OPEN CAST EXPLOITATION OF LIGNITE DEPOSITS UNDER DIFFICULT HYDROGEOLOGICAL CONDITIONS

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Introduction

The lignite deposits of Oltenia are the most important coal deposits of Romania. These deposits are included in the structural unit of the Sub-Carpathian depression within the area between Danube River and Olt River occupying a total surface area of about 4,500 sq. km in three counties: Mehedinti, Gorj and Valcea, fig.1.

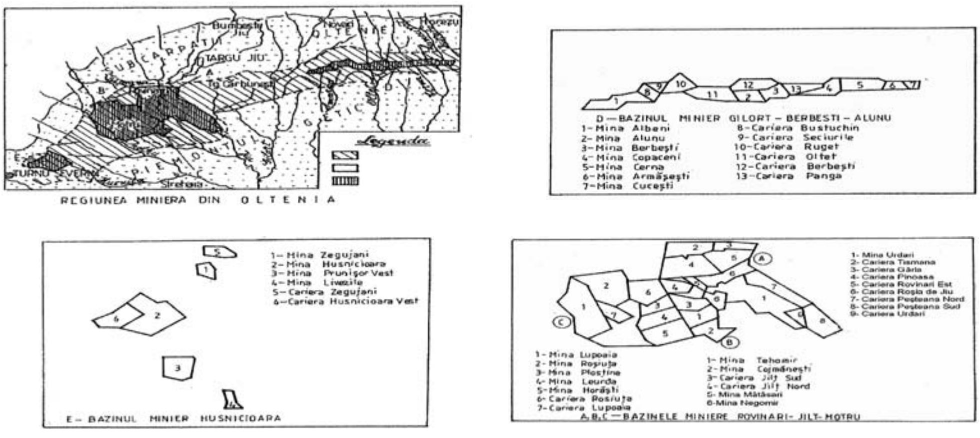

Fig.1 Mining Basins of Oltenia with corresponding mines and open casts

As for the geology, Oltenia deposits belong to the Pliocene formations (Dacian, Romanian and Pontian) and consist of 21 layers of coal with variable thickness and extension, separated by soft, cohesive and non-cohesive waste rocks, predominantly clayous and sandy ones.

The thickness of the lignite layers is varying between several decimeters to several meters occurring either as a compact mass or as several coal beds constituting the layer complex, figure 2.

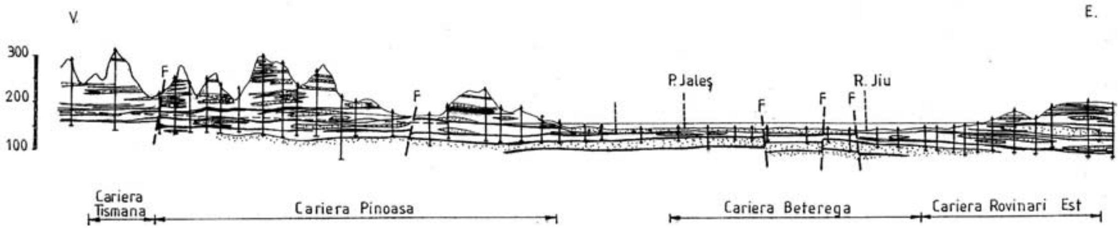

Fig. 2 Geological cross section through Rovinari Mining Basin

The lignite layers are numbered from bottom to up following the sequence of the deposition; A,B,C,D and I…. XVII.

The A,B,C and D lignite layers belong to the Pontian , the I,II,III and IV layers are found in Dacian, the V-VI and VII-VIII layers in the Lower Romanian while the IX-XV layers in the Upper Romanian.

Of the 21 lignite layers the V-VIII layers are exploited in te meadow zone while the V-XII layers are exploited in the hilly zones.

The volume of the lignite reserves of Oltenia known by geological and hydro-geological exploration works is 2,852 millions tones with parameters allowing their categorization as balance reserve.

Oltenia lignite is characterized by the following qualitative features:

- average heat power : 1,700 – 2,200 cal/kg
- waterless ash content: 34-38%;
- humidity; 39-45%
- sulfur content: 0.8-1.2%
- volatile matters : 17-23%^

The lignite deposits of Oltenia are classified based on the geological, geographic and economic criteria in five mining basins as shown in fig.1 Several perimeters have been outlined within each basin, depending on the zonal characteristics of the deposits and exploitation possibilities.

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Of the total promulgated lignite reserves , more than 80% are mineable in open casts while the remaining 20% are mineable by underground methods. During the last years, 90% of the lignite production of Romania was obtained in 16 large open casts located in Oltenia zone, between Olt and Danube Rivers.

The mines and open casts of Oltenia are reporting to SNLO – Tg Jiu and to the three large scale energetic complexes of Rovinari, Turceni and Craiova.

For the lignite deposits of Oltenia consisting of mineable shallow layers of 1.0m up to 8.0 m thick and located in a favorable environment, the open cast method was selected.

All the open casts have been designed with production capacities ranging between 0.5 million tons per year (Berbesti open cast) and 4,4 millions tons per year (Rosia de Jiu open cast).

Depending on the relief conditions and the vertical distance from the surface to the last mineable layers , the open cast depth is ranging between 40 and 110m in the meadow zones and up to 180 m in the hilly zones with a stripping ration for the whole mining field ranging between 3.5 in case of Tismana and Lupoaia open casts and 8.1 c.m waste / ton of of mined out lignite at Berbesti open cast.

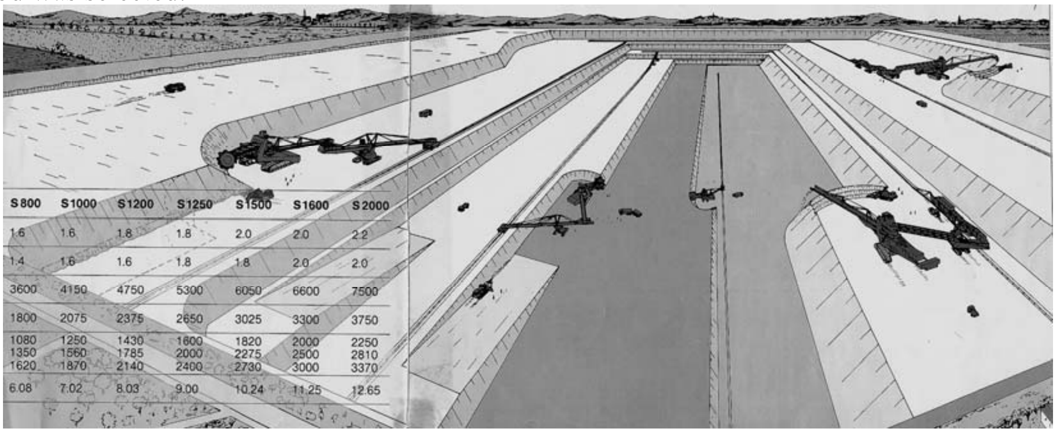

Fig.3 Overview of an open cast equipped with continuous technological flow-sheet

Today, all the open casts of Oltenia are equipped with continuous flow-sheet technologies, figure 3 characterized by the following elements:

- **Excavation** of the mining bulk is performed with rotor excavators of different sizes and technical characteristics which provide efficiencies between 1200 and 4500 m^3/h: SRs 470 $\frac{15}{3,5}$; SRs 1300 $\frac{26}{3,5}$; SchRs 1400 $\frac{30}{7}$ and SRs 2000 $\frac{30}{7}$.

Predominantly, there are used excavators with 1,400 l bucket – more than 50% excavations are carried out using this type of excavator.

The excavation operations are characterized by:

- exploitation of benches of up to 25m high where the haulage level is cut;
- exploitation with sub-benches of up to 10 m high
- exploitation with benches of up to 7 m high when cut beneath the haulage level

The excavation block width may reach 60 m while the working face length could be 2.0 km.

- **Transport** of the mining bulk excavated on the working faces to the storage sites is performed using belt conveyors with the belt width between 1,200 mm and 2,250 mm ,conveyor speed 4.19-6.15 m/sec and transport capacities of 2,500 c.m/h up to 12,500 c.m/h using separate circuits for waste transport to the dumps and useful material to the storage site

The belt conveyors are located on the exploitation benches and there are several options:

- one single belt conveyor along the whole mining face
- two belt conveyors, one along the excavation face
- two belt conveyors end – to – end mounted

The open casts are also provided with different installations required for the transport operations: movable loading installations, track carriages, belt riders, etc.

- **Waste storage** on waste dumps using dumper machines with capacities between 2,500 and 12,500 c.m/h and useful storage in coal stockpiles using the stockers , the take over installations and combined ones which capacities range between 1,250 and 5,600 c.m/h.

The dumpers are provided with booms of 60,70,95,120 and 170 m long. The 120m and 170 m boom dumpers are used for stockpiling the waste by reloading it in the internal dumps.

The modern technological flow sheet of the operating open casts are more simple or more complicated depending on the land morphology, thickness of the overburden, number and thickness of the mineable lignite layers of the area, excavation capacity and sizes of the equipment.

In some open casts where the lignite layers are well individualized the technological flow-sheet could be organized in a simpler manner, that is each excavator is working only in the waste or in coal, on benches constituting separate technological lines.

In other open casts the coal layers are separated by waste intercalations in several benches resulting in difficulties of exploitation with negative consequences on the coal quality and productivity of the excavation equipment.

In many open casts, both excavation of the waste and coal separate benches and the selective-alternative excavation – namely coal and waste on the same bench and using the same excavator- are carried out.

Usually, there are selectively mined the little thick layers (1.0m) and the waste intercalations with thickness over 0.4m.

The following exploitation methods are used in the open casts of Oltenia mining basin.

- The exploitation method with the transport of the waste to external dumps – it is used in the lignite open casts where the final level of the open cast floor has not been reached yet and thus, there have not been provided the premises of the internal dump formation. Currently, this method is used at Pinoasa and Berbesti open casts.
- The exploitation method involving the transport of the waste to the internal dumps – method used in Garla, Rovinari Est, Panga and Ruget open casts, fig 3.
- The exploitation method with transporting part of the waste to internal dumps and the other part to the external dumps – currently used at Jilt Nord, Rosiuta , Oltet open casts.
- Combined method with partial reloading of the waste to the internal dump and partly transporting the waste to external dump – currently used at Tismana II open cast
- The exploitation method transporting part of the waste to the internal dumps and partial reloading of the waste at internal dumps , fig.4 – currently used at: Rosia de Jiu, Tismana I , Pesteana Sud, Pesteana Nord and Lupoaia open casts
- The combined exploitation method transporting part of the waste to the internal and external dumps and partly reloading the waste in the internal dump fig.5 – currently used at Jilt Sud and Husnicioara open casts

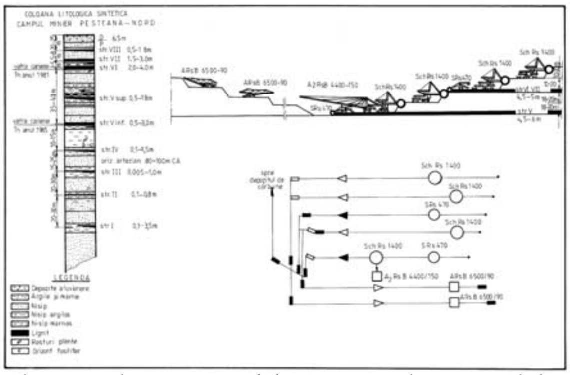

Fig. 4 Exploitation method using the partial transport of the waste to the internal dump and partial reloading of waste to internal dumps Pesteana Nord Open Cast- Rovinari Mining Basin

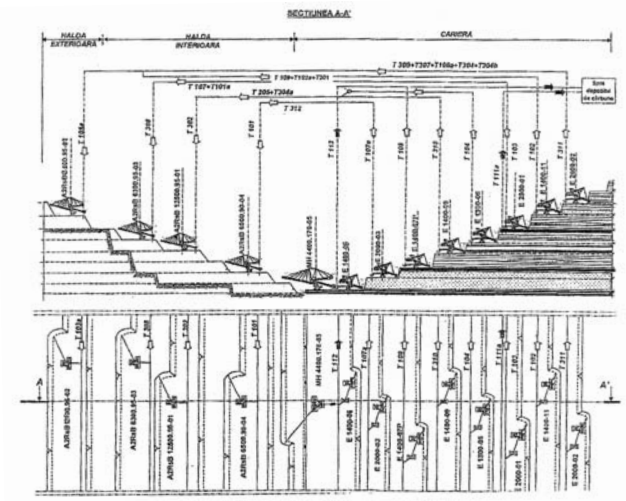

Fig. 5 The combined exploitation method transporting part of the waste to the internal and external dumps and partly reloading the waste in the internal dump

The predominant methods used are those involving besides the waste transport the waste reloading to internal open casts as well.

The working benches of the open casts are 15-25m high , slope angles of 60-65^0 and 1,000 – 2,000 m long. The overall slope angles of the open casts range between 12 and 20^0 depending on the type of rocks from the exploitation perimeter depending on the existing relief conditions. In the meadow areas, the dumps were located near the final contour of the open cast and they have been built vertically with several benches, the maximum height for the deposition on the bench is 15-20m.

Depending on the characteristics of the dumped material (humidity, consistency, loosening coefficient, particle size etc) as well as on the expected heights of the external dumps , they have been built with an overall slope angle between 6 and 9^0

In the hilly zones, the external waste dumps have been formed by filling the valleys near the open cast , the haulage distance to the waste dump is up to 10 km and even longer.

Today, in Romania the lignite exploitation at surface is developed within 16 large size open casts provided with continuous flow-sheet and which, depending on the market, can ensure a total production of almost 30 millions tons of lignite per year.

The production capacity and endowment of the open casts in operation in Oltenia zone is presented in the table no.1.

Table 1

Production capacity and technical endowment of Oltenia open casts

OPEN CAST	PRODUCTION CAPACITY [mil.t/year]	EXCAVATORS					DUMPING MACHINES								STOCKPILE MACHINES				CONVEYORS	
		SRs 470	SRs 1300	Erc 1400	SRs 2000	Total	MH 4400.60	MH 4400.95	MH 4400.170	MH 6500.60	MH 6500.90	MH 6300.95	MH 12500.95	Total	Combined	To stockpile	To clear	Total	No. of belts	Belt km
Mehedinți	**2,2**			**5**		**5**			**1**		**2**			**3**		**4**	**2**	**6**	**28**	**12,8**
Lupoaia	2,3		5	1		6			1			2		3	1	1		2	28	16,4
Roşiuța	2,5			6		6					4			4	1	1		2	42	19,4
E.M.C.Motru		**0**	**5**	**7**	**0**	**12**	**0**	**0**	**1**	**0**	**4**	**2**	**0**	**7**	**2**	**2**	**0**	**4**	**70**	**35,8**
Jilț Sud	3,5			8		8			1		3			4	1	1	1	3	48	35,4
Jilț Nord	2,5	2		6		8				1	2			3	1	1		2	42	26,8
EMC Jilț		**2**	**0**	**14**	**0**	**16**	**0**	**0**	**1**	**1**	**5**	**0**		**7**	**2**	**2**	**1**	**5**	**90**	**62,2**
Gârla	0,8			2		2	1				1			2	4	2	1	7	9	6,1
Rovinari Est	1,7			3	1	4	1			1	1			3					23	15,2
Tismana I	2,5		1	3		4			1		1	1		3					18	12,6
Tismana II	1,5		1	2		3	1	1			1			3					12	8,4
Pinoasa	3,5			5		5					3			3	1	1		2	36	20,2
EMC Rovinari		**0**	**2**	**15**	**1**	**18**	**3**	**1**	**1**	**1**	**7**	**1**		**14**	**5**	**3**	**1**	**9**	**98**	**62,5**
Roşia	4,4		1	5	3	9			1		1	1	2	5	1	1	1	3	42	24,2
Peşteana Sud	0,7		-	2		2			1		1			2	1	2	1	4	10	6
Peşteana Nord	1,4		-	5		5			1		2			3					15	9,4
EMC Roşia		**0**	**1**	**12**	**3**	**16**	**0**	**0**	**3**	**0**	**4**	**1**	**2**	**10**	**2**	**3**	**2**	**7**	**67**	**39,6**
Olteț	1,3	2		2		4					2			2		2	1	3	30	14,3
Berbeşti Vest	0,5	3				3					1			1	1	1		2	17	5,6
Panga	0,7			3		3					2			2					18	6,7
Ruget	0,9	1		2		3	1				1			2	1	1	1	3	13	4,6
EMC Berbeşti		**6**	**0**	**7**	**0**	**13**	**1**	**0**	**0**	**0**	**6**	**0**	**0**	**7**	**2**	**4**	**2**	**8**	**78**	**31,2**
SNLO SA Tg.Jiu		**8**	**8**	**60**	**4**	**80**	**4**	**1**	**7**	**2**	**28**	**4**	**2**	**48**	**13**	**18**	**8**	**39**	**431**	**244,1**

The Gettic depression hosting the lignite deposits form the large size water basin where aquiferous systems which characteristics depend on their position on the stratigraphical column, lithology and thickness of layers and sand benches, their water supply and the flow-rates, are encountered.

The water basin has an extended supply area situated at its West and North ends , but also inside it, along Motru, Jilt, Jiu, Gilort, Amaradia valleys , and the absence of some discharge zones determined the formation of large water accumulations as largely extended aquiferous horizons and complexes.

Because of the deposit geological structure, the complexity of hydro-geological conditions increase from West to East and from North to South.

From hydrogeological point of view the stratigraphic of the coal deposits of Oltenia indicate the presence of two well individualized horizons- the aquiferous phreatic layer and the aquiferous horizon of the IV layer floor – and of a n well individualized aquiferous complex consisting of seven aquiferous layers.

- **Phreatic aquiferous horizon** is well developed mainly in the water course meadow of the zone and it is spread over the extension of the alluvial deposits formed of sands and gravels covered sometimes by a clay bed which form a screen and the water courses have low catching features. It is 5-20m thick and the filtering coefficients are ranging between 1,8 – 12.5 m/day. The hydrostatic level of this horizon is at 45-60m depth depending on the water supply possibilities.

The hydro-geological investigations carried out on the deep aquiferous horizons revealed aquiferous horizons within the Dacian and Romanian formations.

- **Aquiferous horizon of the IV layer floor** develops in the fine or coarse sands between the layers I and IV as the coal layers II and III comprise extended areas where there is no sedimentation while the clay beds are thin; the horizon between the layers III and IV, from hydraulically point of view, are connected with the floor horizons. It is regionally extended and indicates pressures between 15 and 165 m $H2O$ column with inexhaustible water reserves.

The hydrostatic level is between -148 and -186 and raised at the Western part of the region. Initially, in Jiului and Motrului River meadows it showed a artesian feature, but, because of the dewatering works , this feature can be found only in the low meadow zones.

The filtering coefficient is around 1.0 – 7.5 m/day, but with large variations depending on the lithology of the sands.

Aquiferous horizon of IV-V layer interval consists of one or two lens with variable extension formed of fine, rarely medium or coarse sands. The highest piezometer levels were revealed to the North –West side of Rosiuta perimeter while the lowest ones are in Pesteana zone. Because of the extended areas where no sedimentation occurred and with small thickness of layer IV and of the thin and unevenly developed clay beds of the IV layer floor, there are large surface areas where this aquiferous is hydraulically connected to the artesian horizon.

Aquiferous horizon of V layer complex is hosted between the coal banks of the V layer and its thickness may reach up to 15m consisting of fine, clayous or dusty sands.

Compared to the low V and upper V layers the aquifeorus horizon is generally separated by impervious screens , but there exist zones of direct contact with it. The flow-rates are low ranging between 0.1-2liters/ second while filtering coefficients between 0.2 and 0.3 m/day.

Aquiferous horizon of the V-VI layer interval develops over the whole region, but its thickness is low and it spreads as lens to the Northern part.

In the whole Southern zone, it develops as a layer of 20-30m thick , generally extended and constituting one of the main aquiferous horizons of the zone due to its extension and thickness.

In general, this horizon consist of 1-2 banks which are united to the South and occupy the whole interval between layers V and VI. As for the lithology, it consists of fine sands, sometimes containing also gravels, dusty sands. The hydrostatic levels range between + 136.10 m and 248.37 m.

Aquiferous horizon of layer VII-VIII interval consisting of several aquiferous sand banks with an uneven development. As for the lithology, the dusty sands and subordinately, the fine and medium size sands are prevailing. The precipitation water is fed to this aquiferous through the layer ends or the phreatic horizon.

Aquiferous horizon of VIII-X layer interval consist of 1-4 sand banks unevenly distributed. As for the lithology, the aquiferous VIII – X complex consist of fine, clayous dusty sands . In most cases, the aquiferous horizon is separated from the coal layers by clay protection screens, but in all perimeters, there are encountered zones where the sands are at a distance below 1.0 m from the coal layers or even get into direct contact with it.

Aquiferous horizon of X layer roof is hosted in the sand package and is mostly situated above the erosion base in the region on the valley sides. The thickness of the sands range between several centimeters and up to 20m and is in direct correlation with the erosion rate of the region ; the bigger thicknesses are due to the sand layers of the hill crest. From lithology point of view, these layers consist of dusty and clayous sands.

Because of its position above the local erosion base this horizon is characterized by simpler hydrological conditions than the lower horizons. The filtering coefficient is ranging between 0.08 and 0.60 m/day.

The main hydro-geological parameters of the depth aquiferous layers investigated by hydro-geological show significant variations reflecting both the grain size variations of the sand horizons where hosted, and the different potential of supplying the respective aquifeorus layers and the position of the supply zones.

To illustrate it the table 2 presents the hydro-geological parameters for the main open casts and aquiferous horizons from Oltenia coal basins.

Table 2

The hydro-geological parameters for the main open casts and aquiferous horizons from Oltenia coal basins

Open casts Aquiferous horizons		HYDRO-GEOLOGICAL PARAMETERS							
		Underground water characteristic	Filtering coeff. [m/day]	Breakage coeff. [%]	Piezometer pressure [$mcolH_2O$]	Water inflow coeff [m^3/t]	Specific flow rate [m^3/day]	Screen thickness [m]	Tectonics removal rate [accid./ha]
0		1	2	3	4	5	6	7	8
Roşia de Jiu	Phreatic horizon	free level	10-15	0,2-0,3	-	2	30-150	-	none
	Complex VI	upward	0,1-1,0	0,05-0,1	10-30	1	10-80	0-4,0	none
	Complex V-VI	upward	0,3-2,3	0,1-0,15	70-100	1	8-60	10-5,0	none
	V floor and artesian	artesian	1,0-3,0	0,1-0,18	70-200	2	20-100	5,0-20,0	none
Pinoasa	Phreatic horizon	free level	1-5	0,2-0,3	-	0	1-5	-	low
	Complex VI-X	free level	0,1-1,0	0,005-0,1	-	1	1-15	5,0-7,0	low
	Interval V-VI	upward	0,3-2,0	0	10-30	1	5-15	2,0-8,0	low
	V floor and artesian	artesian	1,0-3,0	0	40-100	2	5-20	5,0-20,0	low
Rovinari Est	Phreatic	free level	3-8	0,2-0,3	-	0	5-15	-	moderate
	Complex V-VIII	free level	0,3-1,0	0,005-0,1	-	1	5-10	1,0-4,0	moderate
	V Floor and artesian	artesian	1,0-3,0	0	50-150	2	10-50	10-20	moderate
Peşteana Nord	Phreatic	free level	15-20	0,2-3,0	-	1	30-200	-	low
	V-VI complex	upward	0,3-1,0	0,05-0,1	50-80	1	5-50	0-10	low
	artesian	artesian	1,0-3,0	0	70-150	2	10-70	5-15	low
Jilț Sud	Phreatic	free level	3-8	0,2-0,25	-	0	5-15	-	low
	VI-XII complex	catching lens shaped	0,1-0,8	0,05-0,1	5-15	1	3-5	0-5	low
	VI floor	under pressure	0,2-1,0	0,05-0,1	20-40	1	5-10	0-15	low
Lupoaia	Phreatic	free level	4-6	0,2-0,25	-	-	-	-	none
	V-XII complex	lens shaped free level	0,1-0,5	0,05-0,1	-	0	3-5	0-5	none
	V layer floor	upward lens shaped	0,2-1,0	0,05-0,1	0-5	1	2-5	0-10	none

Further to the investigations performed in every mining basin, there resulted that most of Oltenia deposits are classified from hydro-geological point of view in the group of difficult condition deposits because of the following characteristics:

- Lignite layers are hosted in soft cohesive rocks – clays and marns and non-cohesive rocks – fine, medium and coarse size sands.
- Some lignite layers are overlain by several aquiferous layers and horizons
- From the point of view of the filtering coefficient values there are big differences between the aquifeorus layers : small values k_f <1.0m/day; medium values: k_f <1.0- 3,0 m/day; and high values k_f <3.0m/day
- The thickness of the aquiferous layers range from small thickness (<5m) up to bigger thickness (>15m)
- Pressure of the underground waters is also varying with average values (P=10-30m col H_2O) up to high and very high values (P>30 m col H_2O)
- In case of some aquiferous horizons the static water reserves (aquiferous horizons near the lignite mineable layers) are prevailing and in some other cases, the dynamic water resources (phreatic horizon and artesian horizon of the V coal layer roof) are prevailing.

The exploitation of the lignite layers of Oltenia mining basins was and still is depending on the completion of the dewatering works aiming at:

- increase of the stability of slopes and open cast opening trenches, working benches and open cast and waste dump edges
- prevention of the events related to the underground water discharge in the bench slopes resulting in suffusion of sandy rocks followed by lack of stability events;
- preventing the penetration of artesian water on the open cast bottom of V layer floor

Because of the difficult and very difficult hydro-geological conditions the dewatering of the open cast fields of Oltenia is carried out in two stages and namely:

Preliminary dewatering preceding the mining works by about 1-2 years and required for ensuring the safety of the mining works throughout their completion.

In this stage there are performed the followings:

- complete dewatering of the alluvial deposits where the opening trenches are excavated
- diminution of the pressure of artesian waters from the sandy intercalations of the coal complex as much as possible up to the total dewatering and
- diminution of artesian water pressure from V layer floor up to values which prevent the penetration of the protection screen.

Parallel dewatering is carried out simultaneously with the lignite deposit exploitation to reduce further on the pressure of the artesian waters from layer V floor and of complete dewatering of the alluvial material and aquiferous sands of the coal complexes in advance.

As dewatering works there are used surface works, respectively the trenching for dewatering for the phreatic horizon, fig.6, the large diameter and deep drill holes provided with submersible pumps, fig.7 for the dewatering of the aquiferous formations of the productive complexes and filter free drill holes with free eruption at the open cast floor level, fig.8

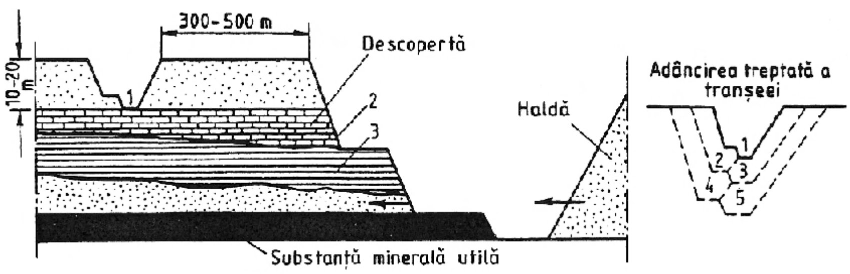

Fig.6 Dewatering with trenches performed in the working face
1-dewatering trenching; 2- working bench; 3- impervious rock

The dewatering trenches used at depth of 8-12 m ensuring flow-rates discharged from the massif at flow rates of about 50-250 c.m /h.

The dewatering drill holes were spaced on a 200 x 100m pattern and their depth was depending on the average thickness of the aquiferous horizon opened by the drainage drill holes and which ranged between 35-50m. The total flow-rate of water discharged from an exploitation perimeter depended on the number of operating drill holes and characteristics of the aquiferous horizon under dewatering process and reaching values of up to 450-500 c.m/h.

The filter free drill holes with free eruption at the floor level were placed in the lowest zones of the open casts where the draining aquiferous contained under pressure water and its roof consisted of resistant rocks which enabled the completion and stability, in time, of the cavity formed throughout the drilling. The flow-rate of such a drill hole ranged between 60-180 c.m/h.

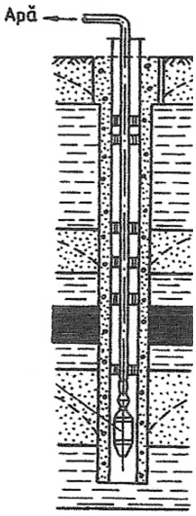

Fig.7 Dewatering with large diameter holes provided with submersible pumps

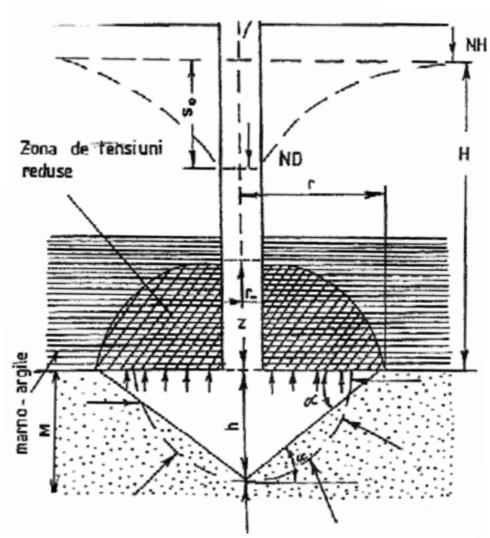

Fig.8 Tension release of the under pressure aquiferous horizon using the filter free drill holes

There have been evacuated so far, 14.0 cubic meters of water by ton of mined out coal, from the mining perimeters showing the most difficult hydro-geological conditions.

The presence of an upward artesian aquiferous horizon in the V layer floor, representing actually, an inexhaustible water reserve requires a technical solution ensuring the safe exploitation of this lignite layer which, only in Rovinari Basin, host a balance reserve of more than 300 millions tons.

In practice, it is about the tension removal of the aquiferous layer from the V coal layer floor and the determination of the open cast floor opening up to a limit that avoid the breakage of the protection screen. An eventual breakage of the protection screen would have resulted in the water penetration in a random manner, in the open cast and its total and final damaging.

Sizing of the open cast opening at the floor

In the open cast with artesian water in the deposit floor it was necessary to make calculation and measurements to establish a correlation between the artesian water pressure , protection screen thickness of the open cast floor and the opening of the open cast floor for the development of the technological flow-sheet under safety conditions.

As the screen thickness could not be influenced, there was necessary to act on the other parameters and namely: tension removal of the artesian aquiferous horizon reaching admissible values and reducing the opening of the open cast floor, fig.9.

To remove the tension of the under pressure aquifeorus layer there was performed the working technology with drill holes free of filter with free eruption at the level of the open cast floor which proved to be efficient both from hydrodynamic and technical – material point of view; their construction is simple and reduced technical features and consequently require lower costs than the classic filter drill holes.

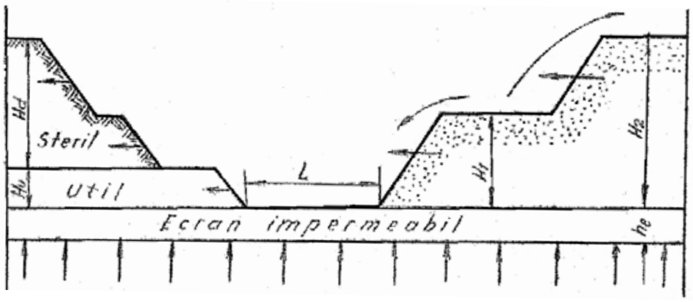

Fig 9 Sizing of the open cast floor opening

The presence of aquiferous rocks with pressure water in the deposit floor determines that the resistance of such a floor reduces under the normal values for the same rocks under unsaturated condition, and in case that the impervious protection screen is too thin, the water pressure can cause the belly out and even the breakage of the floor with worst impacts on the production continuation.

To avoid the breakage of either the floor or the protection screen the following relation must be completed:

$$y_a . P \leq y_e . h_e$$

where**:**
y_a- specific density of the water, tf/ c.m
P – hydrostatic pressure of water from the aquiferous under pressure layer situated beneath the open cast floor , m col. H2O
y_e – volumetric density of rocks of the screen , tf./ c.m
h_e – thickness of the protection screen ,m

Should the relation $\gamma_a \cdot P \leq \gamma_e \cdot h_e$ be not reached, there have to be implemented several measures among which the construction of an internal dump with advance bench from a certain elevation and which slope will maintain a certain distance up to the slope of the deposit under mining.

Currently, in practice, if there is a non-homogenous protection screen, the admissible pressure is calculated based on the relation: $P = 0{,}8 \cdot \gamma_e \cdot h_e$, fig 10.

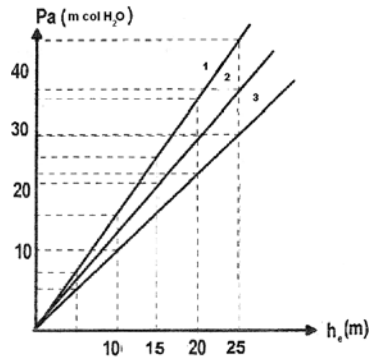

Fig.10 Variation of the admissible pressure (Pa) of the screen depending on the its thickness within the meadow zone
1 - Pa =1,2 $\gamma_e h_e$; 2 - Pa =$\gamma_e h_e$; 3 - Pa =0,8 $\gamma_e h_e$

For the hilly zones, where lignite layers are more inclined than in the meadow zone the following relation for the admissible pressure calculation is recommended :

$$P_a = 2 \cdot \sigma_i \cdot \frac{h_e^2}{b^2} + 1{,}2 \cdot \gamma_e \cdot h_e \qquad \text{(m col } H_2O\text{)}$$

where:
σ is the rock stretching resistance , tf/ sq.m
b- width of the trench base

The correlation between the two parameters of the above relation can be seen in fig 11.

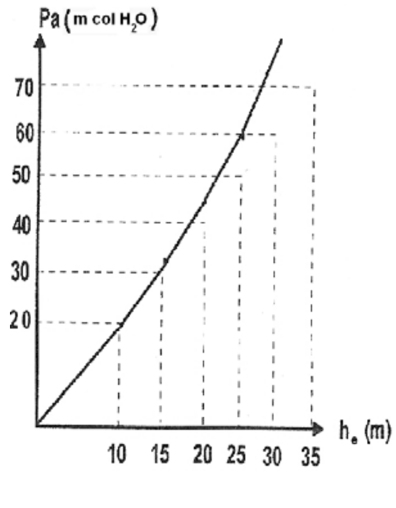

Fig. 11 Variation of the admissible pressure (Pa) on the screen depending on its thickness (h_e) in the hilly zone

The opening of the floor (distance between the two slopes) can be easily determined based on the known relations from the material resistance.

The screen is considered as an encapsulated beam – on one side below the deposit and on the other side below the dump. Due to the pressure evenly distributed from the floor, there will be an evenly distributed stress on the beam throughout the opening.

The maximum bending moment $M_{\hat{\imath}max}$ will be carried out in the two encapsulated supports and is given by the relation:

$$M_{imax} = \frac{p \cdot L^2 \cdot b}{12} \quad \text{or}$$

$$M_{imax} = \frac{(P - \gamma_e \cdot h_e) L^2 \cdot b}{12} \quad \text{(tm)}$$

where: $p = P - \gamma_e \cdot h_e$ is the uniformly distributed load where:

P = pressure at the floor, t/sq.m

L- floor opening, m;

b- beam width , m

Knowing that the resistance module is given by the relations:

$$W = \frac{M_{imax}}{\sigma_i} \text{ and } W = \frac{b \cdot h_e^2}{6} \quad (m^3)$$

it can be written :

$$\frac{b \cdot h_e^2}{6} = \frac{M_{imax}}{\sigma_i} = \frac{(P - \gamma_e \cdot h_e) \cdot L^2 \cdot b}{12 \cdot \sigma_i}$$

$$\frac{b \cdot h_e^2}{6} = \frac{(P - \gamma_e \cdot h_e) \cdot L^2 \cdot b}{12 \cdot \sigma_i} \text{ from where:}$$

$$L^2 = \frac{2 \cdot h_e^2 \cdot \sigma_i}{P - \gamma_e \cdot h_e} \; (m^2)$$

$$L = \sqrt{\frac{2 \cdot h_e^2 \cdot \sigma_i}{P - \gamma_e \cdot h_e}} \quad (m)$$

where besides the other known notations σ_i (tf/ sq.m) represents the breakage resistance at rock stretching of the open cast floor.

Most times the admissible width of "L"floor is determined based on the practice data. It varies between 50 and 100 m.

Based on the above reasoning the thickness of the protection screen for a certain floor pressure can be calculated :

$$\frac{b \cdot h_e^2}{6} = \frac{(P - \gamma_e \cdot h_e) \cdot L^2 \cdot b}{12 \cdot \sigma_i}$$

$$2 \cdot \sigma_i \cdot b \cdot h_e^2 = P \cdot L^2 \cdot b - \gamma_e \cdot h_e \cdot L^2 \cdot b$$

$$2 \cdot \sigma_i \cdot b \cdot h_e^2 + \gamma_e \cdot h_e \cdot L^2 \cdot b - P \cdot L^2 \cdot b = 0$$

$$h_e = \frac{-\gamma_e \cdot b \cdot L^2 \pm \sqrt{\gamma_e^2 \cdot L^4 \cdot b^2 + 4 \cdot 2 \cdot \sigma_i \cdot b^2 \cdot P \cdot L^2}}{4 \cdot \sigma_i \cdot b}$$

$$h_e = \frac{L \cdot b \sqrt{\gamma_e^2 \cdot L^2 + 8 \cdot \sigma_i \cdot P} - \gamma_e \cdot L^2 \cdot b}{4 \cdot \sigma_i \cdot b}$$

$$h_e = \frac{L(\sqrt{\gamma_e^2 \cdot L^2 + 8 \cdot \sigma_i \cdot P} - \gamma_e \cdot L)}{4 \cdot \sigma_i} \quad (m)$$

Calculation model of the protection screen. Stress condition and deformations of the protection screen

Based on the method the ABCD fig. 12 protection screen is actually working, it can be assimilated to an encapsulated plate loaded with a uniformly distributed load equal to the hydrostatic pressure of the aquiferous.

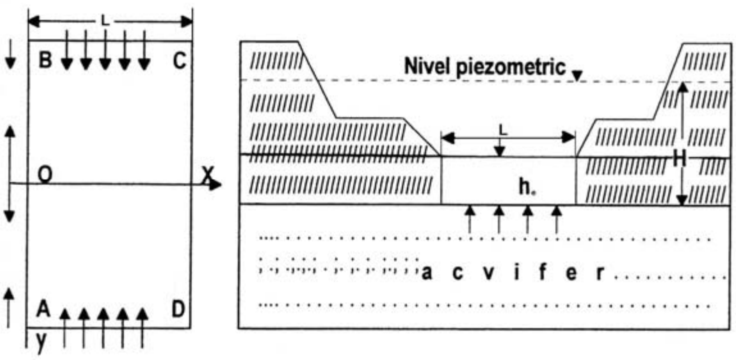

Fig 12. Sizing of the protection screen

To work out this issue, it is first consider the stress of the screen as a plate simply leaning on a the contour , loaded with a load uniformly distributed throughout the surface and then it is considered a plate loaded with bending moments on the contour, resulting at the distributed load and by overlapping the impacts, the real case result.

The maximum stress of the protection screen.

Based on the relations established for the cutting forces and bending moment expressions, the stress diagrams can be drawn up, fig 13.

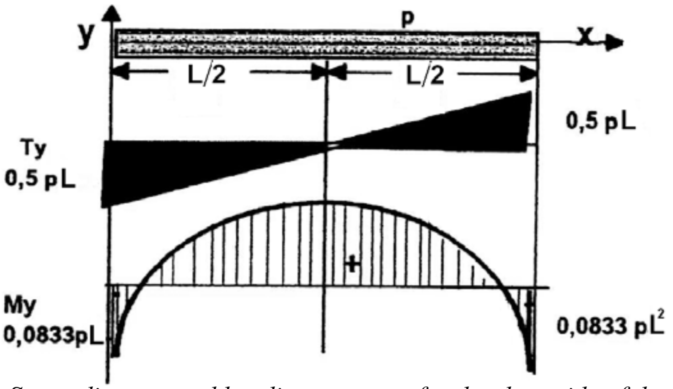

Fig.13 Stress diagram and bending moments for the short side of the screen

The stress diagram shows that the maximum absolute values of the protection screen stress occur in the encasing sectors where $T_{xmax} = 0,5 \cdot p \cdot L$ and $M_{xmax} = 0,0833 \cdot p \cdot L^2$. It partly justifies the fact that some papers consider that the protection screen gets broken because of the shearing in encapsulation .

Actually, it is about a stress consisting of unitary efforts:

$$\tau_{max} = \frac{T_{xmax}}{A} = \frac{0,5 \cdot p \cdot L}{h} = \frac{p \cdot L}{2h}$$

$$\sigma_{max} = \frac{M_{xmax}}{W_z} = \frac{6 \cdot 0,0833 \cdot p \cdot L^2}{h^2} \approx \frac{p \cdot L^2}{2 \cdot h^2}$$

where: $W_z = \frac{b \cdot h^2}{6}$;

if b=1 it results $W_z = \frac{h^2}{6}$

A and Wz representing the area and respectively the bending resistance module of a plate with unitary width and thickness, h.

Taking into account that for the considered case:

$$p = \gamma_0 \cdot H - \gamma \cdot h \cdot \cos\alpha$$

where :

γ is the volumetric density of rocks

γ_0 – specific density of water

H – hydrostatic pressure at the protection screen base

β – inclination angle of the screen against the horizontal line, then the above relations become:

$$\tau_{max} = \frac{(\gamma_0 \cdot H - \gamma \cdot h \cdot \cos\beta) \cdot L}{2h}$$

$$\sigma_{max} = \frac{(\gamma_0 \cdot H - \gamma \cdot h \cdot \cos\beta) \cdot L^2}{2 \cdot h^2}$$

If we accept as criteria for reaching the stress limit condition, the admissible limit at stretching or compression σ of the material of the protection screen and applying the theory of the maximum tangential unitary stresses then the admissible hydrostatic pressure at the horizontal screen base (β=0) is determined as follows:

$$\sigma_a \geq \sqrt{\sigma_{max}^2 + 4 \cdot \tau_{max}^2}$$

$$\sigma_a \geq \sqrt{\left(\frac{p \cdot L^2}{2 \cdot h_e^2}\right)^2 + 4\left(\frac{p \cdot L}{2 \cdot h_e}\right)^2}$$

$$\sigma_a \geq \frac{p \cdot L}{2 \cdot h_e}\sqrt{\left(\frac{L}{h_e}\right)^2 + 4}$$

of which at the end, there is obtained:

$$p = \frac{2 \cdot h^2 \cdot \sigma_a}{L \cdot \sqrt{L^2 + 4 \cdot h_e^2}}$$

$$p = \gamma_0 \cdot H - \gamma_e \cdot h_e \cdot \cos\beta$$

for β =0

$$p = \gamma_0 \cdot H - \gamma_e \cdot h_e$$

$$\gamma_0 \cdot H - \gamma_e \cdot h_e = \frac{2 \cdot h_e^2 \cdot \sigma_a}{L \cdot \sqrt{L^2 + 4 \cdot h_e^2}}$$

$$H = \frac{\gamma_e \cdot h_e}{\gamma_0} + \frac{2 \cdot h_e^2 \cdot \sigma_a}{\gamma_0 \cdot L \cdot \sqrt{L^2 + 4 \cdot h_e^2}}$$

For a certain screen, giving different values of L there is obtained the correlation between the two parameters.

The laboratory determinations on models and practical observations throughout the years in the lignite open casts concluded that the floor opening has not a significant impact on the value of the admissible pressure on the protection screen, fig.14, allowing to ensure a relatively high difference between the coal excavation and the dumping process on an internal dump.

In the zones where the protection screens thickness is lower special working measures are required as follows:

- excavation and dumping equipments from the last bench will not move on the opened screen (stripped) but on the working sub-benches;
- by means of monitoring hydrotechnical drill holes there will be monitored the variations of the aquiferous zone pressure and thus, the required measures can be taken to reduce it;

- infill drilling for stress removal to maintain the hydrostatic level at admissible values;
- the floor opening will be maximum 50m, and the open cast floor will be covered by drains or filtering bed consisting of ballast and 50-60 cm thick;
- under special conditions when the screen thickness is low, useful mineral benches will be left on the open cast floor and thus the difference between the face and dump is reduced.

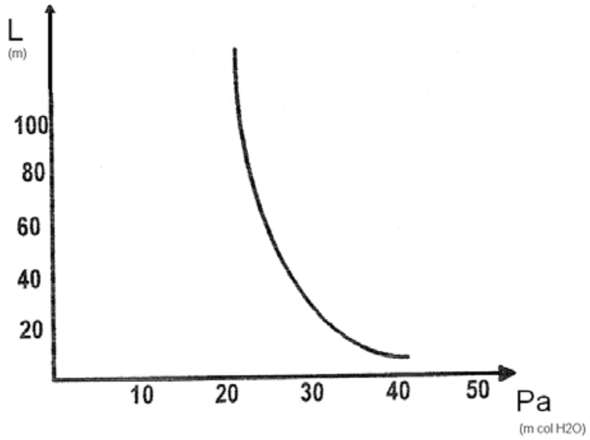

Fig 14. Correlation between the opening of the open cast floor and the admissible pressure on the protection screen

Finally, we conclude indicating that the measures taken on the work site for reducing the artesian horizon pressure on the protection screen and the technological process operation determined that the economic activity developed throughout the years was profitable and safe.

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