HYDROGEOLOGICAL CLASSIFICATION AND EVALUATION OF COAL DEPOSITS

Ilie ROTUNJANU, Maria LAZĂR**

Abstract. *Exploitation of coal deposits, especially in open pits, faces in most cases problems with the drainage of aquifer formations present in the mining area. In order to design and proper choice of schemes and drainage technologies is necessary to know the degree of difficulty in terms of hydrogeological conditions of the mining area. In the literature there are a number of classifications that allow characterizing mining perimeters in terms of hydrogeology, but they are most often based on a single evaluation criterion. Based on studying the hydrogeological characteristics of the aquifer formations and the factors influencing them, this paper proposes a complex classification that takes into account the simultaneous and cumulative action of the parameters that contribute in determining the degree of difficulty of the hydrogeological conditions. This classification is useful for more accurate assessment of the conditions and operating costs from the design phase.*
Keywords: *deposit, coal, hydro-geological characteristics, the influx of water, drainage*

1. General information

The presence of aquifer formations in the geological structure of coal deposits create problems in their exploitation, both for underground mining, but especially for open pit mining, thru the risk of flooding of mining works and extraction fronts, the likelihood of outbreaks of fine or clayey saturated sand or by worsening operating conditions due to the risk of instability of mining works or by reducing the efficiency of installations and technological equipments.

To remedy these problems, drainage works are necessary, with the purposes of drainage and discharge the waters from mining areas.

If for underground mining drainage operations are limited to the drainage and discharge of waters from the areas of influence of working fronts or opening and preparation works, for open pit mining the problem is more complex, since groundwater must be drained and discarded both from the whole complex of rocks located in the overburden as well as from adjacent areas, where, due to large level differences that forms by exploitation, a large influx of water is created, that can be removed either by drainage works placed on the outline that intercepts hydrodynamic currents or by screening (waterproofing) the aquifer formations from the adjacent area.

If the water influx is reduced (in the case of mining perimeters with simple or medium hydrogeological conditions), tackling groundwater can be done by passive drainage, namely by water management and discharge measures. Large influxes of water require active drainage, done by drainage works along with water management works.

The choice of methods, technologies and drainage works is based on knowledge of the hydrogeological conditions, the application field of the various methods and drainage technologies and design bases, in order to establish the volume of drainage works and their placement schemes.

* *Prof.eng. Ph.D, University of Petrosani, Romania*

2. Factors defining the hydrogeological conditions

Hydrogeological conditions characteristic for a deposit may be defined by a number of factors and parameters which influence the behavior of rocks in the presence of water. Based on the hydrogeological data, that must be known since the exploration phase of the deposit, the whole mining process is designed and the exploitation opportunity is appreciated, given that the existence of hard and very hard hydrogeological conditions may lead to the impossibility of exploitation of some deposits.

Among the factors that define the hydrogeology of a deposit are mentioned: geological and hydrogeological structure of the deposit, the characteristics of aquifers and aquifer rocks, the character of groundwater, flow regime, the possibilities for water supply and disposal from aquifer structures, rocks hydraulic conductivity, presence of waterproof formations below and above the deposit, tectonic conditions of the deposit, to which adds the exploitation system and the possibilities of application of various drainage techniques and technologies.

For example, if the deposit is horizontal or with reduced inclination, for its drainage it is necessary to close the drainage area through a drainage outline or an antifiltering outline at the level of aquifer formations, achieved by waterproofing the rocks.

For the inclined deposits, drainage is favored by placing the drainage works on successive lines, depending on the advancement of operation on the inclination.

Number aquifer formations, water supply possibilities and rocks hydraulic conductivity particularly influence the drainage activity. Thus, a deposit with multiple aquifers horizons, even with limited development, is harder to be drained than a deposit with a single large aquifer horizon.

The presence of significant dynamic resources requires additional drainage works, which needs to cumulate a higher flow rate then the dynamic resources flow.

For low permeability aquifers, the time required for drainage is much longer than in the case of aquifer horizons with high hydraulic conductivity and the duration and drainage costs increases, even if the influx of water drained and discharged is lower.

The presence and thickness of waterproof formations with screening role on the top and below the deposit or coal layers can decrease the volume of drainage works, and for underground mines, where the opening of mining works at the base is reduced, the necessity of drainage may even be eliminated. This is not possible for open pit mining as regardless of their thickness, for the top formations drainage must be complete (they represent the overburden), and for the bed formations the reduction of the piezometric pressure is mandatory down to levels that do not jeopardize the protective screen from the bottom of the quarry. For open pits with a large opening to the base, depressurization of aquifer formations from below is mandatory. For example, at the base of Roşia de Jiu and Peşteana Nord open pits, from Rovinari mining basin, there is a artesian horizon with the piezometric level at an elevation of 145-170 m, which by drainage works must be reduced to an elevation of 45-50 m col.H_2O, corresponding to the bottom elevation of the last exploitable coal layer (layer V).

Because all of these factors influence the volume and technical effectiveness of drainage works, which in turn influences the exploitability of a deposit, to assess the conditions under which the exploitation is to be performed, their quantification is necessary in order to asses the hydrogeological conditions and for fitting the deposit in a classification that reflects the operating difficulties in hydrogeological terms.

In the literature there are several classifications that are based on one or more criteria, but without taking into account the simultaneous action of several hydrogeological factors and characteristics.

3. Existing classifications

Among the existing classifications are mentioned those taking into account the degree of flooding of the deposits, defined by the position of the deposit to the local erosion base, the presence or absence near the deposit of surface aquifer sources, lithological composition of rocks within the deposit, rocks hydraulic conductivity, tectonic conditions of the deposit. From this point of view, most of the classification groups the deposits according to the hydrogeological degree of complexity as follows:

- deposits with simple hydrogeological conditions that do not require drainage works, only water management works;
- deposits with moderate hydrogeological conditions that require some drainage works executed in parallel with the opening, preparation and exploitation works;
- deposits with complicated or hard hydrogeological conditions (assuming the existence of hydrodynamic links between aquifers or between them and surface water sources) that requires preliminary drainage works to create safe conditions for opening, preparation and exploitation works;
- deposits with very complicated or very hard hydrogeological conditions (assuming an intensive supply of the aquifers due to the geological and tectonic structure of the deposit and the existence of waters under pressure that can cause significant influxes and even eruptions), which requires intensive drainage both before and during exploitation, aiming the drainage of the aquifer horizons from the overburden of the deposit and the depressurization of those below the deposit thru systematic drainage measures.

Since the size of the flow of water in a mine or quarry is not an index of comparison, because it depends on the expansion of mining works, is recommended the use of water influx coefficient (k_a), which is the ratio between the amount of water discharged ($V_{apă}$) and extracted production (P) in the same period (the volume of water pumped per tone of useful minerals).

Depending on the water influx coefficient, coal deposits are classified into:

- weakly flooded, where $k_a < 3$ m^3/t;
- with average flooding, where $k_a = 3 - 8$ m^3/t;
- with large flood, where $k_a = 8 - 20$ m^3/t;
- with very large flooding or heavily flooded, where $k_a > 20$ m^3/t.

Under this classification, beside the water influx coefficient k_a it must be taken into account the economic importance of the deposits. Based on the size of the water influx coefficient, surrounding rocks character and manifestation of negative geo-mining phenomena it was developed a classification that applies to deposits of lignite in Romania, presented in Table 1.

Table 1 *Classification of deposits taking into account the water influx coefficient and surrounding rocks type*

Class	Hydrogeological conditions	Position of the deposit to the local erosion base	Water influx coefficient k_a (m^3/t)	Characteristics of the surrounding rocks and manifestation of negative geo-mining phenomena
I	Simple	Above and bellow the local erosion base	< 3	Hydrophilic clayey and loamy rocks stable without water influx due to free drainage. Hydrogeological conditions do not lead to slope stability or mining issues.
II	Medium	Above and bellow the local erosion base	3 - 8	Above the local erosion base lenses of aquifer sands are occurring, confined in impermeable rocks without the possibility of water supply. In the bed of the open pits captive aquifers with free level occur, which can cause the swelling of clayey rocks. There are required some measures of drainage of aquifer formations.
III	Hard	Bellow the local erosion base	8 - 20	On top of the deposit there are thick aquifer sands (10-15 m) or complexes of rocks with complicated structure and water influxes. In the bed of the open pits there are captive horizons with ascending waters, causing hydrostatic pressure. To ensure the stability of mining works and to prevent large water infiltrations drainage works are required.
IV	Very hard	Bellow the local erosion base	> 20	On top and in the bed of the open pits aquifer complexes with under pressure waters appear, which causes high hydrostatic pressures, stationed in argillaceous rocks with inflation trends on contour or slip trends on the contour of extraction steps. Measures are needed to reduce the pressure and systematic drainage measures to ensure slope stability, and systems with adequate flow rates to discharge waters in all phases of work.

Since in the exploitation of coal deposits in Romania, the biggest problems in terms of hydrogeological and drainage were raised by the lignite deposits from Oltenia, based on practical results and experience in the field, a classification of deposits depending on operating conditions was proposed, shown in Table 2.

Table 2 *Classification of deposits based on exploitation conditions*

Expl. type	Influence factors		MU	Exploitation conditions			
				Easy	Medium	Hard	Very hard
UNDERGROUND MINING	Stratigraphic	Layers inclination	degree	0 - 3	3 - 5	5 – 10	> 10
		Intercalations share	%	0	10 - 20	20 - 30	> 30
		Fracturing degree	fractures/m^2	0	3	3	> 3
		Thickness of the screen on top	m	> 6	6 - 4	4 - 1	< 1
		Thickness of the screen in the bed	m	> 10	10 - 5	5 - 2	< 2
	Tectonic	Mining pressure	tf/m^2	10 - 20	20 - 25	25 - 35	> 35
		Exploitation depth	m	20 - 40	40 - 60	60 - 90	> 90
		Lignite resistance	daN/cm^2	> 70	40 - 70	25 - 40	< 20
		Surrounding rocks resistance	daN/cm^2	> 70	30 - 70	10 - 30	< 10
		Intercalations resistance	daN/cm^2	> 20	20 - 10	10 - 6	< 6
		Tectonic fragmentation degree	accidents/ha				> 3
	Hydrogeological	Water influx	m^3/t	< 1	1 – 2.5	2.5 - 4	4
		Piezometric pressure	m H_2O	0 - 10	10 - 30	30 – 60	> 60
	Technological	Height of the working front	m	2 - 3	1 – 2.5 3 – 3.5	1.2 – 1.5 3.5 - 4	< 1.3 > 4
		Length of the working front	m	< 50	50 - 80	65 - 80	> 80
		Distance from the exploited area	m	> 50	50 - 20	20 - 10	< 10
		Distance from the aquifer area	m	> 30	30 - 10	10 - 2	< 2
OPEN PIT MINING	Stratigraphic	Layers inclination	degree	0 - 3	3 - 5	5 - 7	> 7
		Share of exploitable layers	%	0	0 - 10	10 - 20	> 20
		Share of unexploitable layers	%	0	0 - 5	5 - 7	> 7
		Consistence index of sterile rocks		< 0.7	0.7 - 0.9	0.9 - 1	> 1

	Tectonic	Terrain morphology (relative to the average elevation of the perimeter)	m	20	20 - 35	35 – 60	> 60
		Exploitation depth	m	20 - 40	40 - 70	70 - 100	> 100
		Tectonic fragmentation degree	accidents/ha	2	2 - 4	4 - 7	> 7
		Share of argillaceous rocks in the overburden	%	20	20 - 50	50 - 70	> 70
	Hydrogeological	Water influx	m^3/t	< 3	3 - 5	5 - 7	> 7
		Number of aquifer horizons		2	2 - 4	4 - 6	> 6
	Technological	Overburden ratio	m^3/t	< 3	3 - 5	5 - 7	> 7
		Medium transport distance of the sterile to the dump	km	< 1	1 - 2	2 - 4	> 4
		Open pit's surface	ha	30	30 - 100	100-190	>190

The disadvantages of the two classifications are multiple, namely:

- first classification only considers the water influx coefficient, the characteristics of the surrounding rocks and the manifestation of negative geo- mining phenomena, which is insufficient compared to the factors that define the hydrogeological and drainage conditions. There may be hard and very hard hydrogeological conditions in the case of low influxes, as a result of a reduced hydraulic conductivity of the rocks or due to their instability in the presence of high piezometric pressure or in the absence of protective screens etc.
- the second classification based on operating conditions, the influence factors considered are numerous, but difficult to quantify in the exploration and exploitation design stages, which leads to subjectivism and sometimes nonconformities with the field situation.

It is therefore necessary to develop a classification able to quantify, on the one hand, the hydrogeological factors, and on the other, the exploitation conditions in the presence of groundwater.

4. Complex hydrogeological classification of coal deposits

Starting from this need, based on experience in the field, on existing information, drainage activity results in conditions specific to the lignite deposit from Oltenia and the experience of 20 years, a research team from the Department of Mining Engineering and Geology processed and synthesized available data which led to the classification shown in Table 3.

According to this classification, coal deposits can be classified in terms of hydrogeological conditions into four classes, namely:

- Class I - simple hydrogeological conditions that do not require drainage works, only water management works;
- Class II – medium hydrogeological conditions that require drainage works and water management works;
- Class III – hard hydrogeological conditions, due to the presence of aquifer formations on top and in the bed of the deposit, which requires drainage works for the aquifer formations from the top of the deposit and depressurization works for the aquifer formations in the bed of the deposit in the presence of screens with reduced thickness;
- Class IV – very hard hydrogeological conditions, where aquifer formations contain water under pressure, the hydraulic conductivity of rocks is reduced and the geo-mining conditions are unfavorable in the absence or existence of screens with reduced thickness and the presence of tectonic dislocations.

The values of the hydrogeological parameters chosen to define the corresponding conditions for each class reflects in part the difficulty degree of drainage works, whereas in reality, the hydrogeological characteristics of the aquifer formations may have different values within the same aquifer or from an exploitation block to another. From this results that in terms of parameter values, the same deposit can be classified into several classes, according to the presented classification.

For practical use of this classification, the shear in which the analyzed parameters affect the drainage of lignite deposits must be appreciated both qualitative and quantitative. Practical experience has shown that many problems, in which regards drainage of deposits, occurs when there are pressurized water aquifers within the exploitation perimeter, in conditions of a large influx of groundwater and in the absence of protective screens located on top and in the bed of exploitable strata. From this point of view, a lignite deposit must be placed in the class corresponding to the most unfavorable value of these parameters.

A second criterion for integration of coal deposits according to the presented classification is

that a deposit belongs to a class indicated by the values of the majority of the considered hydrogeological parameters.

Compared to the situation of lignite deposits from Oltenia, the exploitability of coal layers is closely related to the hydrogeological conditions. The area in which the deposit is located forms a large hydrogeological basin, in which there are a number of horizons and aquifer complexes whose hydrogeological characteristics are dependent on their vertical position, lithological characteristics of aquifers, variations in particle size of the rocks and the thickness of sand layers. Due to the geological structure of the region, the hydrogeological conditions vary from one mining perimeter to another, with difficulty degrees from easy to very hard.

Of the probated aquifers, the one located in the bed of lignite layer IV is noticed, characterized by regional expansion, high thickness and flow rates and piezometric pressures that sometimes exceed 100 m col. H_2O, which imprints an artesian character in exploitation areas of the layers V and VI. Other aquifers, located at higher elevations, generally have a limited extent, lower flow rates and pressures and higher filtering coefficients.

Table 3 *Complex hydrogeological classification of deposits*

Class	Hydro-geological conditions classification	Position of the deposit to the local erosion base	Number of aquifer horizons	Thickness of the aquifer strata (horizons) M (m)	Piezometric pressure H (m)	Permeability of rocks k_f (m/day)	Water influx coefficient k_a (m^3/t)	Character of ground water	Thickness of the protective screen (m)		Type of aquifer horizon	Characteristics of aquifer rocks
									on top	in the bed		
I	Simple	Above and below the local erosion base	1 – 2	0 – 10 (< 20)	0 – 10	> 10	< 3	With open level	> 6	> 10	Phreatic or captive with open level	Sand and gravel or coarse sands
II	Medium	Above and below the local erosion base	2 – 4	10 – 20 (20 – 40)	10 – 30	1.0 – 10	3 – 5	Easily ascending	4 – 6	5 - 10	With open level and captive	Medium sands
III	Hard	Below the local erosion base	4 – 6	15 – 25 (40 – 60)	30 – 80	0.5 – 2.0	5 – 10	Ascending	2 – 4	3 – 5	Captive	Fine or dusty sands
IV	Very hard	Below the local erosion base	> 6	> 25 (> 60)	> 80	0.1 – 1.0	> 10	Ascending and artesian	< 2	< 3	Captive	Dusty or clayey sands

Table 4 *Hydrogeological parameters of lignite exploitation perimeters from Oltenia*

Open pit (quarry)	Aquifer horizons	HYDROGEOLOGICAL PARAMETERS							
		Character of groundwater	Filtering coefficient k_f (m/zi)	Coefficient of transfer capacity k_c (%)	Piezometric pressure H (m col. H_2O)	Water influx coefficient k_a (m^3/t)	Specific flow q (m^3/d)	Screen thickness h (m)	Tectonic fragmentation degree (accidents/ha)
0	1	2	3	4	5	6	7	8	9
ROŞIA DE JIU	Phreatic horizon	open level	10 - 15	0.2 – 0.3	-	12.63 – 16.32	30 – 150	-	absent
	Complex VI	ascending	0.1 – 1.0	0.05 – 0.1	10 - 30		10 - 80	0 – 4,0	absent
	Complex V – VI	ascending	0.3 – 2.3	0.1 – 0.15	70 - 100		8 - 60	1.0 – 5.0	absent
	Bed V and artesian	artesian	0.356 – 3.0	0,05 – 0.13	70 - 200		20 - 100	5.0 – 20.0	absent
PINOASA	Phreatic horizon	open level	1.0 – 5.0	0.2 – 0.3	-	3.7	1 – 5	-	reduced
	Complex VI - X	ascending	0.1 – 1.0	0.05 – 0.1	-		1 – 15	5.0 – 7.0	reduced
	Complex V – VI	ascending	0.009 – 3.17	0.1	3.7 – 28.6		5 – 15	2.0 – 8.0	reduced
	Bed V and artesian	artesian	0.172 – 18.86	0.15	14.7 – 170.8		5 - 20	5.0 – 20.0	reduced
ROVINARI EST	Phreatic horizon	open level	3.0 – 8.0	0.2 – 0.3	-	4.9 – 5.41	5 – 15	-	moderate
	Complex V – VIII	open level	0.3 – 1.0	0.05 – 0.1	-		5 – 10	1.0 – 4.0	moderate
	Bed V and artesian	artesian	1.0 – 3.0	0.15	50 - 150		10 – 50	10.0 – 20.0	moderate
PEŞTEANA NORD	Phreatic horizon	open level	15.0 – 20.0	0.2 – 0.3	-	12.87	30 – 200	-	reduced
	Complex V – VI	ascending	0.3 – 1.0	0.05 – 0.1	50 – 80		5 – 50	0 – 10.0	reduced
	Bed V and artesian	artesian	1.0 – 3.0	0.15	70 – 150		10 - 70	5.0 – 15.0	reduced
JILȚ SUD	Phreatic horizon	open level lens-shaped	3.0 – 8.0	0.2 – 0.25	-	1.7	5 – 15	-	reduced
	Complex VI - XII	captive	0.1 – 0.8	0.05 – 0.1	5 – 15		3 – 5	0 – 5.0	reduced
	Bed of layer VI	under pressure	0.2 – 1.0	0.05 – 0.1	20 - 40		5 - 10	0 – 10.0	reduced
LUPOAIA	Phreatic horizon	open level	4.0 – 6.0	0.2 – 0.23	-	0.7	-	-	absent
	Complex V – VIII	open level lens-shaped	0.1 – 0.5	0.05 – 0.1	-		3 – 5	0 – 5.0	absent
	Bed of layer V	ascending lens-shaped	0.2 – 1.0	0.05 – 0.1	0 – 5		2 – 5	0 – 10.0	absent
OLTEȚ	Top of layer II	open level lens-shaped	0.02 – 0.7	0.1 – 0.11	0 - 20	0.8	0.54 – 2.10	2.0 – 15.0	absent
	Bed of layer I	open level	0.1 – 1.42	0.1 – 0.11	20 - 100		2.29 – 7.58	0 – 10.0	absent

The aquifers horizons are grouped into two categories: aquifers with regional expansion, located in Dacian, beneath layer VII of coal, supplied in marginal areas of the region, without drainage possibilities and aquifer horizons in Romanian and inferior Pleistocene, which have supply and drainage areas both in marginal areas of the hydrogeological basin and in the internal valleys that cross the region.

The strongest aquifers are in the first category, especially the aquifer formed in the bed of the layer IV of coal, considered the main artesian horizon.

In terms of lithological constitution, aquifer horizons are very different, variations of rocks are found frequently even for the same horizon, from one exploitation perimeter to another, or even within the same perimeter.

If in the phreatic aquifer horizon coarse sand or sand mixed with gravel specific to alluvial terraces is found, in the other aquifer horizons there can be found sands ranging from the medium to fine, dusty or clayey, that have a low water transfer rate and are characterized by very low filtering coefficients. The existence of pressurized water makes them very dangerous in terms of possible blowouts or rupture of the protective screen.

The filtering coefficients vary within very wide limits, from 2.5 to 53.7 m/day for the alluvial deposits and from 0.2 to 0.3 m/day in the complex of the layer V of coal.

The synthesis of hydrogeological parameters for exploitation perimeters from Oltenia showing hydrogeological problems is presented in Table 4. From this table it is seen that in the case of Roşia de Jiu and Peşteana Nord perimeters the most unfavorable exploitation conditions, in hydrogeological terms, are meet.

For overall hydrogeological characterization of the two perimeters and the integration into the proposed classification, were analyzed hydrogeological parameters defining aquifer formations and were considered the most unfavorable from the point of view of drainage and exploitation conditions. The analysis results are shown in Tables 5 and 6.

Table 5 *Hydrogeological characterization and classification of Roşia de Jiu mining perimeter*

Hydrogeological parameters	Limit values in the mining perimeter	Class	Characterization of hydrogeological conditions
Filtering coefficient, k_f (m/day)	0.032 – 0.42	IV	Very hard
Piezometric pressure, H (m)	50.12 – 163.0	IV	Very hard
Water influx coefficient, k_a (m^3/t)	12.63 – 16.32	IV	Very hard
Thickness of protective screen, h (m)	5 – 20	III	Hard
Character of groundwater	Ascending and artesian	IV	Very hard

Table 6 *Hydrogeological characterization and classification of Peşteana mining perimeter*

Hydrogeological parameters	Limit values in the mining perimeter	Class	Characterization of hydrogeological conditions
Filtering coefficient, k_f (m/day)	0.05 – 0.3	IV	Very hard
Piezometric pressure, H (m)	50.0 – 150.0	IV	Very hard
Water influx coefficient, k_a (m^3/t)	12.87	IV	Very hard
Thickness of protective screen, h (m)	5 – 15 0.2 – 0.5	III	Hard
Character of groundwater	Ascending and artesian	IV	Very hard

According to the integration criteria of lignite deposits in the proposed classification, the two mining perimeters are situated in class IV, with very hard hydrogeological conditions, although some upper aquifer horizons might be situated into class II or III, with medium or hard conditions. Hard or very hard conditions in the lower horizons, and especially the large inflows of water into the lower exploitation steps, is explained by the large bumps that are created during exploitation and drainage of the deposit and the expansion of areas affected by depressions created during drainage, which may include new areas with hydrodynamic links, as a result of the geological structure and tectonics of the deposits.

5. Conclusions

Since the exploitability of deposits is influenced by hydrogeological conditions, it requires their knowledge, as well as the factors that influence them.

Determination of the hydrogeological conditions of a deposit is based on exploration works, continued with hydrogeological research works, which seek to establish: the expansion of aquifer formations and horizons, supply and drainage possibilities, their position in the productive complex, determination of hydrogeological characteristics of aquifer formations, the influence over the exploitation conditions and others.

Since the hydrogeological evaluation of the deposits and the techniques and technologies of drainage, as well as drainage expenses depend on the hydrogeological conditions of the deposit, a proper classification based on objective criteria is a necessity.

Because the existing classifications do not take into account several criteria or the cumulative action of factors influencing the hydrogeological conditions of the deposit and conditions drainage activities, a new classification is proposed. This classification quantifies the hydrogeological and exploitation conditions, based on several factors and parameters that characterize the deposit.

It is estimated that based on this classification a better classification of coal deposits in terms of hydrogeological conditions can be made, and therefore, the evaluation of exploitation conditions and costs of extraction will be a much more rigorous one.

References

1. Gheorghe, Al., Bomboe, P.
Mining hydrogeology (in Romanian), Technical Publishing House, Bucharest, 1963.

2. Enache, C.
Ore deposits drainage (in Romanian), Scrisul Românesc Publishing House, Craiova, 1985.

3. Rotunjanu, I., Trandafir, D., Popescu, S.
Optimization of drainage schemes for the lignite quarries from the Northern Oltenia basin (in Romanian), Mining Revue, no. 8/1996.

4. Rotunjanu, I., Lazăr, M. ş.a.
Classification and evaluation of lignite deposits in terms of hydrogeological conditions (in Romanian), Scientific research contract MCT, 1995.

5. Rotunjanu, I.
Current drainage problems of coal deposits from Oltenia (in Romanian), Mining Revue, no. 3 – 4/2001.