Petrographic characteristics of coal from waste dump of abandoned mine Gruve 2 in Longyearbyen, Svalbard

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Abstract. In the paper the petrographic characteristics of coal from waste dump of abandoned mine Gruve 2 in Logyearbyen, Svalbard are described. The coal samples originated from a dump of waste material, situated near the mine entrance. The microscopic petrographic features as well as random reflectance were tested. Basic chemical-technological parameters as moisture $W_t$, ash content $A_{db}$, volatile matter content $V_{daf}$, total sulphur content $S_{db}$ and gross calorific value $Q_{s,daf}$ were assigned. The samples examined belong to medium rank $D$ (ortobituminous coals), macerals of the vitrinite group prevail in the coals’ petrographic composition. The coals analyzed are characterized by low ash and sulphur content but high volatile matter content and mean values of the combustion heat.

1. Introduction
The Svalbard archipelago is located in the Arctic Sea and belongs to Norway. It extends between $76^\circ$ 28’ N and $80^\circ$ 49’ N as well as $10^\circ$ 32’ E and $33^\circ$ 31’ E. The area of the archipelago is 62 924 km$^2$. Svalbard consists of several islands and the largest one is Spitsbergen (Vestspitsbergen) – 39 368 km$^2$. The capital city Longyearbyen is located in the middle of the main island, in Isfjorden area. This is also where majority of Spitsbergen inhabitants live (altogether 2.7 thousand, 2017). In Longyearbyen one will also find a coal mine Gruve 2, called Julenissegruva (figure 1).

The archipelago of Svalbard forms the emergent northwestern corner of the Barents Sea Shelf, which was uplifted by Late Mesozoic and Cenozoic crustal movements. In the geological composition of Svalbard it can be distinguished two structural floors: crystalline pre-Devonian basement and differentiated sediment cover. Crystalline basement involves rich complex of metamorphic rocks called Hecla Hoek Succession [Harland 1997].

In the region of Svalbard occur coal seams of various age and coalification grade. They comprise both lignite, hard coal and anthracite [Birkenmajer 1992; Zagożdżon 2013].

The Longyear seam belongs to the Central Basin situated in the central Spitsbergen and it represents Tondalen layers (Paleocene) of Firkanten formation. Thickness of the Longyear seam reaches 1.25 m and the coals range from hvb c to hvb a type [1].

The samples described in the paper come from Longyearbyen area, where the deposits fall under the angle 4-6° (locally 12-16°) to the south [Gabzdyl]. There are up to five seams with extension reaching 50 km. On the 20-meter sector of profile occur (from the bottom) following seams: Svea (1,3 m), Todalen (0,2-0,6 m), Longyear (1,25-1,7 m), Svarteper (0,5 m) and Askeladd (1,4 m) [Gabzdyl, Harland, Piepjohn].
The Longyearbyen area located in Isfjorden represents an area with the largest in the whole archipelago quantity old mines. The oldest mine, Gruve 1, (also known as Amerikanergruva,) was founded in 1906. The mine was in operation since the beginning of 1920. In 1938 a decision was made to open mine Gruve 1b, located in the same coal seam as Gruve 1, where the exploitation took place until 1958. The Gruve 2 was opened in 1922, it was partially equipped with machines taken from Gruve 1 mine. In 1941 over 300,000 Mg coal per year was produced in those mines. In 1937 a new shaft was opened in Gruve 2b mine, named Julenissegruva and located in the southern district of Longyearbyen. In 1941, residents of Longyearbyen were evacuated because of war activities, and the mine was destroyed and set on fire by the German in 1943. The fire last until 1962. Mining was continued until the turn of the years 1967/68 [6].

In the paper there are characterized coals and their parameters of quality are analyzed, in order to ascertain if they fulfil conditions required nowadays by solid fuels. The paper includes a contribution for discussion about relevance of continuing and developing of coal exploitation in Longyearbyen and possible recovery of coal from the dump of coal mining wastes.

![Figure 1. Map of coal mines in Isfjorden](image-url)
2. Sampling and methodology

Nowadays in closed coal mine Gruve 2 the entrance to the adit has been blocked by ice and permafrost and that is why it is impossible to take coal samples directly from the seam (at the exploitation face, from the gallery sidewall etc.). Therefore, the coal samples have been taken from a small coal dump which originated in the place where the excavated material was loaded to the cable car (figure 2). The Gruve 2 mine exploited the only coal seam in the limited surface, therefore, it may be assumed that the taken samples are representative for the coal occurring in this area of Longyearbyen.

![Gruve 2 coal mine. The arrow shows the place of coal sampling.](image)

Four coal samples (L1, L2, L3, L5) and one sample of mudstone with layers of vitreous coal (L4) were selected from among the samples of coal and rocks. They were next turned into polished sections for microscopic petrographic tests as well as vitrinite concentrate briquettes for mean reflectance tests.

Microscopic examinations and the assignment of random reflectance were done using microscope Axioscope Zeiss equipped in microphotometre. Additionally in the coal samples (L1, L2, L3, L5) there were examined basic chemical-technological parameters: moisture $W_a$, ash content $A_{db}$, volatile matter content $VM_{daf}$, total sulphur content $S_{db}$ and calorific value $Q_{s,daf}$. These assignments were done according to Polish standards (PN-80/G-04511, PN-80/G-04512, PN-81/G-04516, PN-81/G-04513, PN-81/G-04514).

3. Petrographic description of the samples

Microscopic tests showed a significant diversity of the examined coal samples. Sample L1 – represents bright coal [7]. It demonstrates predominant content of macerals of vitrinite group (80%), where telinite prevails over collotelinite (table 1). In some places the presence of pseudovitrinite with typical stratification and structure as in telinite was observed. Occurrence and genesis of so called pseudovitrinite, as already known, are not straightforward. In 1997 in Wellington a working group named "Pseudovitrinite" of ICCP distinguished pseudovitrinite next to the macerals of vitrinite group [8; 9].

The higher value of mean random reflectance in the examined samples of coal (at 0.1-0.2% in comparison to vitrinite confirms presence of vitrinite; this may result from a direct neighbourhood of inertinite [18; 12].
The configuration of small slits, cracks and scratches which are parallel or perpendicular to bedding clefts is also distinct as well as the lack of pyrite in these grains [10] (figure 3).

![Figure 3. Pseudovitrinite with parallel slits visible.](image1)

![Figure 4. Funginite in vitrinite.](image2)

The presence of pseudovitrinite in coal may indicate to drier conditions during the sedimentation of peat [9, 11]. On the basis of some extensive research, Taylor G.H., et al. [12] concluded that the majority of pseudovitrinites originated in telmatic forest or reed-forest environment with low level of groundwater. Such conditions facilitated permanent inflow of oxygen to the peat which was under intensive gelification. Periods of significant drop of water level and surfacing of the swamp enabled oxidation of gelified parts of the peat. Koch J [13] suggests that laminas of pseudovitrinite are remnants after gymnosperms forest plants’ roots.

![Figure 5. Weathering cracks filled with a mineral substance.](image3)

![Figure 6. Semifusinite.](image4)

The content of macerals of inertinite groups (9%) and liptinite groups (7%) is relatively low. This composition indicates (simplifying) that this lithotype originated in paleoswamp in stable facies conditions. However, periods of higher or lower water level could have occurred when thin laminas of water enriched in liptinite or inertinite originated.

Diverse content of inertinite in the sample calls some attention (table 1), particularly the presence of funginite and secretinite which suggests that the presence of fungus spores and tissues of fungi forming secretions contributed to decomposition of wood material (figure 4). The domination of cutinite in the liptinite group was observed.
The presence of mineral matter is low (4%) with the highest participation of secondary carbonates which fill cellular spaces and weathering microcracks (figure 5). Pyrite is present in slits of cracks, but it may also be observed, to a lesser extent, in dispersion form. Clay minerals showed the smallest participation.

Sample L2 represents the type of banded bright coal. It reveals lower content of vitrinite (57 %) with higher content of inertinite (21%) and liptinite (19%) than in the L1 coal sample (table 1, figure 6). As far as the group of inertinite is concerned, inertodetrinite and micrinite showed the highest share. Fusinite and semifusinite cells are filled mainly with carbonates. Sporinite prevailed in the liptinite group.

Petrographic composition shows that this coal could be formed when the facies conditions in paleoswamp at biochemical stage of this lithotype formation were clearly transient to a moist and even highly moist environment [7].

It is also confirmed by low content of mineral substances (3 %). The highest share was showed here by carbonates, lower – by sulphides and the lowest by clay minerals.

Sample L3 represents the type of coal which is similar to sample L1 and which belongs to bright coal (figure 7). The sample examined has slightly lower content of vitrinite (74%) and a higher content of inertinite (12%) and liptinite (9%) than it was observed in sample L1 (table 1). Also the presence of funginite and secretinite was observed in this sample.

Participation of mineral substance was also low (5%) with domination of carbonates. Sample L5 represents dull coal and, comparing to other samples, it shows high content of liptinite (32%) and inertinite (11 %) and low content of vitrinite (41 %) (table 1).

This type of coal has the highest content of mineral substance 4 (16 %) with the highest participation of sulphides as well. Carbonates have some smaller share in this sample, whereas the content of clay minerals is the lowest. The presence of biotite was also observed in this sample (figure 8); the biotite had already been observed earlier in the Longyear seams coal and described by other authors [14].

Particular attention in the sample is paid to the diversity of forms of mineral substance occurrence. The most frequent way of coal grains mineralization with pyrite is the dispersed form in a shape of small grains of ca. 1 µm. The genesis of pyrite in this form is attributed to the processes at syngenesis stage. A similar type of pyrite also fills (but to a lower extent) cellular spaces in fusinite, it is described as early diagenetic formation [11; 21]. Euhedral pyrite with regular cristal habit of grains with dimensions of up to 10µm was also observed. It was often seen in the cells of fusinite (figure 9). Compact and massive grain concentration of euhedral form, creating isolated and irregular or lenticular form could also be found in basic coal mass and sometimes they accompanied clay minerals. The euhedral form of sulphides was formed at the stage of syngenesis and early diagenesis [12; 15].

![Figure 7. Macerals of inertinite group (funginite, semifusinite) and liptinite group (resinite).](image)

![Figure 8. Mineral from mica group (biotite?).](image)
Pyrite in the framboidal form creating nodular concentrations ranging from several to dozens micrometers (figure 10) was also found in the coal mass. It forms two genetic varieties. One of them is framboidal pyrite of bacteria origin which forms micrograin aggregates among clay minerals. Whereas the second is pyrite representing massive nodular concentrations or forms divided by crystals of secondary carbonates. The origin of framboidal pyrite is considered as syngenetic or early-diagenetic [12; 15; 16].

Microscope analysis also showed pyrite in a form of small veins filling slits or cracks. The pyrite filling these spaces has massive form, rarely euhedral or grainy (figure 11). The genesis of pyrite present in this form is attributed to the processes taking place at the epigenetic stage or late epigenesis [15, 17].

While comparing micropetrographic analyses of the coal samples taken from the dump with the coal samples taken directly from the seams of a former mine [14], it may be noticed that the results obtained are similar. Despite the passage of time and numerous other factors (e.g. atmospheric) the samples taken from the dump were not significantly changed. Domination of a detrovitrinite subgroup was observed in the macerals of vitrinite group in the coal taken directly from the mine and described in article [14]. Whereas the coals described in this article were characterized by the predominance of telovitrinite subgroup.
Sample L4 represents fine-grained mudstone. It is characterized by aleurite structure, layered texture accented with the presence of small layers containing thin smudges, laminas and small lenses of coal situated parallel (figure 12).

Clastic material is represented mainly by quartz and micas (domination of biotite) near which grains of feldspars (plagioclases) may sometimes be found.

In the mudstone examined a small amount of carbonates was observed, and the carbonates formed few crystalline concentrations of siderites. However, a larger participation of clay binder or silician-clay binder of a basic mass type was seen.

Table 1. The macerals and minerals content in samples from the Gruve 2 Mine.

| Macerals and minerals | Sample number (%) vol. | L1 | L2 | L3 | L4* | L5 |
|-----------------------|------------------------|----|----|----|-----|----|
| VITRINITE             |                        | 80 | 57 | 74 | 51  | 41 |
| gelinite+corrogelinite|                        | 1  | 0  | 1  | 0   | 0  |
| telinite              |                        | 38 | 27 | 27 | 24  | 20 |
| collotelinite         |                        | 25 | 16 | 19 | 16  | 12 |
| collodetrynite        |                        | 16 | 14 | 17 | 10  | 9  |
| vitrodetrinite        |                        | 0  | 0  | 0  | 0   | 0  |
| INERTINITE            |                        | 9  | 21 | 12 | 16  | 11 |
| semifuzinite          |                        | 2  | 2  | 4  | 5   | 4  |
| fuzinite              |                        | 1  | 1  | 1  | 1   | 2  |
| inertodetrinite       |                        | 2  | 6  | 4  | 7   | 4  |
| micrinite             |                        | 2  | 9  | 1  | 3   | 1  |
| macrinite             |                        | 0  | 3  | 0  | 0   | 0  |
| funginite+secretinite |                        | 2  | 0  | 1  | 0   | 0  |
| LIPITINITE            |                        | 7  | 19 | 9  | 22  | 32 |
| sporinite             |                        | 2  | 10 | 3  | 9   | 15 |
| kutinite              |                        | 4  | 3  | 5  | 4   | 6  |
| liptodetrinite        |                        | 0  | 4  | 0  | 3   | 3  |
| resinite              |                        | 1  | 2  | 1  | 6   | 8  |
| MINERALS              |                        | 4  | 3  | 5  | 11  | 16 |
| sulphides             |                        | 2  | 2  | 2  | 3   | 9  |
| carbonates            |                        | 2  | 1  | 3  | 7   | 6  |
| clay minerals         |                        | 1  | 1  | 1  | 1   | 1  |

Explanation: L1, L2, L3, L5 – coal samples, *L4 – rock (mudstone), with laminated coal where the maceral group was studied.

4. Reflectance

The values of random reflectance of vitrinite R°, in the samples examined, showed a range from 0.65% – 0.78% (table 2). This means that the coals examined were characterized by similar coalification degree. Basing on the value of R°, according to International Classification of Coal in the Seam (ECE 1998), these coals may be classified as coals of medium rank C, so called orthobituminous (C).

The low rank C indicated in these samples is also confirmed by low values of standard deviations (std. 0.04-0.07%) of reflectance measurement results R° (table 2).

Similar values of reflectance (between 0.64 and 0.70%) were obtained for coal samples taken from outcrops of coal seam in Bear’s Valley in Longyearbyen [18]. Vitrinite reflectance of coals in the Adventdalen varied from R° = 0.41 till R° = 0.78 [19].
Table 2. Results of mean reflectance measurements. (\%)

| Sample      | L1   | L2   | L3   | L4   | L5   |
|-------------|------|------|------|------|------|
| Mean random value | 0.70 | 0.78 | 0.66 | 0.76 | 0.65 |
| Stdv        | 0.06 | 0.07 | 0.04 | 0.05 | 0.05 |
| Maximum:    | 0.90 | 1.04 | 0.77 | 0.88 | 0.78 |
| Minimum:    | 0.58 | 0.56 | 0.58 | 0.60 | 0.49 |

While analyzing the shape of reflectograms (figure 13), it may be pointed out that they are slightly asymmetric, they have a shape similar to Gauss's normal distribution. Reflectograms are characterized by one maximum. Reflectance measurements are in the range of 2.5 to 5 V stages.

Weathering has negative effects in the industrial uses of coal, e.g. reduction of heating value. The reason for these changes are not yet well understood [20]. Storage of coal in oxidizing air can modify coal’s physical and chemical weathering [21]. Examined samples have been stored in the low temperature oxidation conditions for dozens of years. Thus, the course of reflectograms probably results from weathering processes which, to a small extent, caused changes in the coals examined.

Figure 13. Reflectograms of examined coal samples.
5. Technological features of the coals examined

The results of coal chemical and technological investigations showed some small differentiation (table 3). Low participation of analytical moisture $W_{ar}$ (0.59-0.85%) and relatively low ash content $A_{db}$ (1.87-2.87%) were observed in all the samples examined, thanks to which the coal could be considered as belonging to the group of coals with high grade of cleanness according to ECE classification (1998). Only in one sample L5, which was strongly mineralized, a high content of $A_{db}$ equal 23.68% was observed. It indicates to a good quality of coal, as regards the ash content.

Apart from ash $A_{db}$, also the total sulphur $S_{t}^{db}$ is an important quality parameter connected with the nature of the facies environment, where the coal seams were formed, [12]. Total sulphur content in the coals examined was low (from 0.68% to 0.86%), excluding the L5 sample (highly mineralized coal) where its share was the highest: 4.12%.

The volatile matter content was relatively high $V_{daf}$ ranging from 36.21 to 43.0% and slightly differentiated, which is connected with a variable petrographic composition of the samples examined and possibly also with coal weathering processes.

The obtained values of combustion heat $Q_{s}^{daf}$ vary slightly (from 30.8 to 32.9 MJ/kg), which proves the mean coalification degree measured according to the ECE classification (1998, 2002) [22].

The presented characterization of the samples examined proves that the coal from those seams meets the quality criteria. These criteria are mainly total sulphur content at the working stage below 1.0% and ash content at the recalculation by deposit moisture up to 20.0%.

Table 3. Chosen chemical-technological parameters of the coals examined

| Sample number | Moisture $W_{ar}$ (%) | Ash $A_{db}$ (%) | Volatile matter $V_{daf}$ (%) | Total sulphur $S_{t}^{db}$ (%) | Heat of combustion $Q_{s}^{daf}$ (MJ/kg) |
|---------------|-----------------------|-----------------|-------------------------------|-------------------------------|--------------------------------------|
| L1            | 0.59                  | 2.87            | 40.32                         | 0.86                          | 32.40                                |
| L2            | 0.85                  | 1.87            | 36.21                         | 0.68                          | 30.80                                |
| L3            | 0.74                  | 2.63            | 43.00                         | 0.79                          | 31.30                                |
| L5            | 0.59                  | 23.68           | 42.56                         | 4.12                          | 32.90                                |

6. Conclusions

The samples examined belong to orthobituminous D coals. Macerals of the vitrinite group prevail in the coals’ petrographic composition, hence the coal was classified to the group of humic bituminous coal. The coals analyzed are characterized by low ash and sulphur content but high volatile matter content and mean values of the combustion heat.

Despite the examined coals’ long-term storage on the ground surface, they show no significant traces of weathering. This may be linked with the severe climate of Svalbard.

Features of the coals examined indicate that from the technological point of view they may be considered as valuable energetic material.

Technological parameters and coal quality allow to use it, considering current requirements for solid fuels. Presented results may comprise a contribution for discussion about development of coal exploitation from waste dump in the region of Longyearbyen.

Possible decisions about taking these tasks have to be preceded by quantitative analysis of the amount of coal disposed on the waste dumps as well as ecological aspects.

7. References

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