The Suitable Geological Formations for Spent Fuel Disposal in Romania

C. Marunteanu
University of Bucharest
6, Traian Vuia St., Bucharest, 020956, Romania

G. Ionita
ANDRAD
21-25, I. D. Mendeleev St., Bucharest, 010362, Romania

I. Durdun
S.C. GEOTEC S.A.
5-7, Vasile Lascar St., Bucharest, Romania

ABSTRACT

Using the experience in the field of advanced countries and formerly Romanian program data, ANDRAD, the agency responsible for the disposal of radioactive wastes, started the program for spent fuel disposal in deep geological formations with a documentary analysis at the national scale. The potential geological formations properly characterized elsewhere in the world: salt, clay, volcanic tuff, granite and crystalline rocks,. are all present in Romania. Using general or specific selection criteria, we presently consider the following two areas for candidate geological formations:

1. Clay formations in two areas in the western part of Romania: (1) The Pannonian basin Socodor - Zarand, where the clay formation is 3000 m thick, with many bentonitic strata and undisturbed structure, and (2) The Eocene Red Clay on the Somes River, extending 1200 m below the surface. They both need a large investigation program in order to establish and select the required homogeneous, dry and undisturbed zones at a suitable depth.
2. Old platform green schist formations, low metamorphosed, quartz and feldspar rich rocks, in the Central Dobrogea structural unit, not far from Cernavoda NPP (30 km average distance), 3000 m thick and including many homogeneous, fine granular, undisturbed, up to 300 m thick layers.

INTRODUCTION

Commissioned in 1996, the nuclear power plant (NPP) at Cernavoda raises the issue of radioactive waste disposal. The Romanian Electricity Authority initiated a program of management and disposal of spent fuel in deep geological formations. ANDRAD (Romanian National Agency for Radioactive Waste) is a new governmental agency created in 2004 for disposal of radioactive waste that revitalises the subject.

Clay, which is a newly considered potential host rock, and four other already analyzed rock types [1]: salt, volcanic tuff, granite and old platform green schists were included in a new comparative analysis designed to select the suitable geological formation for spent fuel disposal in Romania. The used criteria are not of equal importance, nor are they to be construed as specifications for the construction of a geological repository. They are intended to be a basis for determining the suitability of a given repository site in comparison to other geological formation and alternative sites.

SELECTION PROCESSES AND CRITERIA

The common opinion today is that the only practical way for safe spent fuel disposal is in deep-laying bedrock. Five geological rock types recommended around the world as host rocks are widespread in Romania and considered potentially suitable as geological barriers for underground disposal. They are our candidate host formations and comprise: salt, volcanic tuff, granite, old platform green schists and clay. We used the following main general geological (seismicity, depth, size and shape, structural homogeneity, virgin state etc) and specific criteria for each formation in a documentary analysis at the national scale to identify potential candidate areas :

- *Seismic intensity of area;*
- *Size and shape of the rock body;*
- *Petrologic and structural homogeneity;*
- *No adjacent area with major dam site and*
- *No area with subsurface mining.*

GEOLOGICAL HOST FORMATIONS FOR SPENT FUEL DISPOSAL IN ROMANIA

Salt Deposits

Rock salt seems to be one of the most suitable formations to host radioactive waste disposal. As a result of its plasticity, rock salt is practically impermeable and due to its favorable geomechanics properties it remains stable or ductile over long periods of time.

There are more then 190 salt deposits in different geological and tectonic condition in Romania, mainly in the Carpathian Orogen and the Transylvanian Basin. There are also some salt deposits in the Maramures Depression and the Moesian Platform.

In the Carpathian Orogen area, the contrasting tectonic conditions controlled the fragmentation of the salt layers by lateral or vertical distribution as diapiric bodies (stocks or pillows), affected by overburden folds or thrusts. The s*eismic intensity* of this area exceeds the related criterion, the seismic intensity being usually more than 7 (MKS) and including the Vrancea great earthquake center.

In the Transylvanian basin, Neogene depressions developed above the Inner Carpathian deformed units and the post tectonic covers contain Lower Badenian salt, laying generally on the Dej tuff. In the central part of the Transylvania Depression, the thickness of salt is 100 – 200 m and 300 –500 m in the structures constituting cores of gas bearing domes at 2 – 4 km depth. On the margins of the Transylvania Depression, the salt suffered intensive diapirism, forming sometimes more than 1000 m high stocks.

The size and shape of the salt body was the second structural criterion. The selected host bodies of salt should be pillow or stock diapirs, measuring 1.5 km^2 in horizontal cross-section area and being at least 500 m thick.

The depth of the repository should be enough to separate the repository from any surface process (extreme conditions of scour or erosion) and long-term geological movements, such as recent crustal movements or diapirism. According to the results of the German investigation on salt, even the worst-case scenario would not affect a waste repository located several hundreds meters below the cap rock. Under these conditions, the minimum depth of the repository should be 600 m, with a 300 m thick the salt roof. [2, 3, 4]. Outcroping diapirs generally show higher rates of diapiric rise and should by avoided. Estimating the rate of salt dissolution and the volume of dissolved salt in Romania, the resulting rising rate is 10 – 30 mm/year during a period of 2000 – 5000 years, but the presence of terrace deposits on the dome surface indicates that the process is intermittent [5].

The virgin state of the salt massif. No area with present or past salt extraction activities would be selected as repository site.

Based on the aforementioned screening criteria, four salt massifs were selected for continued analysis.

Granite Rock Massifs

Granite rocks (igneous rock, as well as crystalline rock) are generally hard, strong and weathering resistant. They also provide an adequate shield against radiation and heat produced by the radioactive waste. Studies carried out on granites in different countries (e.g. Loviisa - Finland, Stripa and Äspö - Sweden, Grimsel - Switzerland) show permeability values lower than 10^{-9} m/sec in sound rocks but much higher values in fractured zones [6].

Seventeen of the most important granite massifs in Romania and their characteristics were analyzed. Based on the seismic intensity criterion, only zones with seismic intensity less than 7 (MKS) were accepted. Following is a listing of the other criteria and the related results:

- *Size and shape of the granitic body* – All the selected massifs have large extend, occuring as batholithic or laccolithic forms.
- *Petrologic and structural homogeneity* – Massive structure, equigranular texture, low degree of fracturing and no major tectonic faults are the favorable characteristics, occuring especially in the cores of the granite massifs.
- *No adjacent area with major dam site* – The reservoir water load and the increased water pressure can produce local hydrological systems that should be avoided.
- *No area with subsurface mining* – Massifs with present or past mining works shoud be avoided.

Based on these criteria, four granite massifs were selected: one in Dobrogea and three in the western part of Romania.

Volcanic Tuffs

The Dej tuff is one of the most important volcanic tuffs in Romania. It forms a continuous layer in the Transylvania Depression and is covered by a salt formation. Only one area in the northeastern part of the Transylvania Depression, which is more than 400 m thick at 800 – 1500 m depth was selected. Weathering zones and some confined aquifers are present in this layer.

Old Platform Green Schists

Similar to crystalline rocks, the Old Platform green shists rocks are very hard, strong, massive and weathering resistant. The main mineralogical components are quartz and plagioclase feldspar. Chlorite is responsible for the green color.

The Dobrogea Central massif is known as a rigid horst and is a raised portion of the basement block. The Hercynian green shists, measuring more then 5000 m in thickness, overlay Pre-Cambrian crystalline rocks. They consist of coarse to fine grained greywacke, with intercalations 200 – 300 m thick, and are homogeneous and undisturbed strata. The main systems of faults mainly strike parallel with Pecineaga – Camena (N) and Ovidiu – Capidava (S) West – East faults and the second North – South faults divide the Central Dobrogea horst into blocks. The potential sites were selected by avoiding the faults zones and retaining the blocks with maximum massiveness. Sedimentary covers sporadically occur on small areas as upper Jurassic - lower cretaceous limestone. Quaternary deposits cover large areas with loessic deposits. A geological section through Central Dobrogea is presented in the Figure 1. Following is a listing of the general criteria applied and the related results, including potential sites in green schists:

- *Stratigraphy and mineralogy* - Four stratigraphical levels with different mineralogy, granulosity and stratigraphical positions are present: (1) low level coarse grained sandstone and conglomerates (infragreywacke level); (2) low coarse grained level (lower greywacke sandstone) with 0.10 – 1.00 m thick layers, sometimes with 1,00 – 3,00 m thick fine-grained intercalations; (3) upper coarse grained (upper greywacke), 300 m thick, more homogeneous and massive, with 2.00 – 6.00 m thick sandstones and 0.10 – 0.20 m thick conglomerate intercalations, fine-grained and very homogeneous and continuous at the upper part; and (4) upper level (supragreywacke) with stripped textures and fine-grained.
- *Thickness of green schists formation* - Based on geophysical investigations (gravimetric, magnetometric, seismic, electrometric etc.) and direct geological mapping, the isobaths map at the base of the green schists formation was constructed. The maximum thickness is found in the south – eastern part (Siutghiol Lake area), where the thickness is about 6000 m, compared with 3000 – 5000 m elsewhere in the region.

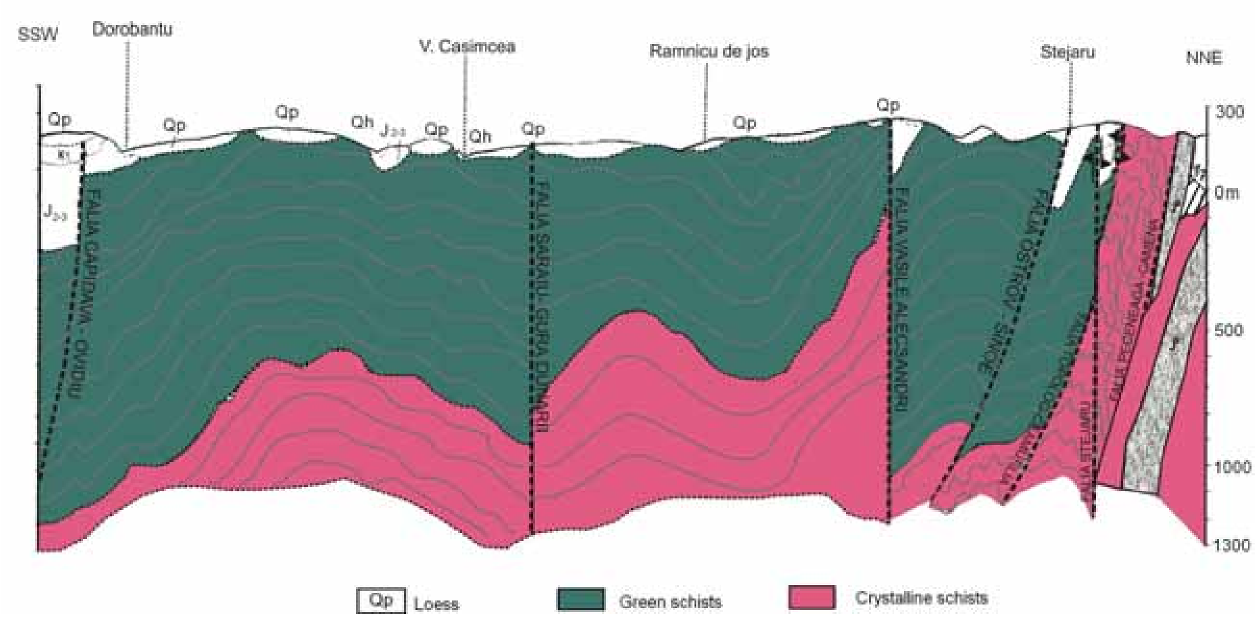

Fig. 1. Geological section through Central Dobrogea

- *Central Dobrogea tectonics* - The rigid blocks of Central Dobrogea are bordered by two NW-SE trending well-known faults: the Pecineaga – Camena fault to the North (N) and the Ovidiu – Capidava fault to the South (S) and two N-S trending faults: the Danube fault to the West (W) and the Black Sea fault to the East (E). There are also other faults parallel to the aforementioned faults (Ostrov – Sinoe and Saraiu – Gura Dunarii, E-W, and Vasile Alecsandri, N-S). The crustal movement maps show other, different zones/blocks, including a relative stable area in the Danube area and a subsidence area in the SW Constanta, with a maximum value for crustal movements of maximum ± 3 mm/year. Sites inside blocks with minimum vertical displacements were chosen,

avoiding the fault zones and zones with recent crustal movements. The stable western part of Dobrogea was selected due to its minimal vertical movements.
- *Seismicity of Central Dobrogea* - According to Romanian norms, the seismic intensity generated by the Vrancea earthquakes is here less than 7 (MKS) and the returning period is Tr = 50 years. The biggest Pontic earthquake (1901) generated in the region seismic movements with an intensity of less than 7 (MKS). The local seismicity generated by fault activity is here no more than 4 on the Richter scale. A few small seismic centers are present along the Pecineaga - Camena fault and the Ovidiu - Capidava fault.
- *Hydrogeology* - In the eastern part of the Central Dobrogea, the contact between the Jurassic limestone and the green shists constitutes a rich aquifer, serving as a water supply for the Black Sea coast area. This eastern area was avoided.
- *Weathering of green schists* – The mineralogy of the green schists is mainly represented by 80% quartz-feldspar and by chlorite, sericite etc. representing the remaining 20%. Quartz and sericite are stable. Feldspars and chlorite are instable at super-gene alteration.
- *Geotechnical characteristics* - The laboratory tests on the green schist cores provided the following values: density: $\gamma = 2.60 – 2.75$ g/cm^3; compacting degree: 98%; porosity: n = 0.4 – 2.0 %; compressive strength: Rc = 80,000 – 140,000 kN/m^2 and bearing capacity: $\sigma > 6000$ kN/m^2.

Following the application of the above criteria, five potential sites with high degree of compaction and vertical stability were chosen in the western part of the Central Dobrogea. This area provides also a small population density, only 30 – 60 inhabitants/km^2 and few small villages.

Clay

Due to its properties – low permeability, homogeneity, retention capacity of radionuclide, etc, - the clay formation might be at the top of the preferred host geological formation for spent fuel disposal in Romania. Our analysis took account the following properties of the clay formations:

- Grain size distribution: clays and silts with grain size smaller than 0.125 mm (Romanian Standards);
- Low - permeability K< 10^{-4} cm/sec; and
- Depth of the upper part of the clay formation - more than 400 m; minimum thickness - 400 m.

Based on the screening summarized below, the following clay formations of different ages were selected for continued evaluation:

1. Pannonian in the Pannonian Depression (the western part of Romania near the Hungarian border);
2. Pannonian in the Transylvanian Depression;
3. Eocene – Lower Stripped Clay in the Transylvanian Depression;
4. Lower Badenian - Lower Sarmatian in the Transylvanian Depression;
5. Upper Cretaceous in the Moesian Platform and
6. Dacian – Romanian in the Carpathian avant-fosse.

Seismological criterion - Considered the tectonic phenomena by avoiding basins with seismic intensity more than 7 (MKS), close to the Vrancea earthquakes: Carpathian avant-fosse, south of the Moldavian Platform and large areas of the Pannonian Depression, Moesian Platform and Transylvanian Depression.

Hydrogeological criterion - Many clay formations include at different levels big aquifers. There are many big thermal aquifers at the lower part of the Pannonian Depression at the contact with the crystalline basement (for instance Oradea - Baile Felix area, where the aquifer has Q = 17000 cm/day at 90^o C). There are also more Pannonian and Quaternary aquifers in the upper part of the Pannonian clay formation, some of them being used for water supply in Timisoara, Arad or Satu Mare. Quaternary terrace deposits with free-level aquifers are located along the main rivers, e.g., Bega, Mures, Crisuri, and Somes. The Eocene lower stripped clays include sometimes in the central area the limestone of Rona with an aquifer of Q = 5 l/sec, but there are many areas where the limestone is missing. In the area of the Moldavian Platform, the Quaternary aquifer along the Siret River and the artesian aquifer in limestone and sandstone from the Prut river area were also considered. In the Moesian Platform, there are many big aquifers hosted in gravels or sands up to 200 – 250 m depth or deeper, in Jurassic or Cretaceous limestone or dolomite. All these areas were avoided.

The gas and oil structures criteria - In the Transylvanian Depression, there are many accumulations of gas and oil. In a northeastern area (Somes River Valley, near Jibou), the host formation was eroded and no gas or oil accumulations were found. In the Pannonian Depression, gas and oil deposits are still being explored and extracted. These deposits were formed usually at the contact with the crystalline basement. In the Zarand – Socodor area, the crystalline basement is present at 3000 m depth and there are no gas or oil accumulations.

Based on the detailed screening process, only the following two clay-formation areas were selected for further study:

1. Zarand – Socodor in the Pannonian Depression area, near the Hungarian border, where the Pannonian clay deposits are more than 3000 m thick, with many bentonitic layers and no gas or oil accumulations. One disadvantage could be the presence of aquifers in the upper part of the clay deposits, many of them artesian or ascending.
2. Somes – Guruslau in the northwestern part of the Transylvanian Depression (Somes River Valley, near Jibou) in the Lower Stripped Eocene Clays. The clay formation here is more than 1200 m thick and a large sector of Rona limestone is missing. The structure is more or less undisturbed, and homogeneous and thick layers have intercalated lenses of gravel or sand.

CONCLUSIONS

In the authors’ not exhaustive opinion, only the following two geological formations should be selected as “candidates” for further study for underground spent fuel disposal:

1. *Old platform green shists* from Central Dobrogea, not far from Cernavoda NPP are recommended due to their thickness, hardness, massiveness, homogeneity and impermeability. The main mineralogical components, quartz and plagioclase feldspars, provide good geotechnical characteristics. The weathering was found extending only to a depth of 20-50 m, and occurring in the discontinuities. Five potential sites were selected inside homogenous blocks, in a stable area in the western part of Central Dobrogea.
2. *Clay formations*, recommended by their impermeability and retention capacity, and generally far from the Cernavoda NPP. Two potential areas have been identified: the Pannonian clay, in the Pannonian Depression (near Curtici), 3000 m thick and many intercalated bentonitic layers; and the Eocene Stripped Clay, in the Transylvanian Depression (on Somes Valley, near Jibou), 200 m thick and with montmorillonitic mineralogical composition.

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