 34, 433–600, Wien.
- Buser, S. 1977: Osnovna geološka karta SFRJ, list Celje 1:100 000. – Zvezni geološki zavod, Beograd.
- Buser, S. 1979: Tolmač lista Celje. Osnovna geološka karta SFRJ 1:100 000. – Zvezni geološki zavod, 72pp., Beograd.
- Cimerman, F. 1967: Oligocene beds in Upper Carniola (Slovenia) and their foraminiferal fauna. – Bull. Sci. Conseil Acad. RSF Yugoslavia, 12, 251–253, Ljubljana.
- Cimerman, F. 1979: Oligocene beds in Slovenia. In: Drobne (ed.), Geological development in Slovenia and Croatia, Guidebook. – 16th European Micropaleontological Colloquium, 65–70, Ljubljana.
- Dozet, S. 1985: Poročilo o geoloških raziskavah na območju rudniške antiklinale. – Geološki zavod, 16 pp., Ljubljana.
- Dozet, S. & Rijavec, L. 1994: On the geological relations of the Šentjur-Planina-Trobni dol-Loka at Zusem area. – Rud.-met. zbornik, 41, 27–41, Ljubljana.
- Grad, K. 1962: Geološke razmere med Rudnico in Savo. – Geologija, 7, 113–118, Ljubljana.
- Grad, K. 1967: Geologija Kozjanskega. – Geogr. zbornik, 4 razr. SAZU, 10, 7–16, Ljubljana.
- Granigg, B. 1910: Mitteilungen über die steiermärkischen Kohlenvorkommen am Ostfuss der Alpen Österr. – Ztsch. f. Berg.-u. Hüttenwesen, 58, 41., Wien.
- Grill, R. 1941: Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molassic-Anteilen. – Oel und Kohle, 37, 595–602, Berlin.
- Hamrla, M. 1954: Geološke razmere ob severnem robu laške sinklinale vzhodno od Savinje. – Geologija, 2, 118–144, Ljubljana.
- Hamrla, M. 1955: Geologija Rudnice s posebnim ozirom na rudne pojave. – Geologija, 3, 81–109, Ljubljana.
- Hamrla, M. 1987: Optična odsevnost nekaterih slovenskih premogov. – Geologija, 28/29, 293–317, Ljubljana.
- Jelen, M. 1984: Poročilo o palinološki raziskavi vzorcev jedra vrtine Tdp-1/84 (Trobni dol). – Geološki zavod, Ljubljana.
- Jelen, M., Mervič, H., Horvat, A. & Pavšič, J. 1990: Sprememba mikrofosilnih združb v oligocenu Zasavja. – Geologija 31, 32, 329–345, 1988/89 Ljubljana.
- Jelen, M., Aničič, B., Brezigar, A., Buser, S., Cimerman, F., Drobne, K., Monostori, M., Kedves, M., Pavšič, J., & Skaberne, D., 1992: Model of positional relationships for Upper Paleogene and Miocene strata in Slovenia. In: Interdisciplinary Geological conference on the Miocene epoch, 1992, IUGS subcommission on Geochronology; Ancona. Abstracts and field trips. 71–72.
- Jelen, B., Kedves, M., Skaberne, D., Brezigar, A., Buser, S., Cimerman, F., Drobne, K., Monostori, M., Pavlovec, R. & Pavšič, J. 1994: Dorog type (Middle Eocene) Spore-pollen assemblage in the Socka Beds of Slovenia I. – Plant Cell Biology and Development, 5, 20–28, Szeged.
- Kovič, P. 1984: Poročilo o petroloških preiskavah piroklastitov vrtine Tdp-1/84 iz Trobnega Dola. – Geološki zavod Ljubljana.
- Kovič, P. 1985: Sedimentološke raziskave v severovzhodni Sloveniji. – Geološki zavod, 14 pp., Ljubljana.
- Kuščer, D. 1962: Terciar Posavskih gub. Elaborat za sklad Borisa Kidriča, Ljubljana.
- Kuščer, D. 1967: Zagorski terciar. – Geologija, 10, 5–58, Ljubljana.
- Mioč, P., Ravnik, D. & Hamrla, M. 1983: Geološke in geofizikalne raziskave na območju Šmarjeta-Lahomno. – Geološki zavod, 38 pp, Ljubljana.
- Mišič, M., 1984: Mineraloške raziskave glin v letu 19984 – Vrtina Tdp-1/84. Geološki zavod Ljubljana.
- Munda, M. 1939: Stratigrafske in tektonske prilike v rajhenburški terciarni kadunji. Inavguralna disertacija. – Rud.met. zbornik, 3, 49–170, Ljubljana.
- Munda, M. 1942: Poročilo o nahajališču rjavega premoga v Babni gori pri Žusmu. – Geološki zavod, Ljubljana.
- Munda, M. 1953: Geološko kartiranje med Hrastnikom in Laškim. – Geologija, 1, 37–89, Ljubljana.
- Nosan, A. 1956: Razvoj oligocena in miocena v Sloveniji. – Prvi jugosl. geol. kongres (Bled), 47–54, Ljubljana.
- Odin, G. S., Jelen, B., Drobne, K., Uhan, J., Skaberne, D., Pavšič, J., Cimerman, F., Cosca, M. & Hunziker, J. C. 1994: Premiers Eger geochronologiques de niveaux volcanoclastiques oligocenes de la Région de Zasavje, Slovénie. – Giorn. Geol., ser. 3^a, vol. 56/1, 199–212, Bologna.

- Orehek, S. & Kovič, P. 1984: Poročilo o sedimentološki raziskavi vzorcev Trobni dol. – Geološki zavod, 9 pp., Ljubljana.
- Papp, A. 1954: Miogypsinidae aus den Oligozän von Zagorje (Slowenien, Jugoslawien). – *Geologija*, 2, 168–178, Ljubljana.
- Papp, A. 1955: Lepidocyclinen aus Zagorje und Tuhinjska dolina östlich von Kamnik (Slowenien). – *Geologija*, 3, 209–215, Ljubljana.
- Papp, A. 1963: Die biostratigraphische Gliederung des Neogens im Wiener Becken. – *Mitt. Geol. Ges.*, 56/1, 225–317, Wien.
- Papp, A. 1975: Die Grossforaminiferen des Egerien. In: T. Baldi et J. Seneš (Ed.): OM Egerien. Chronostratigraphie und Neostatotypen. – *Miozän der Zentralen Paratethys*, 5, 289–297.
- Pavšič, J. 1983: Sur l'âge des argiles de la base de l'Oligocène de Poljščica. – *Geološki zbornik*, 4, 93–99, Ljubljana.
- Pavšič, J. 1985: Nannoplancton de la partie inférieure de l'argile marine oligocène en Sloénie. – *Geološki glasnik*, 28/2, 171–177, Ljubljana.
- Petrascheck, W. 1926/29: Die Kohlenlager der Dinarischen Gebirge Altösterreichs (Jugoslawien und Italien). – *Kohlengologie der österreichischen Teilstaaten*, II. Teil, 321–360, Katowice.
- Petrica, R. 1983: Raziskave premoga na območju Trobni dol. – *Geološki zavod*, 21 pp., Ljubljana.
- Petrica, R., Rijavec, L. & Dozet, S. 1995: Stratigraphy of the Upper Oligocene and Miocene beds in the Trobni dol area (Kozjansko). – *Rud.-met. zbornik*, 42/3–4, 127–141, Ljubljana.
- Rijavec, L. 1959: Mikropaleontološko poročilo o vzorcih okolice Loke pri Žusmu, Šmarja pri Jelšah in Podplata. – *Geološki zavod*, Ljubljana.
- Rijavec, L. 1965: Razvoj terciarnih sedimentov med Rudnico in Bočem. – *Geologija*, 8, 112–118, Ljubljana.
- Rijavec, L. 1974: Mikropaleontološka raziskava vzorcev lista Celje 1:100 000 za leto 1970–1974. Manuskript. – *Geološki zavod*, Ljubljana.
- Rijavec, L. 1983: Mikropaleontološka raziskava vzorcev iz okolice Trobnega dola. – *Geološki zavod*, 8 pp., Ljubljana.
- Rijavec, L. 1984a: Biostratigrafske raziskave v vzhodni Sloveniji za leto 1984. Manuskript. – *Geološki zavod*, 17 pp., Ljubljana.
- Rijavec, L. 1984b: Oligocen i miocen područja između Rudnice i Boča (Istočna Slovenija) na osnovi mikrofosila. – *Disertacija*, 142 pp., Zagreb.
- Rijavec, L. 1984c: Mikropaleontološke raziskave vzorcev iz vrtine Tdp-1/84 (Trobni dol). – *Geološki zavod*, 7 pp., Ljubljana.
- Rijavec, L. 1986: Mikropaleontološke raziskave vzorcev iz vrtine Tdp-2/84 (Trobni dol). – *Geološki zavod*, 18 pp., Ljubljana.
- Rijavec, L. & Pleničar, M. 1979: Neogene beds in Slovenia. Geological development in Slovenia and Croatia, Guidebook. – 16th European Micropaleontological. Colloquium. 71–78, Ljubljana.
- Stur, D. 1871a: *Geologie der Steiermark*, 654 pp., Graz.
- Stur, D. 1871b: Versteinerungen aus den Sotzkaschichten von Kink bei Reichenstein in Untersteiermark. – *Verh. Geol. R.-A.*, 95 pp., Wien.
- Zollikofer, Th. 1861: Ueber die geologischen Verhältnisse des Südöstlichen Teiles von Untersteiermark. – *Jb. Geol. R.-A.*, 12, 311–366, Wien.
- Winkler, A. 1924: Ueber den Bau der östlichen Südalpen. – *Mitt. Geol. Ges.*, 16, 1–272, Wien.