CHAPTER 4

THE PROBLEM OF SITE SELECTION FOR A RADIOACTIVE WASTE REPOSITORY IN BULGARIA

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Abstract. The approach to the solution of the problem of site selection for the construction of a high level radioactive waste (RAW) repository in Bulgaria has passed so far through two stages. The first stage includes the regional survey of the country on a 1:500,000 scale to select regions with suitable conditions for further investigations. At the second stage, 18 sites have been selected in these regions, to be subjected to more detailed analysis. Two types of areas, providing comparatively favourable conditions, are considered in the present work: the marl terrains in northwest and northeast part of the Fore-Balkan in north Bulgaria, and the Sakar granite pluton in southeast Bulgaria. The marls are clayey and have a thickness of up to 1000 m. They are situated in a zone of calm tectonics and seismicity of VII-VIII degree on the MSK scale. All available data for the Sakar granite pluton are also favourable. Additional *in-situ* and laboratory investigations have to be carried out for both types of formations with the view of collecting the necessary specific information, required for the in-depth RAW disposal.

4.1 INTRODUCTION

The Bulgarian Nuclear Power Plant (NPP) of "Kozlodui" is equipped with 6 nuclear reactors of the VVER type (produced in Russia) and has an output of 3760 MW of electric energy, which is 35 - 40 % of the total output of the country. The construction of the second Nuclear Power Plant of "Belene" has been stopped because of civil protests.

So far, the unsolved problem of radioactive waste (RAW) processing and storage is one of the reasons for the negative social reaction and for the attitude of ecological organizations against nuclear power generation. Vast quantities of unprocessed low and medium level wastes have been accumulated after nearly twenty years of operations at the Kozlodui NPP. Their total volume at the closing of the plant is estimated to be from 128,000 to 170,000 cubic meters in the cemented state.

The problem with the highly radioactive wastes is still more serious. During the last several years, Russia refuses to further process the waste fuel, which is now stored at a temporary repository. Negotiations are in progress for the signing of a new agreement, according to which the vitrified highly radioactive wastes obtained after the spent fuel processing are to be returned to Bulgaria for final disposal. In case that such agreement is not achieved, the spent nuclear fuel will be stored for several decades at a temporary repository in Kozlodui. In 1991, the Council of Ministers of the Republic of Bulgaria imposed the task of developing a concept for the construction of a national RAW repository on the Bulgarian Academy of Sciences (BAS) with the view of accelerating the solution of the problem. A large team of scientists from the Earth Sciences Division of BAS was organized to study foreign experience and to make a thorough analysis of the natural environment in Bulgaria. As a result, areas and geological complexes that appear favorable for further investigations concerning the construction of RAW repositories have been determined (Milanov et al., 1993).

The problem of selecting sites and rock systems, suitable for highly active RAW has been carried out in two stages. A preliminary screening of the territory of the country has been performed, and single regions distinguished where suitable geological formations are expected to be found. A subsequent screening has been carried out in these regions to select 18 sites offering considerably better conditions.

4.2 PRELIMINARY SCREENING OF THE TERRITORY OF THE COUNTRY

The territory of Bulgaria has a complex and diverse geo-

logical structure. Part of it is affected by young Alpine tectonics and is characterized by complex and difficult geological conditions from the point of view of the problem to be solved.

Rocks and formations ranging in age from the Precambrian to the Quaternary make up the geological structures of the country. The metamorphic and magmatic complexes are distributed mainly in south Bulgaria: the Rhodopes massif, the Sredna Gora and the Sakar-Strandzha zone, and the sediment complexes in the region of the Balkanides, the Kraishte and in the Moezian platform. The volcanogenic sediments and volcanic complexes are well developed in the Sredna Gora (of Upper Cretaceous age) and in the Rhodopes massif with Paleogenic formations (of Oligocene-Miocene age) situated on its periphery.

The Bulgarian territory falls entirely within the region of the Alpine-Himalayas orogeny (Boncev, 1971) and this is the prerequisite for the relatively complex tectonic conditions. Deformations were established which are related to the Precambrian mega stage in the development of the highly metamorphic complexes as well as the Caledonian Variscian deformations, early and late Alpine deformations and the neotectonic deformations related to rock complexes of the Fanerozic mega stage.

The superposition of various tectonic movements in the course of time has led to the formation of folded structures, varying in type and magnitude, and terrains of block or block/thrust structures. The rock complexes in them are strongly deformed and have hydrogeological and geotechnical engineering conditions which are difficult to model. This especially concerns the Balkanides, the Kraishte, the Strandzha zone and parts of the Rhodopes massif. Fault zones exist in these morphotectonic units, along which neotectonic movements of an amplitude of up to 3400 m occur, accompanied by rock deformations and the development of exogenic geological processes.

The selection of zones with low tectonics, from the Neogene to the present, and containing suitable rock complexes is facilitated by the carefully studied geology of the country. The whole territory of Bulgaria is presented on geologic, tectonic, engineering geology and hydrogeology maps on scales from 1:10,000 to 1:1,000,000. Amap of the geologic hazards in Bulgaria has recently been published on a scale of 1:500,000 (Iliev et al., 1994). The new geologic map of Bulgaria on the scale of 1:100,000 has been very useful for the geologic screening of the country. It is based on the lithostratigraphic principle and provides a very good idea for the distribution, composition and structure of rock complexes. There is also available information for the in-depth structure of the lithostratigraphic units, which provides a means of choosing rock complexes of great thickness and suitable properties (granites, gneisses, volcanic rocks, serpentinites, marls and clays. Evaporitic rocks have not been considered since they are of industrial interest or are situated at great depth.

The geological analysis of the country has been supplemented by analyses from the other earth sciences. The lithostratigraphic information, combined with data from tectonic and seismic investigations, has provided the possibility of delineating zones of relatively less tectonics, where the number of active faults is smaller and the seismic centers are of smaller magnitude. The seismic characteristics of the Balkans peninsula and Bulgaria are reflected by a series of maps, showing locations of strong earthquakes up to 1990 with the magnitude-depth distribution, the possible epicenters of strong earthquakes, the seismic risk for a period of 1000 years, etc. The specificities of the temperature regime and of the geothermal field are also taken into consideration.

The contribution of engineering geological analysis consists of information about the texture and structure of the rock massifs, the physical, mechanical and chemical properties, and the conditions for the construction of underground openings in them.

The hydrogeological conditions in Bulgaria are summarized in maps of different scale, which provide information about the groundwater basins, their water transmissibility and rock filtration properties. Vast regions of the country have been excluded from further consideration on the basis of the available hydrogeological information, proving that RAW disposal in them is impossible.

The geographic analysis has taken into account the relief characteristics, the hydrographic network, the climatic specificities, the natural resources, the economic-geographic and conditions of population. A map has been created on the basis of the density of population, the network settlements and the average distance between settlements, on which five types of regions are distinguished from the point of view of the problem to be solved. The possibilities of utilizing about 260 mines for disposal purposes have been studied separately, and a selection has been made for the most prospective sites. The comparison and juxtaposition of the results of these

different earth sciences have led to the selection of regions offering the best conditions for investigating a site, suitable for the construction of a RAW repository. On this basis, a "Map of Categorization of Terrains in the Territory of Bulgaria" has been prepared on a scale of 1:500,000. A reduced copy of this map is presented in Figure 4.1.

The categorization has been performed on the basis of the following principles:

- All natural conditions of the country are considered but priority is given to the geological conditions;
- Preference is given to those regions where positive assessments of the geologic, seismic-tectonic and hydrogeological conditions coincide and the other conditions are not negatively assessed;
- Except for natural conditions, other factors are taken under consideration too—technogeneous loading, demographic conditions, ecological conditions, interests of tourism, etc.

The regions possessing favourable characteristics are concentrated mainly in the northwest and northeast parts of the country (Fig. 4.1). They contain: (a) rock complexes of considerable thickness and surface distribution; (b) no active faults; (c) level of seismicity that is lower than the VII - VIII degree according to the 1000 year map; (d) hydrogeological conditions that are acceptable; and (e) a density of population that is not too great.

4.3 METHOD FOR SELECTING SUITABLE SITES

The next step in the procedure of site selection has been to distinguish several tens of areas and mines in the regions with favourable conditions, where comparatively good geologic settings exist for the in-depth disposal

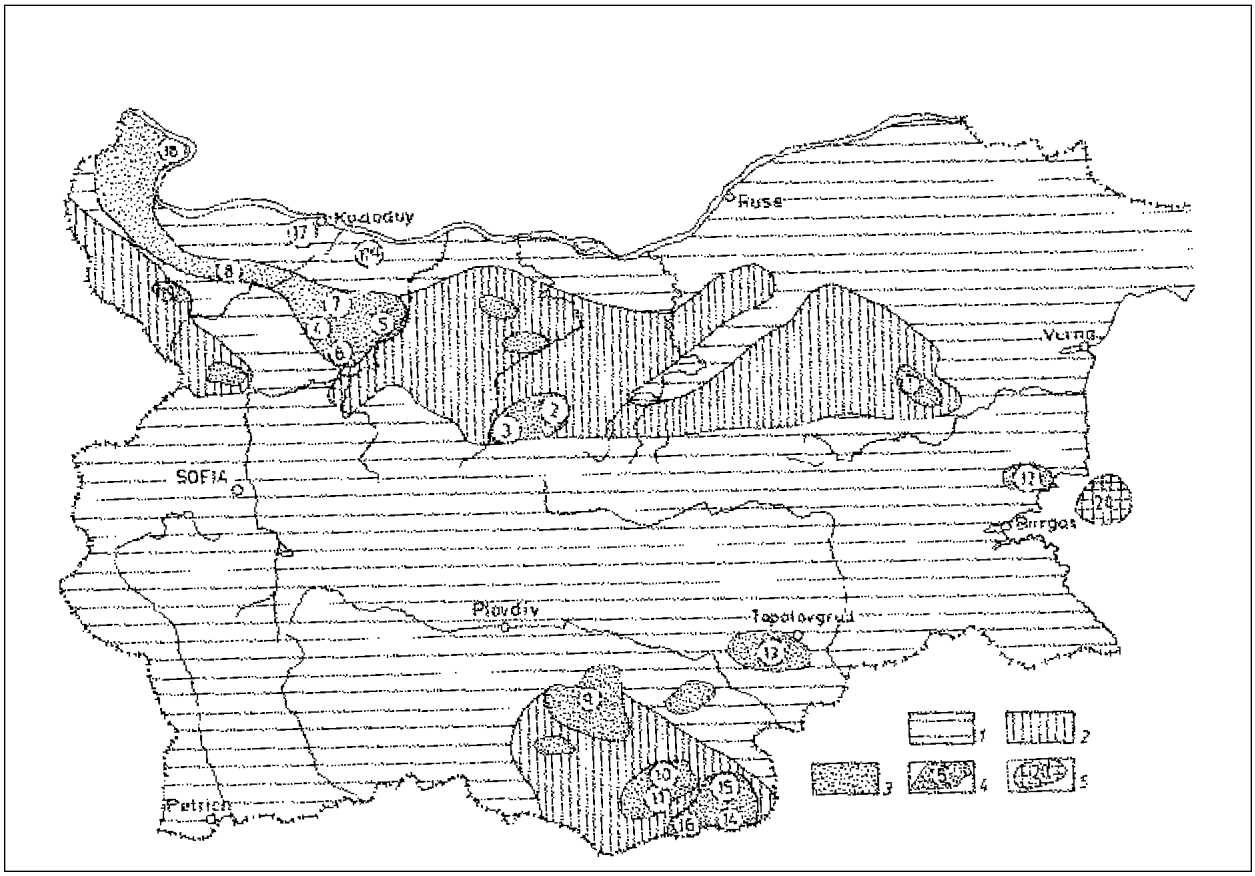

Figure 4.1. Map showing categorization of the Territory of Bulgaria into: (1) site unsuited for RAWrepository construction; (2) prospective sites for further investigations; (3) regions with selected single sites for additional investigations; (4) a particular numbered site; and (5) a tunnel in the Black Sea offshore area (after Kostadinov and Kozhoukharov, 1992).

of highly radioactive wastes. Their number has been reduced to 18 by the method of successive elimination. The selected 18 sites have been investigated in more detail on the basis of the available information and minimum additional investigations. A report has been prepared for each of the sites, summarizing the geology, hydrogeology and engineering geology information. The reports are supplemented by detailed geologic maps and lithostratigraphic profiles.

The comparative analysis of the sites is performed on the basis of the criteria proposed by the special commission of the EC countries (European Catalogue 1979, Orlowski and Shaller, 1990), taking into consideration the specific conditions in Bulgaria. The criteria have been divided in four groups: (a) rock-linked parameters; (b) basic formation parameters; (c) formation - environment factors; and (d) supplementary selection factors. The rock-linked parameters include the rock's sorption capacity, thermal conductivity and solubility. The formation is evaluated by a larger number of parameters: thickness, minimum depth, surface area, homogeneity and uniformity, permeability and geotechnical properties. The environment in which the formation exists is evaluated by three important factors: hydraulic gradient, seismicity and tectonics. The additional factors include: the availability in the region of a rock formation and its potential use for economic purposes, the sensitivity of the zones to climatic and hydrologic changes and socio-geographic and population conditions.

The sites have been classified according to their suitability on the basis of an ordinary expert analysis, as well as by means of a system analysis (Vachev and Evstatiev, 1994). Priority scales have been developed for each criterion for the purposes of system analysis.

This classification has a preliminary character because the available information on the most important criteria such as sorption of the rock, its filtration properties and the hydraulic gradient, are insufficient for quantitative assessment. However, the sites composed of Lower Cretaceous marls in the Fore-Balkan, the Sakar granite pluton, and the gneiss and serpentinite massifs in the East Rhodopes, although at a preliminary stage, have been determined as the most favorable for further investigations.

4.4 CHARACTERISTICS OF SITES

Examples of prospective disposal sites from two different areas are presented in order to show the degree of investigations and the completeness of the available data at the conceptual stage. The first area is situated in north Bulgaria and consists of thick marl complexes, and the second is in south Bulgaria in the Sakar granite pluton.

4.4.1 Prospective Sites in Lower Cretaceous Sediments of Fore-Balkan

A vast depression was formed in the Fore-Balkan of north Bulgaria during the Lower Cretaceous where sediments, mainly of marl composition, are deposited (Nikolov and Khrischev, 1965). These sediments have been carefully investigated at the surface and at depth during explorations for oil and gas deposits, and their tectonic conditions and lithostratigraphic structure have been studied in detail (Nikolov et al., 1991). They have been subjected to additional analysis in three reports which are supplements to the Concept of BAS for a National RAW repository (Nikolov and Ruskova, 1992, Monov, 1992, 1993).

The information presented below is obtained from these reports. The results from the analysis show that several sites situated in northwest and northeast Bulgaria are most favorable for more detailed future investigations. These sites contain comparatively pure clayey marls of great thickness, up to 1000 m and more. The marls in central north Bulgaria contain thick accumulations of limestones and sandstones. Some of them are water-bearing, and for this reason are excluded from further consideration.

4.4.2 Prospective Sites in Northwest Bulgaria

Several sites situated between the Iskar and Ogosta rivers fall into this category (sites Nos. 4, 5, 6, and 7 in Fig. 4.1). They are situated at a distance of 60-80 km south of the Kozlodui NPP. They are in the northern strip of the west Fore-Balkan, which is characterized by relatively calm neotectonics. Intensive tectonic activity had ceased after the Pyrinean phases, when the Fore-Balkan was formed. There are no active faults in the vicinity of the sites. The seismicity is of the VII degree on the MSK scale for a period of 1000 years.

Gas deposits have been discovered in the region, and as a result, there are more than 150 deep boreholes. This has provided data for lithostratigraphic and geophysical investigations and the investigation of geological structures both at the surface and at depths down to 3500 m (Fig. 4.2).

The Sumer and Mramoren formations which consist of

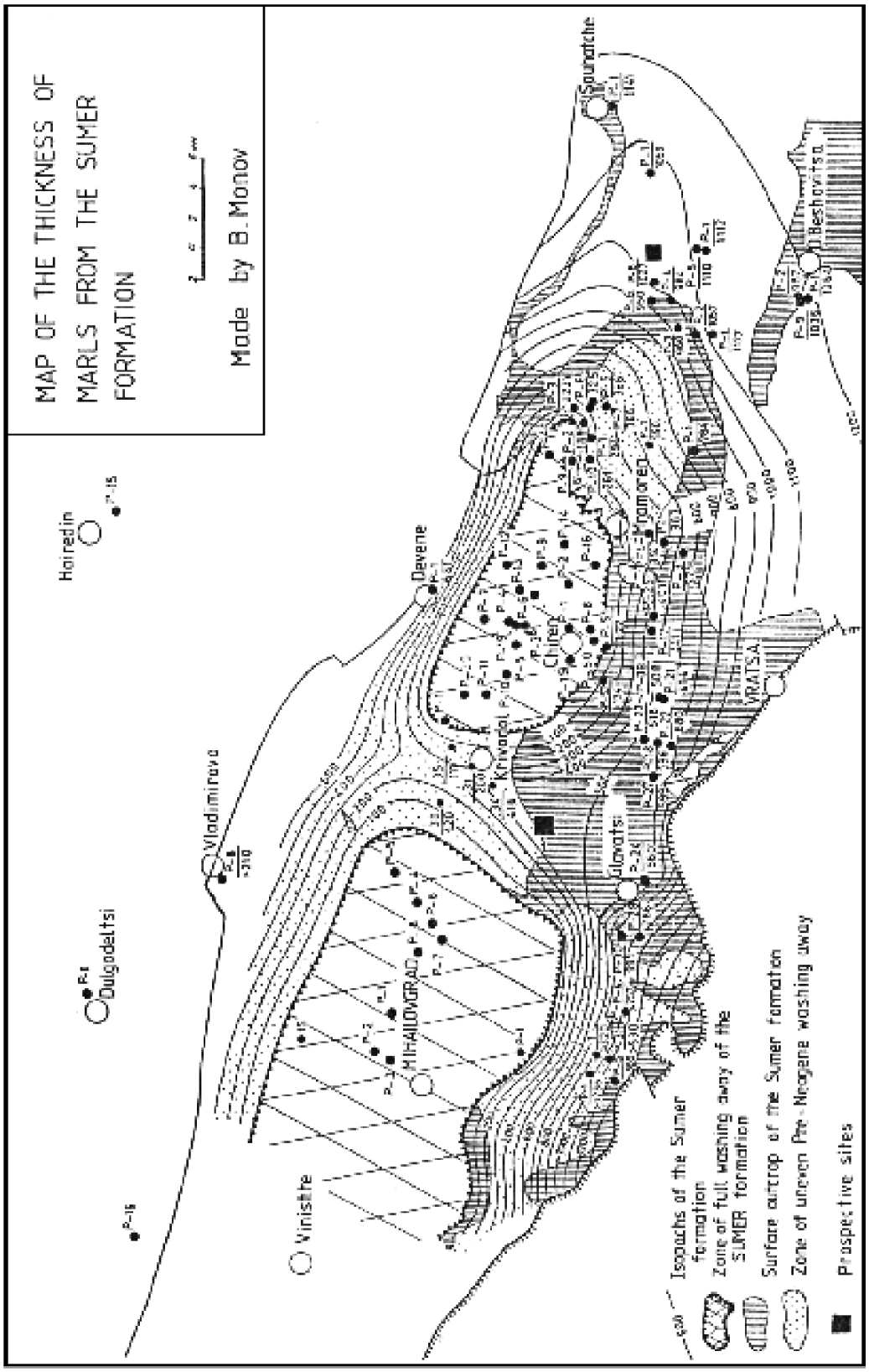

Figure 4.2. Map of the thickness of marls of the Sumer Formation (after Monov, 1993).

very thick clayey marls are of greatest interest from the point of view of the construction of an in-depth repository (Fig. 4.3). The available hydrogeological data indicate that the marls are dry and of very low permeability.

4.4.3 Prospective Sites in Northeast Bulgaria

The Gorna Oryahovitsa formation, in the Lower Cretaceous sediments of northeast Bulgaria, is most interesting as a prospective site for RAW disposal. (Nikolov et al., 1991). The formation consists of Lower Cretaceous clayey marls where terrigenous intercalations are almost absent (Figs. 4.4 and 4.5). The selected site (No. 1 in Fig. 4.1) near the village of Zlatar, Shoumen district, is situated in a shallow anticline and is characterized by a low level of neotectonics and lack of active faults. The marl thickness exceeds 600 m. The Ticha formation, which is a buffer zone also containing thick marl layers, occurs in the Gorna Oryahovitsa formation (Fig. 4.5). The seismicity of the region is of VIII degree on the MSK scale according to the seismic map for a period of 1000 years.

The Concept of BAS accepts marl terrains as possibilities for both in-depth disposal of high level RAW and the surface-type repository for low- and medium-level RAW. From the point of view of problems related with the attitude of the population concerning the RAW repository, it is advantageous to build repositories for both types of waste at one and the same place.

Two types of repositories are proposed for consideration for in-depth disposal of high level RAW: (1) mine disposal and (2) borehole disposal. The comparatively small volumes of this type of waste make it possible to consider the construction of the second type of repository, which is less expensive and possesses certain technological and ecological advantages. Moreover, considerable experience exists in Bulgaria on the performance of deep boreholes, in marl rocks, in relation to the exploration for oil and gas deposits.

4.4.4 Prospective Sites in Magmatic-Metamorphic Terrains

Several sites with magmatic and highly metamorphic rocks in southeast Bulgaria are proposed in the Concept of BAS. The following sites have been selected after comprehensive analysis of natural conditions in this part of the country: the Byala Reka structure, composed of Precambrian highly metamorphic gneisses; the Avren and Zhâlti Chal sites, composed of metaultrabasites; the Sakar site, composed of Paleozoic granites and two sites in the East Rhodopes Paleogene depression, composed of volcanic and volcanogenic sediments (Nos. 9, 10, 11, 13, 14, 15 and 16 in Fig. 4.1). Preliminary explorations on these sites have been performed by Kozhoukharova (1992), Kozhoukharova and Kozhoukharov (1992), and Kozhoukharova, et al. (1992).

4.4.5 Prospective Sites in Paleozoic Granites of Sakar Pluton

The Sakar site in southeast Bulgaria (No 13 in Fig. 4.1) is entirely within the area of the mountain of the same name. The region is composed of Precambrian high-crystalline metamorphites, Paleozoic metasediments and granites, Triassic metasediments and Pliocene formations (Kozhoukharov et al., 1994a, b). From a tectonic point of view, the region falls into the range of the Sakar unit, which is a component of the Sakar-Strandzha tectonic zone. About 60% of the site is composed of Paleozoic granites, known as the Sakar pluton. At the surface, the granites have been well investigated, but there are no data about their condition at depth. There are no active faults in them from the neotectonic stage; faults of this type are observed along the periphery of the mountain beyond the limits of the pluton. The seismicity is of the VII degree on the MSK scale for a period of 1000 years.

4.4.6 Characteristics of Sakar Pluton

The Sakar pluton was emplaced entirely among the Precambrian high-crystalline, ortho- and para-metamorphites of the Prazhodopian supergroup (Kozhoukharov, 1984, 1987) with presumed age of Archaic (?) - Lower Proterozoic. It intrudes and is partially metamorphosed by contact with the porphyric blastic migmatites of the Pânovo formation, the different gneisses, gneiss-schists and schists, amphibolites, graphite- and iron-bearing quartzites, etc., of the Zhâlti Chal variegated formation as well as the metaconglomerates of the Konstantinovo formation. Amultitude of xenolites of these rocks occur in the peripheral parts of the pluton. At its western end, the Sakar pluton crosses and contact metamorphoses Upper Carboniferous sediments. The basic varieties of the granitoids in the Sakar batholith are three: uniformly grained; porphyric and porphyroid and aplitoid-pegmatoid (Alexandrovo) granites.

The porphyric granites are found in the western parts of

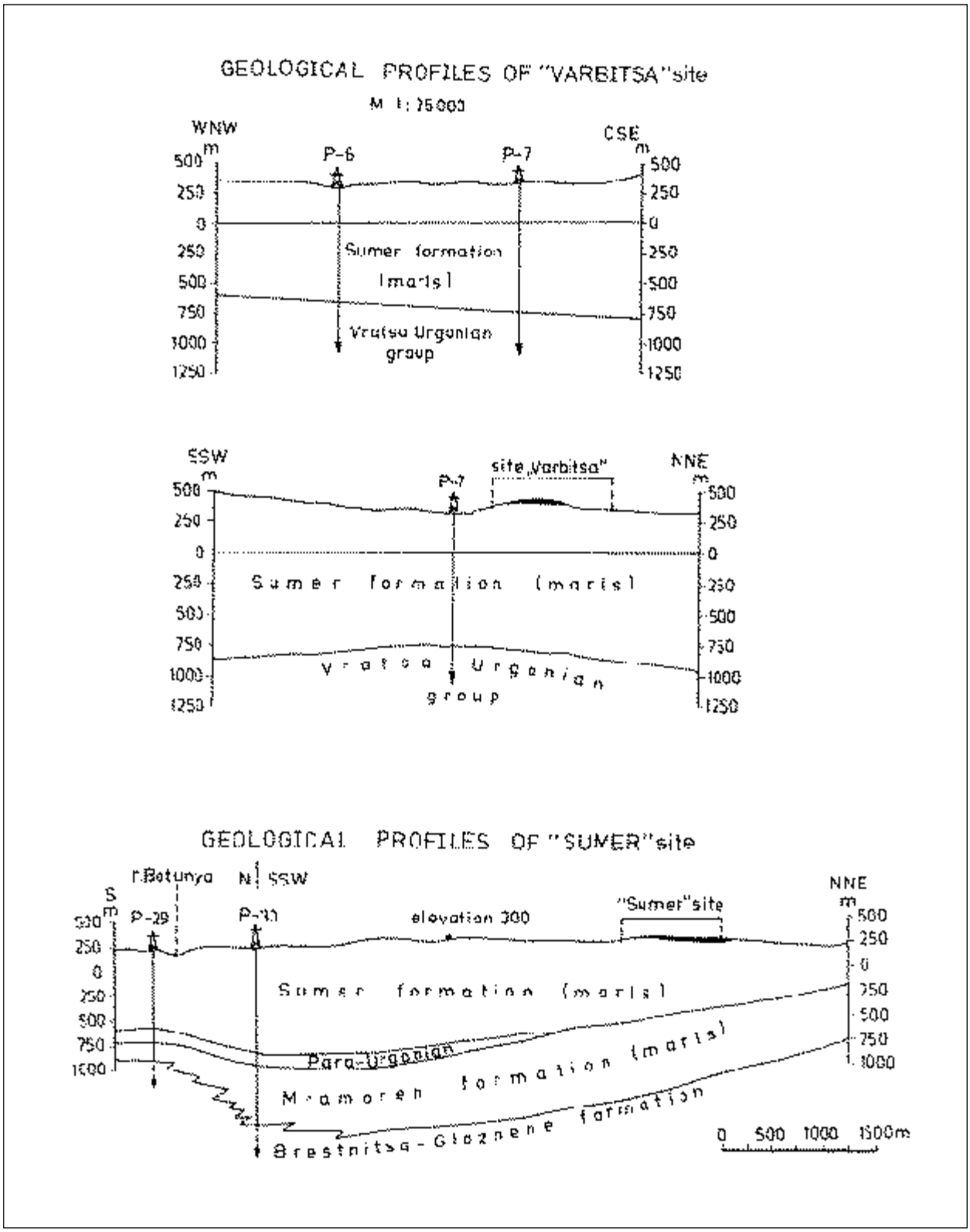

Figure 4.3. Geological profiles of the "Varbitsa" and "Sumer" sites (after Monov, 1993).

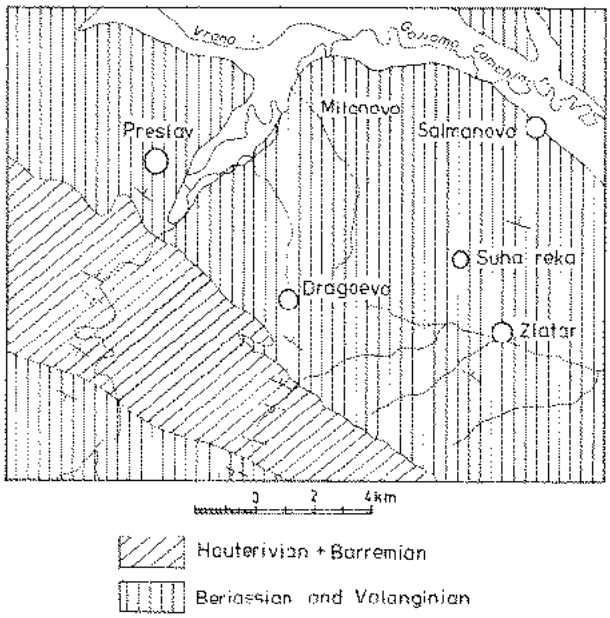

Figure 4.4. Geological map of the Zlatar site (after Nikolov and Ruskova, 1992).

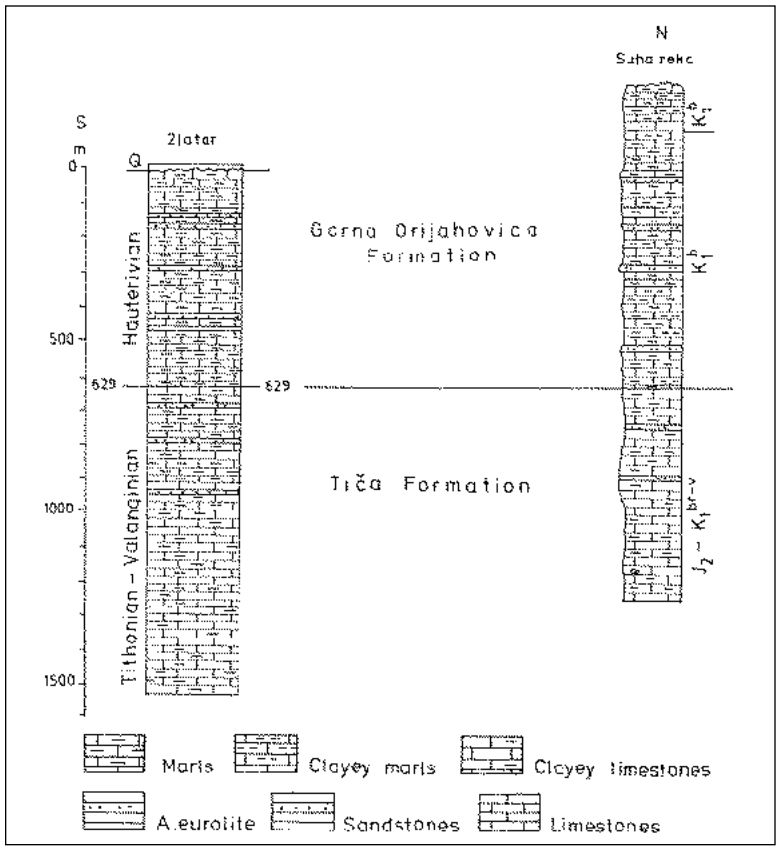

Figure 4.5. Lithostratigraphical columns of the Zlatar site (after Nikolov and Ruskova, 1992).

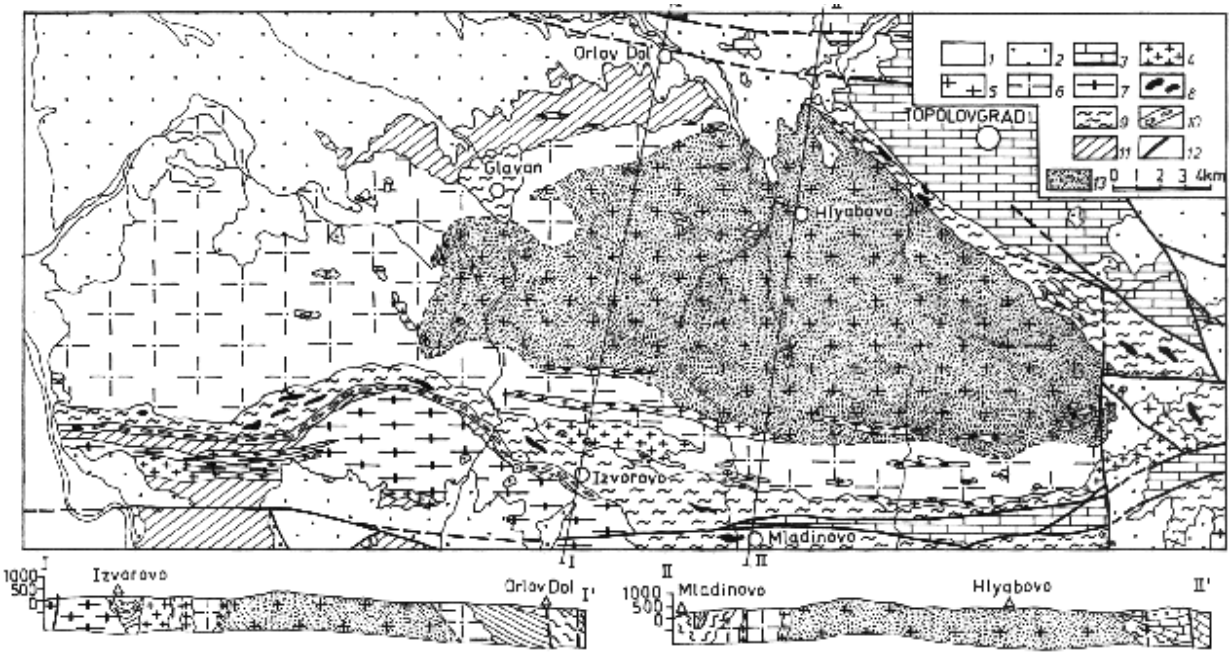

Figure 4.6. Geological map of the Sakar pluton: 1 - Quaternary; 2 - Pliocene sediments; 3 - Upper Paleozoic and Triassic metasediments; 4 - leucocratic (Alexandrovo) granites, Sakar pluton; 5 - medium-grained granites; 6 - porphyric granites, Precambrian; 7 - Lessovo gneiss-granites; 8 - metaultrabasites; 9 - Zhâlti Chal variegated formation; 10 - Konstantinovo metaconglomerate formation; 11 - Pânovo porphyric-blastic formation; 12 - faults; 13 - a site, suitable for high level RAW disposal (after Kozhoukharov, 1992).

the pluton. The porphyries are of potassium feldspar and are characterized by a great variety of sizes and rock saturations. Their length usually varies from several centimeters to 7-8 cm, sometimes reaching 12-15 cm. The porphyric granites are biotitic to two-mica ones. The uniformly grained granites are medium to coarse grained. They elevate the region between the villages of Glavan, Balgarska Polyana, Hlyabovo, Sakartsi and the neighbourhood of the Bairaka and Karaburun peaks. The micas are of the biotite type, but two-mica varieties also occur.

The mineral composition of the two facial varieties is analogous. They are composed of: quartz, plagioclase, microcline, biotite and occasionally of muscovite and accessory minerals - apatite, zircon, garnet, sphene and clinozoisite. Biotite is often replaced by muscovite and some microclines exhibit later crystallization and active erosion of the plagioclases.

The Alexandrovo leucocratic, aplitoid-pegmatitic granites have a wider distribution than that shown on the map sheet. They occur in the form of elongated bodies and veins mainly in the east-west direction in the southern parts of the pluton, where they cross the rocks of the Pânovo and Zhâlti Chal formation and the two facial varieties of the Sakar batholith.

The granites are fine- and medium-grained and occasionally coarse-grained. Three varieties are distinguished among them: medium-grained muscovite granites, coarse-grained pegmatoid granites and fine-grained aplitoid granites. The individual varieties are transformed into each other, but the dominating granites are medium grained, while the aplitoid ones mainly occupy the peripheral parts of the rock bodies or fill some of the veins. These granites do not differ in their mineral composition from the other two varieties of the Sakar batholith except for the biotite content, which is quite rare or missing in the Alexandrovo granites.

Different opinions have formed concerning the age of the Alexandrovo and Sakar granites, covering the range from the Archaic (?) to the Jurassic. The direct geological relationships between the Alexandrovo and Sakar granites, which intrude and contact metamorphose the

rocks of the Paleozoic Klokotnitsa Formation, as well as outliers of granite in the Lower Triassic metasediments (Sakar type) provide the basis for assuming that their age is Upper Paleozoic.

Three categories of terrains are distinguished in the Sakar pluton according to its internal structure. The site, composed of medium-grained granites, indicated by a special symbol on the geological map (Fig. 4.6) is considered to be the most suitable for further investigation and construction of a RAW repository.

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