4.4. Impact on Subsoil Geology

4.4.1. Characterization of Subsoil of the Site

The Cernavoda NPP Unit 3 and Unit 4 sites are situated in the large geologic, morphologic, tectonic and structural unit of South Dobrogea.

The waved bottom of this region is made up of a sedimentary series, slightly changed, having the age of the superior Proterozoic, known under the name of green shists (Ref. 4.4-12).

The sedimentary cover, unconformity laid down over the Paleozoic bottom, is made of deposits belonging to the Jurassic, Cretaceous, Tertiary and Quaternary periods. These formations have typical platform aspect, with small - thickness and sedimentary discontinuities, due to the repeated tectonic movements, which took place in the two adjacent Carpathic and Balcanic synclinals (figure 4.4.1-1).

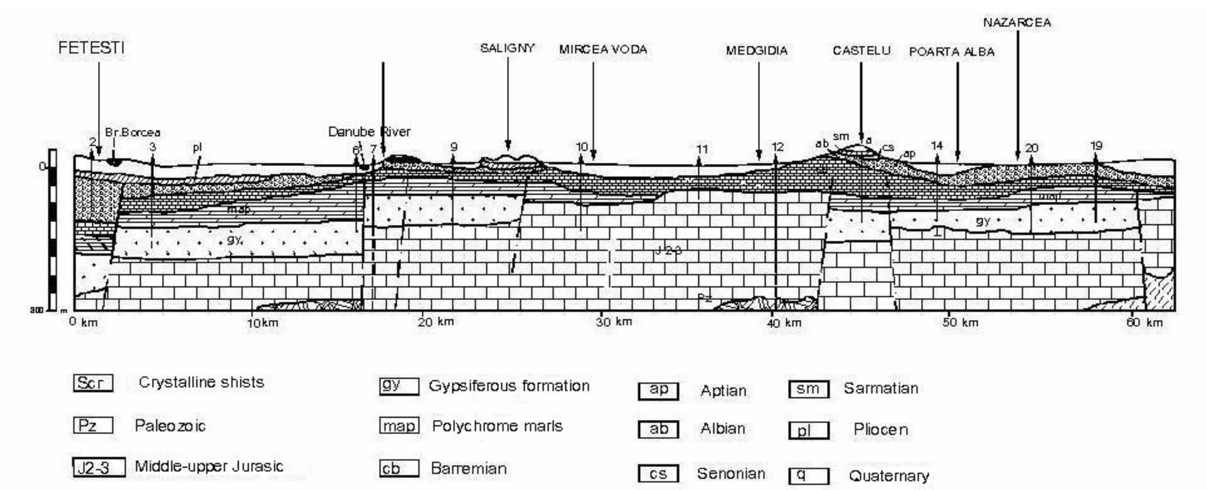

Figure 4.4.1-1. Geological and structural profile

Based upon the investigations performed in the period of studies and during construction works, in the enclosure perimeter and in the neighbourhood, it was established that the geologic deep formations belong both to Jurassic and Cretaceous period, while at the surface they are represented by Quaternary deposits (middle and inferior Pleistocene).

The studies have shown the fact that the geologic structure of both site area and site itself offers good conditions of stability and foundation for nuclear plant buildings, and consequently does not put problems concerning to nuclear safety.

Cernavoda NPP Unit 3 and 4 sites, in the developing limits of the formations of Cretaceous age, are situated on Barremmian limestones and have at the foundation elevations of the nuclear buildings Barremian limestones (Figure 4.4.1-2, 4.4.1-3).

Due to the geological structure vaulting, uplifted to west, the base geological formations can be reached at higher elevations in Unit 4 site than in Unit 3 site.

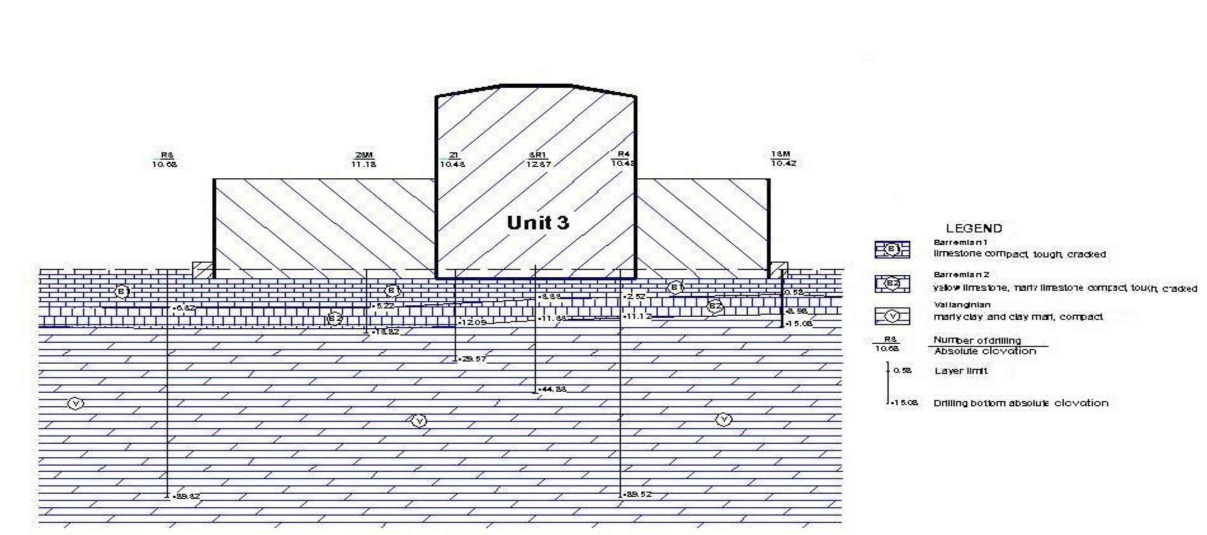

Figure 4.4.1-2. Geological longitudinal section across U 3 Reactor Building axis

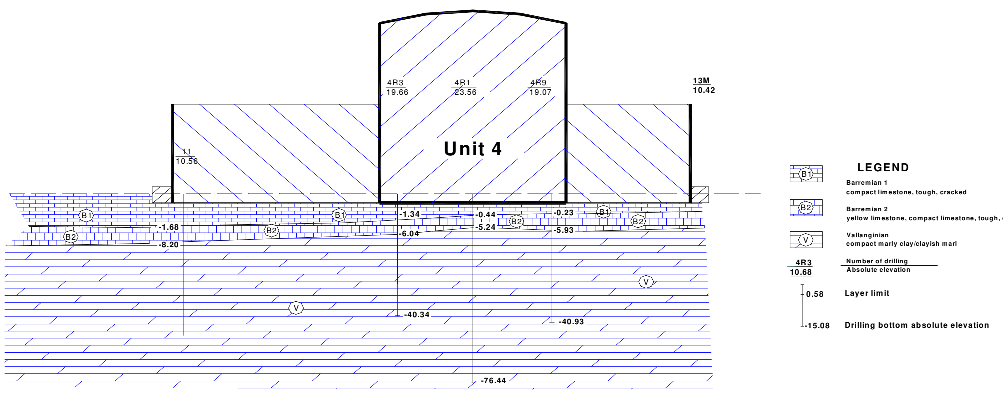

Figure 4.4.1-3. Geological longitudinal section across U 4 Reactor Building axis

The Barremian is made up of Cernavoda limestones, quite various from petrographic point of view, fact which determined their segregation in two horizons, B1 and B2.

B1 – the superior horizon - made up of white, hard, cracked limestones, porous white-yellowish limestones, shell limestones, oolithic yellow clayish-sand limestones, friable white chalk limestones, being disposed in almost all horizontal layers, being 0.20-1.00m in thickness, with a slight arch to the middle of the quarry. The thickness of the B1 layer in the Unit 3 area is ranging between 15.30m and 5.70 m, and in the Unit 4 area the thickness is ranging between 6.70 and 11.20 m (Table 4.4.1-1).

B2 - the horizon is made up of yellow-brown limestones with intercalation of white, porous cracked limestones, makes up a transient layer between B1 marls and limestones. This horizon seems to be no homogeneous, both in thickness and in constitution, having an average of 30 ÷ 40 % limestones and 60 ÷ 70 % clayish limestones, compact yellow clayish limestones and compact sands. The thickness of B2 layer in Unit 3 area ranges between 6 and 8.30 m, and in the Unit 4 area is ranging between 1.90 and 4.80m.

The Vallanginian marl layers, generally described as layer V, are compact, being practically fission and cracks free, presenting more sandstone and clay areas. In some boring samples, millimeter sand films are evident. It is worth to mention that the marl surfaces present a rising arch in Reactor Building 4 area and a lowing arch towards Reactor Building 1 area.

Table 4.4.1-1. Variation of the layers thickness in the area of the Reactor Buildings of Unit 1÷Unit 4

Layer	Unit 1	Unit 2	Unit 3	Unit 4
	Layer thickness (m)	Layer thickness (m)	Layer thickness (m)	Layer thickness (m)
B1	15.00-20.60	20-26	15.30-15.70	6.70 - 11.20
B2	8.20-8.90	8.40- 9.20	6.00-8.30	1.90 - 4.80
V	~ 50.00	~ 50.00	~ 50.00	~ 70.00

Legend:

B1 = barremian limestone – superior horizon,

B2 = barremian limestone – inferior horizon

V = vallanginian marl

4.4.2. Tectonic Structure, Neotectonic and Seismic Activity

4.4.2.1. Tectonic Structure and Neotectonic Activity

From geological point of view, the Cernavoda area is placed in the eastern part of the Moesian Platform. This platform represents a solid block to the south of the Carpathian Foreland (Ref. 4.4-12).

The Moesian Platform is affected by several trans-crustal faults. The most important one is the Intramoesian Fault that separates the Moesian Platform in two main blocks: the Dobrogean Block in the northeast and the Wallachian Block in the south. The NPP Cernavoda is situated in the Dobrogean Block (South Dobrogea) of the Moesian Platform. Another important fault is Capidava –Ovidiu Fault that separates the Central Dobrogea by South Dobrogea (Fig.4.4.2-1).

The geological structure is represented by the basement and sedimentary cover, respectively. The basement consists of Precambrian metamorphic rocks, represented by kata and/or mesometamorphic rocks of Lower and Middle Proterozoic age, and ankimetamorphic of turbidities type, named “Green Schists” of Vendian – Lower Cambrian age. The platform cover is formed in few sedimentary cycles: Cambrian-Carboniferous, Permian – Triassic, Jurassic- Cretaceous, and Tertiary (Ref. 4.4-1).

South Dobrogea

South Dobrogea, the tectonic unit where the Cernavoda Nuclear Power Plant is located, is bounded North by Central Dobrogea, by the major crustal fault Capidava – Ovidiu. From the tectonic point of view it represents the uplifted eastern sector of the Moesian Platform, which deepens step by step to the West and East (Black Sea offshore).

South Dobrogea is characterized by two structural levels: a lower structural level, represented by the basement, and an upper structural level, represented by the sedimentary cover, discordantly disposed on the basement. The geological formations of the cover have a non-uniform areal distribution and great facies variation, which shows that their sedimentation occurred in a zone tectonically active during Mezozoic and, partly, Neozoic.

The crystalline basement is intensively tectonised, affected by a series of faults, orientated N – S and WNW – ESE, which have been determined especially using gravimetric, magnetic and seismometric data. The evolution during Mezozoic indicates an intense tectonic activity, some old faults being reactivated, others being created. There are two systems of faults:

- the older NNE – SSW system;
- the newer WNW – ESE system, which affects the first one (Fig 4.4.2-2).

The structure of the Mezozoic and Neozoic sedimentary formations, among which limestone deposits prevail, is complicated due to the existence of many vertical and subvertical faults. These ones divided this area in uplifted or subsiding tectonic blocks. The faults were generated after the deposition of Upper Jurassic – Valanginian limestones and were active during Cretaceous and Paleogene. Most of the blocks ceased to move before the deposition of Sarmatian formations, which appear like an almost continuous plate, gently dipping to the East.

Because of the vertical movements, some blocks are emerged, others submerged. At the same time, the last ones were eroded while in the others, sedimentation was continuous. As these phenomena occurred successively, the sedimentary formations are discordantly disposed and the current positions of geological limits vary from one block to another.

At the same time, these successive movements resulted in different throws of the same fault, measured at certain markers. There are no general and uniform throws of the faults. The structural map of South Dobrogea (Fig. 4.4.2-2) was made, based on information provided by boreholes and geophysical data. The faults are before Miocene (Barenian – Sarmatian) and they show the relative position of the tectonic blocks (Ref.4.4-1). The isobaths at the top of the Upper Jurassic – Valanginian limestone formations show the morpho-structural relief of each block (Fig. 4.4.2-2). The relationships between the tectonic blocks are represented in geological cross-sections (Fig. 4.4.2-3, 4.4.2-4) (Ref. 4.4-1).

The WNW – ESE faults are parallel to the major fault Capidava – Ovidiu and continuous. From North to South they are: Cernavoda – Constanta fault, Rasova –

Costinesti fault, North Mangalia Fault and Mangalia Fault. Between these ones there are the NNE – SSW faults, forming the tectonic blocks with variable dimensions (Ref. 4.4-1).

The tectonic blocks between these faults are presented, with the following characteristics:

- delimitation of the tectonic blocks and their relative positions with respect to the surrounding ones;
- depth of the basement of the Mezozoic – Neozoic cover, particularly the bottom of the Upper Jurassic – Valanginian limestone formation;
- variation of the thickness of the limestone formation and the relationships with the covering formations;
- position of different faults and their throws at different limits.

The zone between the Capidava – Ovidiu fault and the Cernavoda – Constanta fault

In this zone there are 5 tectonic blocks, separated by vertical faults, which, from West to East, have the characteristics shown in the cross-section I – I' (Fig.4.4.2-3).

The Capidava – Ovidiu fault is a crustal regional fault. It determines the uplifting of the crystalline basement by 700 – 1000 m. Thus the lower boundary of the limestone formation (J_3 – V) is located at isobathic depths between -30 and -300 m in the northern sector and between -500 and -1200 m in the southern sector. Jurassic limestones outcrop in the Ovidiu zone.

The Cernavoda – Constanta fault puts in contact tectonic blocks with different structural positions, so that the throws measured at different limits are very varied. On the whole, the southern sector is more uplifted, by an average of 300 m in Cernavoda – Poarta Alba area (200 m in the West and over 500 m North of Siminoc), and more subsided to the East, due to the accentuated uplifting of the northern blocks Poiana and Constanta.

The movement along this fault was both vertical and horizontal, on a 8 km distance (senestral so that the transversal fault Agicabul from the northern sector continues with the East Siminoc fault.

The zone between the Cernavoda – Constanta fault and the Rasova – Costinesti fault

In this zone, there are several tectonic blocks, of variable size, their characteristics being represented in the cross-section II – II'' (Fig.4.4.2-3).

Thus, one can remark an uplifted tectonic block in the Eforie zone, from where there is a deepening step by step to the West (Romanian Plain) and East (Black Sea offshore), along a fault with throws from 80 to 200 m.

The Rasova – Costinesti fault, which crosses the whole South Dobrogea, puts in contact several tectonic blocks, with uplifted or submerged tectonic positions. The throws are variable along the fault, both in magnitude and direction. There is also a horizontal movement along the fault, by 6 km, measured on the fault East Cobadin, in continuation of the fault East Siminoc (dextral throw).

The zone between the Rasova – Costinesti fault and the North Mangalia fault

In this zone, the structure is less complex. There are uplifted and submerged tectonic blocks which, from West to East, have the following characteristics: the faults are more spaced out towards the Romanian Plain, with an uplifted block in the Deleni – Cobadin zone and deepening in large steps (200 – 400 m) towards West and lower throws, between 50 and 200 m, to the East.

The North Mangalia fault is a complex fault, which puts in contact uplifted and submerged tectonic blocks, with variable throws (100 – 300 m), with changing directions from one block to another. One can remark a horizontal senestral movement by 3 km (along the East Cobadin fault) (Fig. 4.4.2-4).

The zone between the North Mangalia fault and the border with Bulgaria

In this zone, there are two sectors with different structure: the western sector (between the Danube and the East Negru Voda fault) and the eastern sector (between the East Negru Voda fault and the coastline).

In the eastern sector the structure is more complicated, due to the existing faults. The most important is the Mangalia fault, orientated East – West, like the North Mangalia fault. The Mangalia fault has a complex character, putting in contact blocks with different positions, so that the throw direction may change along the fault. The throw is between 100 and 300 m at the lower boundary of the limestone formation. At the same time, the horizontal movement is senestral, with a displasement of around 6 km.

The zone located South of the Mangalia fault and East of the East Negru Voda fault is strongly divided by NE – SW faults and one WSW – ENE fault.

Analyzing the whole structure composed of tectonic blocks, of the Pre-Sarmatian formations from South Dobrogea, one can remark several uplifted blocks, located in the central zone, on an approximate N – S alignment. Within these blocks, the Upper Jurassic – Valanginian limestone formation is thinned at around 350 m and covered discordantly with newer formations, also with low thickness.

To the West, the limestone formation deepens step by step and becomes thicker, reaching over 1000 m thick near the Danube. The covering formations usually have low thickness, therefore the upper boundary of the limestone deposits is located at tens of meters deep.

To the East, the Upper Jurassic – Valanginian limestone formation is also deepened and, generally, has a complex structure, due to the existence of the numerous faults. There are littoral zones where the limestone formation is thinned or even disappears, like in the Straja – Lazu – Topraisar – Costinesti zone.

East of the major (initially continuous) fault Agicabul – East Siminoc – East Negru Voda, the newer formations which cover discordantly the Upper Jurassic – Valanginian limestone formation, are well developed, especially the Senonian and Cenomanian ones, with thickness reaching 300 – 400 m. Starting from Costinesti zone to the South, there are Eocene deposits (Ref. 4.4-1).

All the WNW – ENE major faults continue towards East, affecting the continental boundary of the Black Sea and having the same characteristics on the shelf and *slope*. They were identified on several seismic cross-sections, observing the throws comparable with the ones on the land. They are covered discordantly by Oligocene, Miocene and Pliocene formations, showing again their character of inactive faults (Ref. 4.4-1).

In conclusion, even if the zone around the Cernavoda Nuclear Power Plant is affected by faults, these ones are old, sealed and they didn't move at least since Paleogene, as they are covered discordantly by Eocene and Oligocene formations in the shelf zone of the Black Sea and in the southeastern part of Dobrogea and by Miocene (Badenian and Sarmatian) as well as Quaternary formations in the remaining part of the territory (Fig. 4.4.2-3, 4.4.2-4).

In Cernavoda area the relief is completely different. On the right bank of the Danube, in Dobrogea, there are cliffs, some of them higher than 10 m with respect to the left bank and to the zone between the two branches closing Balta Ialomitei. Based on the studies it can be specified that this morphologic feature is due to erosion, not to active tectonic processes (Ref. 4.4-1). Data provided by boreholes located west of the Danube show a structure in blocks, similar to the one from South Dobrogea, down going step by step, while the identified faults are old and covered discordantly by Upper Miocene – Quaternary formations, with thickness increasing progressively to the west.

Taking into account the whole geological context and the tectonic evolution of the zone around the Cernavoda Nuclear Power Plant, on a radius of over 50 km, it results that this one is tectonically stable, without recent reactivations and without obvious elements of tectonic activity (Ref. 4.4-1).

4.4.2.2. Seismic Activity

According to the last geological, geophysical, seismotectonical, seismological study and ground dynamics data taking into account all the supplementary information data, it results that the seismicity of the Cernavoda NPP site can be influenced by 7 seismic sources: Vrancea subcrustal seismic zone, Vrancea crustal seismic zone, North Dobrogea seismic zone, Sabla seismic zone, Dulovo crustal seismic zone, Romanian Plain seismic zone, local crustal seismic zone (Fig. 4.4.2-5) (Ref. 4.4-2, 4.4-12).

The seismic sources identified from the point of view of the seismic potential (maximum observed magnitude and maximum possible magnitude (M_w is moment magnitude and M_{G-R} magnitude by Gutenberg – Richter scale) are characterized by the following:

Seismic source: Vrancea – intermediate (subcrustal) earthquakes:

- Maximum observed magnitude: M_w = 7.7, M_{G-R} = 7.5;
- Maximum possible magnitude: M_w = 7.9, M_{G-R} = 7.7;
- The depth to the foci is between 60 and 180 km.

Seismic source: Vrancea – normal (crustal) earthquakes:

- Maximum observed magnitude: M_w = 4.7, M_{G-R} = 4.7;
- Maximum possible magnitude: M_w = 5.0, M_{G-R} = 5.0;
- The depth to the foci is between 5 and 54 km.

Seismic source: North Dobrogea (Galati – Tulcea Fault):

- Maximum observed magnitude: M_w = 5.1, M_{G-R} = 5.1;
- Maximum possible magnitude: M_w = 5.4, M_{G-R} = 5.4;
- The depth to the foci is between 0 and 34 km.

Seismic source: South Dobrogea (Şabla):

- Maximum observed magnitude: M_w = 7.1, M_{G-R} = 7.1;
- Maximum possible magnitude: M_w = 7.2, M_{G-R} = 7.2;
- The depth to the foci is between 0 and 30 km.

Seismic source: Dulovo:

- Maximum observed magnitude: M_w = 6.5, M_{G-R} = 6.5;
- Maximum possible magnitude: M_w = 6.7, M_{G-R} = 6.7;
- The depth to the foci is between 0 and 44 km.

Seismic source: Romanian Plain (Intramoesian Fault):

- Maximum observed magnitude: M_w = 5.4, M_{G-R} = 5.4;
- Maximum possible magnitude: M_w =5.7, M_{G-R} = 5.7;
- The depth to the foci is between 0 and 44 km.

Seismic source: local earthquakes:

- Maximum observed magnitude: M_w = 4.2, M_{G-R} = 4.2;
- Maximum possible magnitude: M_w = 4.5, M_{G-R} = 4.5;
- The depth to the foci is between 0 and 34 km.

From the analysis of the effects in the zone of Cernavoda due to the historical and instrumental earthquakes occurred in the seven seismic sources, it results that the intensity of the maximum seismic movement in the zone of the Cernavoda Nuclear Power Plant is imposed firstly by the seismic activity of the Vrancea intermediate earthquakes and by that of the crustal earthquakes from the Sabla and Dulovo seismic sources. The other four sources have a negligible influence on the seismicity of the Cernavoda NPP.

As per the seismic qualification philosophy adopted for CANDU PHWR-600 nuclear-electrical plants, in the design two levels of design earthquakes will be considered, both of them imposed by the plant nuclear safety requirements, namely:

- Design Basis Earthquake (DBE). The Design Basis Earthquake (DBE) for a plant is defined as an engineering representation of potentially severe effects in the free field at the site, of earthquakes applicable to the site that have a sufficiently low probability of being exceeded during the lifetime of the plant. The DBE is expressed in the form of ground response spectra (GRS) or time-histories (Ref. 4.4-3);
- Site Design Earthquake (SDE). The Site Design Earthquake SDE for a plant is defined as the engineering representation of the effects in free field at the site, of a set of possible earthquakes, having an occurrence rate, based on historical records of actual earthquakes, of 0.01 per year as maximum. The

SDE is expressed in the form of response spectra or time-histories (Ref 4.4-3).

On basis of the seismo-tectonic and probabilistic analysis made in the conservative assumptions, the levels for the design earthquakes defined by the ground maximum acceleration in free field on a component in horizontal plane were obtained. For the other component in the horizontal plane orthogonal to the first one, the same value is considered while for the vertical direction, two thirds of a component in horizontal plane is considered (Ref. 4.4-4).

As values of intensities and acceleration the two design levels have been defined by:

- SDE level - I = VII degrees MSK – 64, a = 0.1 g;
- DBE level - I = VIII degrees MSK – 64,a = 0.2 g.

For the design, the seismic action corresponding to those two levels has been defined by the response spectra given in free field for a horizontal component.

For the vertical direction, the same spectral shape is conservatively, considered, and the corresponding spectra is considered 2/3 out of the response spectra in horizontal plan. In order to confirm the design data regarding the seismic activity of Cernavoda NPP site, SNN finalized the documents: ”Probabilistic Seismic Hazard Assessment (PCRA) for Cernavoda NPP”, Code 01551-PSA-IR-116, dated 2005/04/29 and “Level 1 Probabilistic Safety Assessment. Seismic Events Analysis for Cernavoda NPP Unit 1”, Code IR-01551-PSA-111, January, 2005 (Ref. 4.4-7). The materials were analyzed and certified by a mission of IAEA experts, which were favorably approved.

The conclusions of these documents confirm the qualification level considered in the design for Cernavoda NPP for a seismic event, having an acceleration of 0.2 g, and an occurrence frequency lower than 1E-3, as it was considered in the Final Safety Report.

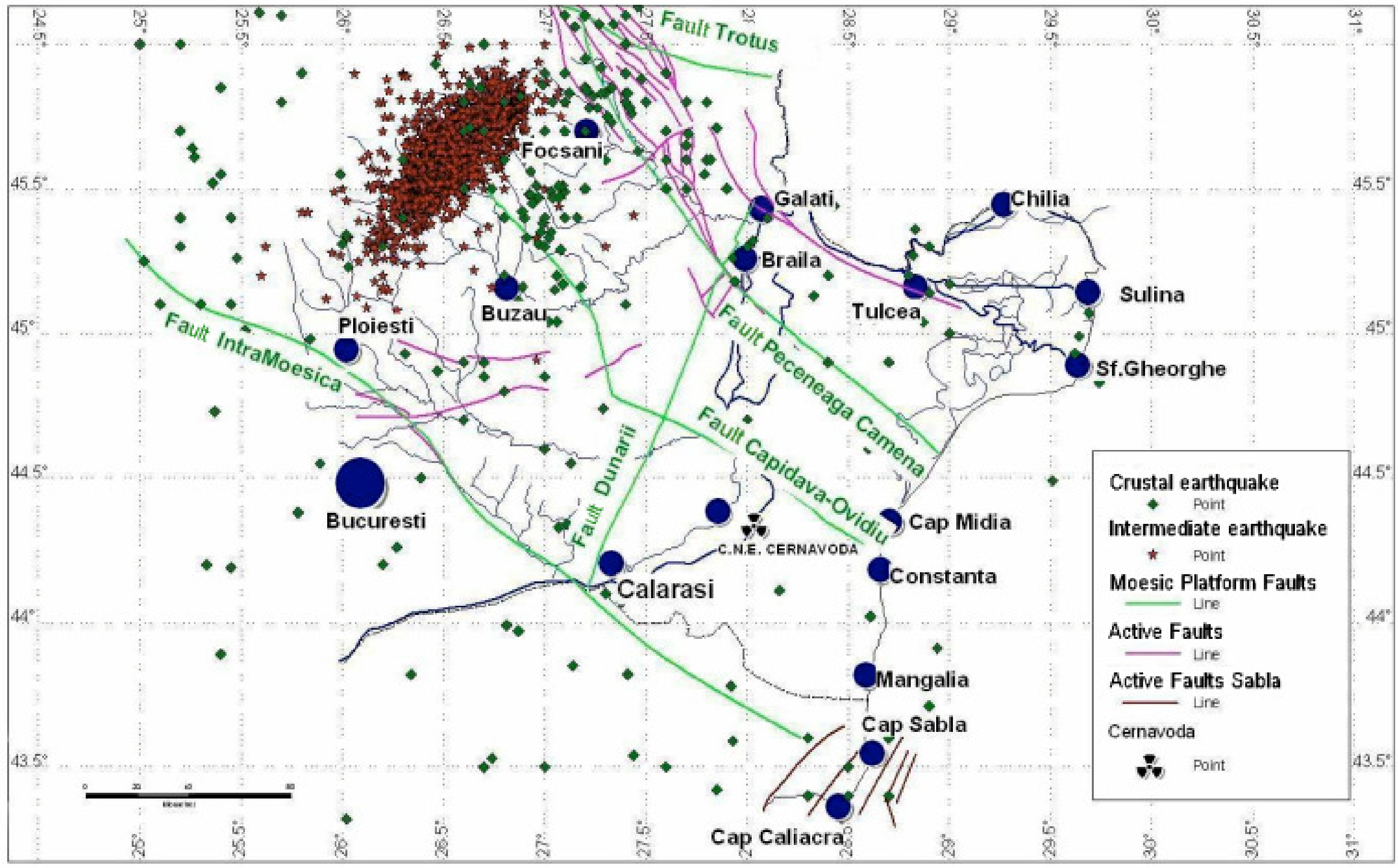

Figure 4.4.2-1. Tectonic map and crustal and intermediate earthquakes (Ref. 4.4-1)

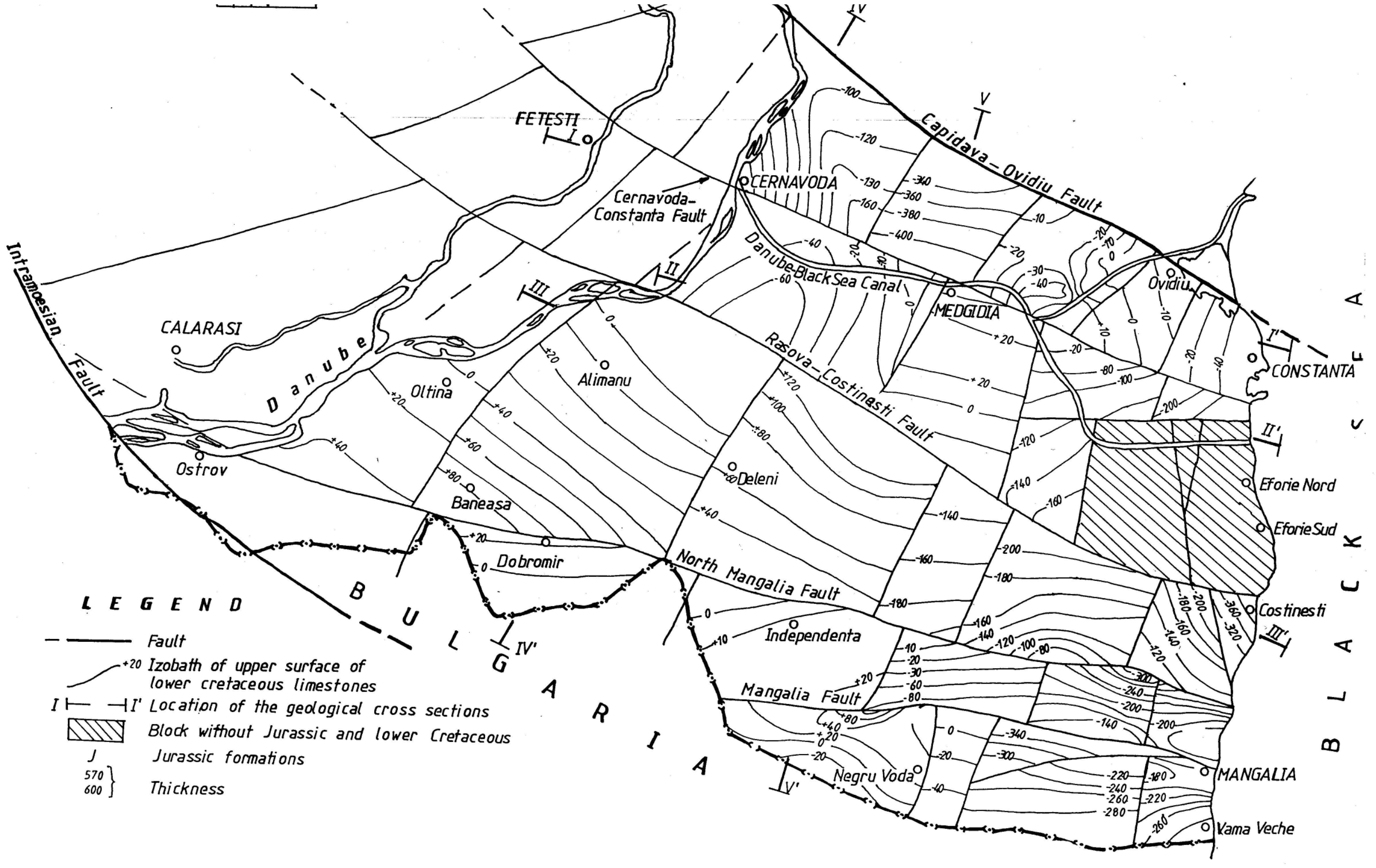

Figure 4.4.2-2. Structural map of South Dobrogea

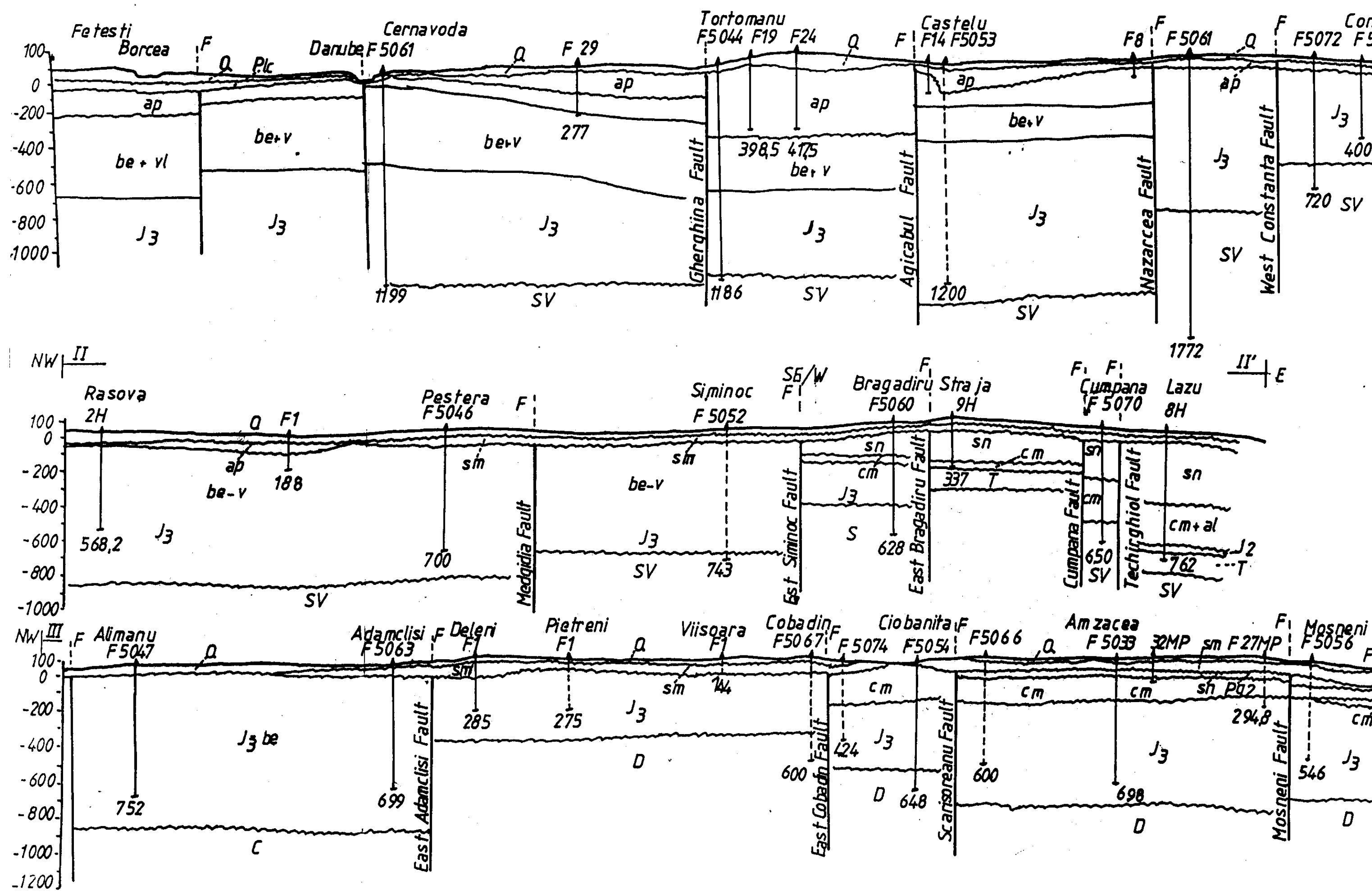

Figure 4.4.2-3. Geological cross-sections (I, II, III) (Ref. 4.4-1)

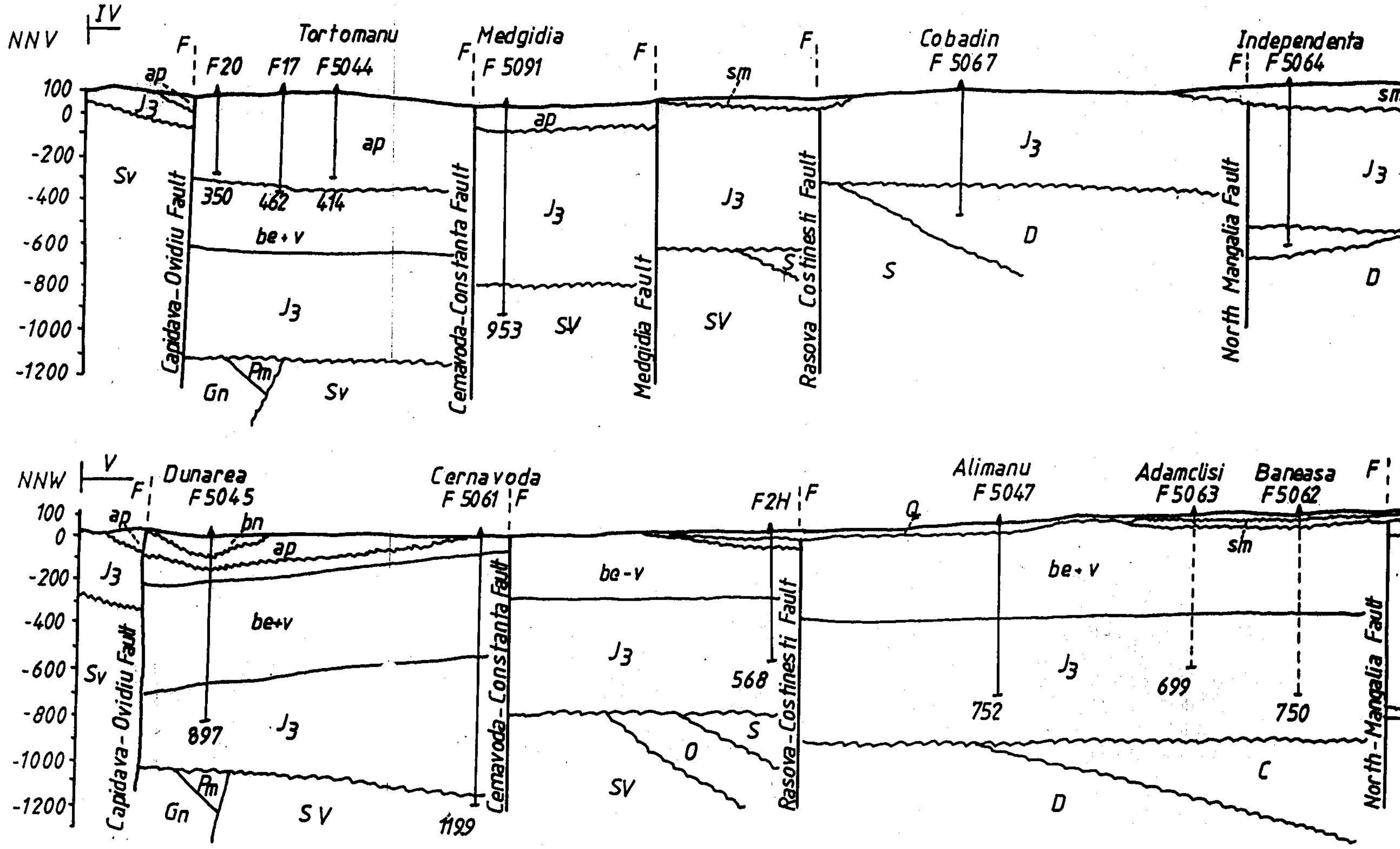

Figure 4.4.2-4. Geological cross-sections (IV and V) (Ref. 4.4-1)

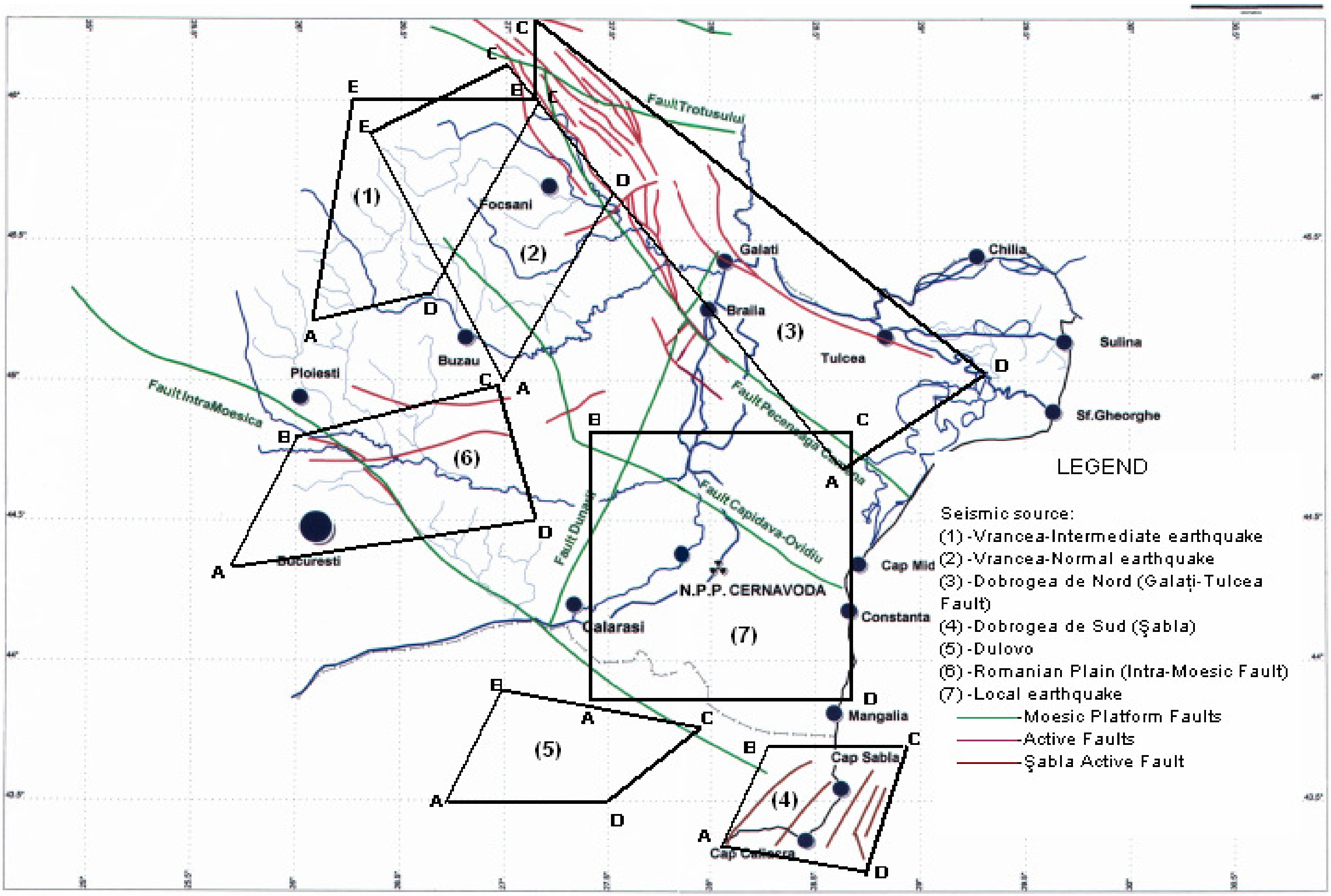

Figure 4.4.2-5. Seismic sources (Ref. 4.4-2)

4.4.3. The Protection of the Subsoil and of the Underground Water Sources

The ground water level within the Cernavoda NPP site varies, in natural regime, between + 8.50m BSL – normal level, and + 12.00 mBSL – maximum level, depending on the levels of the Danube (the distribution basin). Water level variations within the Unit 3, respectively Unit 4 buildings area are diminished by an underground waterproof enclosure (grout curtain and reinforced concrete wall) and also by a drainage system.

The drained shielded enclosures are performed around the buildings which belong to each nuclear unit, between the ground level (+ 15.80 mBSL) and the impervious marl strata. The shielded enclosures were performed by cement grouting in limestones and by reinforced concrete in the upper back-filling level.

Subsoil and ground water are protected by various measures presented in Chapters 2 and 4. Ground water motion from the shielded enclosure towards outside is prevented by reducing the ground water level inside.

The discharge of the water from the enclosure is made through a drainage system by pumping (Qmax = 20 l/s). The water is discharged in the rainfall water drainage system, after the dosimetric control (tritium and gamma). In case of accidental contamination, the water discharge from the shielding enclosure to the rainfall water drainage is stopped until the problems are fixed.

4.4.4. Underground Geotechnical Characteristics

The geotechnical characteristics were basic data taken into consideration when the Cernavoda NPP site design was prepared and the buildings were constructed.

The geotechnical characteristics are also taken into account in the Unit 3 and Unit 4 design.

Regarding the geotechnical characteristics of the bedrock, these are presented below in Table 4.4.4-1 (according to Ref. 4.4-5).

Table 4.4.4-1. Geotechnical characteristics

Layers	Geotechnical characteristics for static analysis														
	Apparent specific weight	Specific weight	Porosity	Grading (clay fraction	Plastic limit W_L = upper	Swelling pressure	Vertical coefficient of	Volume	Fracture strenght	Shear strength	E static modulus for	G shearing static	Poisson's	Admissible conventional pressure	
														Basic combination	Special combination

										Angle of internal friction	Cohesion				Axial reaction at foundation plate	Eccentric reaction at foundation plate	Axial reaction at foundation plate	Eccentric reaction at foundation plate
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
U/M	tf/m^3	tf/m^3	%	%	%	daN/cm^3	cm^2/s	%	daN/cm^3	grade	daN/cm^3	daN/cm^3	daN/cm^3	--	daN/cm^3	daN/cm^3	daN/cm^3	daN/cm^3
B1-Limestone, white, hard, cretaceous	2.3	2.70	24						- 195 153	28	1.5…2.0	12000	4500	0.33	10	12	12	16
B2- Interlayer of clays, high fissured limestones	2.1	2.71	30	31..78	W_L=29…48 W_P=11.5…15.2	0.4	$2•10^{-4}$	1.6	25 70 60	26	0.1…1.0	3500	1300	0.31	9	11	11	14
V - Marl clays (Valanginian-Hauterivian 3)	2.1	2.71	29	31…78	W_L=29…48 W_P=11.5…15.2		$3•10^{-4}$	2.7	30 70 -	20…25	1.0…2.0	4000	1500	0.31	10	12	12	16

4.4.5. Protected Geological Sites

There are not any protected geological sites within or near the Cernavoda NPP site.

There is no information regarding the existence of underground valuable mineral resources in the site area.

4.4.6. Estimation of the Impact on Subsoil

The main buildings of Unit 3 and Unit 4 are already built. The impact on subsoil of the previous engineering works for preparing the site and constructing the buildings and various systems will not be modified during the Unit 3 and Unit 4 completion period.

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