Toward Site Selection of Permanent Geological Disposal for High-Level Nuclear Waste in Jordan

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Abstract
A preliminary investigation of geological conditions carried out to locate potential sites for repositories for high- and medium- level radioactive wastes. These sites should have potentially being able to provide satisfactory conditions for radioactive waste disposal. Therefore, large effort has been done to review and study the foreign experience in this field. To characterise the properties of the host rock, extensive laboratory investigations have been performed using various geological, petrographycal, mineralogical, physical and mechanical tests. Three recommended areas have been selected, the basalt in northeast Jordan, 30 Km north of Safawi city. The second area is the limestone from Ma'an area, and the third area is the granite from Aqaba area. Detailed geological, petrographyical, mineralogical, and physico-mechanical tests have been carried out for each rock from the selected areas. All results are discussed in this study.
Keywords: Nuclear waste, Geological disposal, Thermal properties.

1 Introduction

Deep disposal in stable geological formations is a means of safe containment of long-lived radioactive materials over periods of many thousands of years. Deep disposal ensures that any risk from exposure due to accidental intervention or natural disturbance is reduced to a very low level.

The problem of providing a permanent and reliable method of isolating radioactive waste from the biosphere is of great concern among the more advanced, as well as the developing, nations of the world. All the leading nuclear countries have adopted the geologic repository approach for radioactive waste disposal (Witherspoon and Bodvarsson 2006). The primary concern in deep underground burial is the selection of a geologic formation that will contain and isolate the wastes so that radioactive nuclides from the waste do not enter the biosphere in amounts that will endanger public health and safety. The host material should be capable of supporting waste canisters over a long period. In addition, the load-bearing capacity of the host material should not be impaired as a result of sudden or gradual stress changes.(Read 2004)

Various rock types are being investigated in the different countries with geologic storage programs. Many countries are considering fractured granitic rock; others clay, salt, or sedimentary rock.(Fairhurst 2004)

In Jordan, the current amount of radioactive waste is relatively small and mostly generated from the spent sources of medical, agriculture, industrial and research and teaching institutions Aziz. And MA'LY 2000). Jordanian Atomic Energy Commission (JAEC) has been conducted the collection, processing as well as storage of spent radioactive sources of LILW.

Currently, a national interim storage facility for the country's radioactive waste and nuclear materials was constructed on the premises of the (JAEC) headquarters on the outskirts of Amman - provides 500 cubic metres of storage for low- and intermediate-level radioactive waste for up to 50 years. The waste has been generated by hospitals, universities, industry and scientific research centres (Aziz and Ma'ly 2000).

Recently, Jordan signed a contract to build the kingdom's first nuclear power plant, with two 1,000-megawatt reactors in the country's north. Therefore, it is important to have a strategic program containing all regulation and plans for permanent disposal of high level long life radioactive waste in deep geological rock formation.

Jordan is a relatively small country situated at the Middle East and occupies an area of approximately 96,188 square kilometres.From the practical standpoint, it may be very difficult for small countries to find a HLW repository site that is satisfactory geologically and, at the same time, can satisfy planning restrictions. On the other hand, the geological situation in a particular country may not be favourable, and the country has no choice except to store the waste at ground surface for an indefinite period (Witherspoon, 1996). Moreover, from the economic standpoint, countries with relatively small nuclear energy programs and relatively small volumes of HLW are faced with solutions that are essentially uneconomic (Segelod 2006). A large proportion of the disposal costs are independent of waste volume, particularly those related to concept development, site selection and characterization and, to a large extent, construction and operation of the facility.

Selection a disposal site in Jordan

Nationwide Screening

A preliminary investigation of geological conditions to locate potential sites for repositories for high level radioactive wastes in Jordan has been carried out on the basis of existing data in the public domain. Large number of available geological date from previous geological survey, explorations for oil and gas deposits, and water well drilling has been collected, reviewed and analyzed. The following map (Figure 1) has been created which shows the location of current and potential mineral resources and natural reserve based on the data collected from the Natural Resources Authority (NRA) 2013. The analysis has taken into account the rock complexes, no active faults, level of seismicity, the natural resources, and density of population that is not too great (Witherspoon and Bodvarsson 2006).

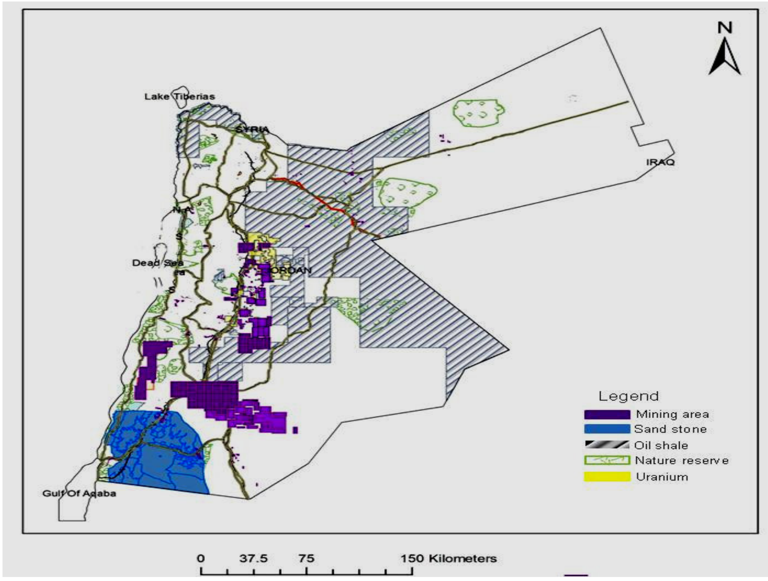

Figure 16. The location of current and potential mineral resources and natural reserve

Based in the above criterion, the west part of Jordan (West of Jordan Hejaz Railway) was excluded from being a potential site for the repository. The reasons are: the most of Jordan population are concentrated in that region, the formations of the east part of Jordan are more likely to be fractured (Al-Zoubi and, Ben Avraham 2002) and the seismic activity is potentially high. The population density in the most of the eastern part of Jordan are very low and probabilistic seismic hazard are potentially low (Abdallah et. Al 2006). (Figure 2).

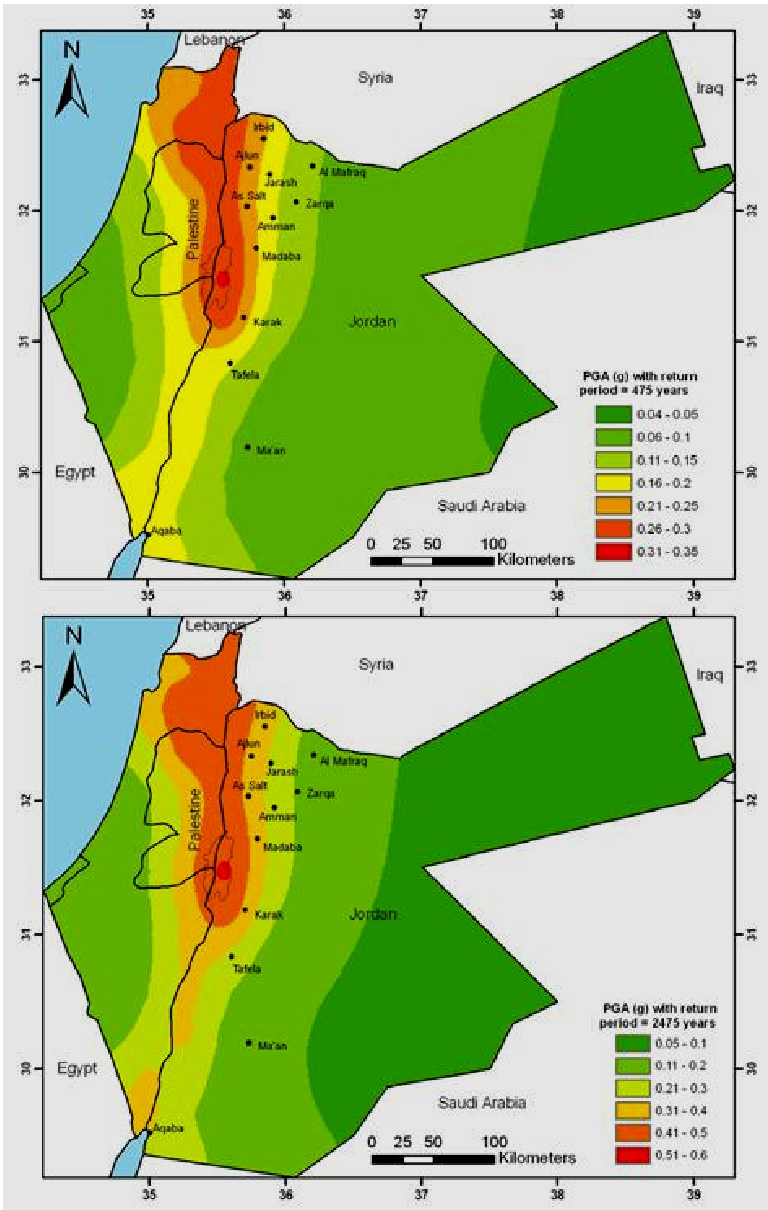

Figure 17. Probabilistic seismic hazard map for peak ground acceleration at 10% (upper) and 2% (lower) probability of exceedance in 50 years on firm-rock site conditions.(Jaradat 2008)

Some areas from the east part of Jordan were excluded in the passes of the mining activity, mineral recourses and natural reserves based on the inforation obtained from the NRA.

We conclude that the regions possessing favourable characteristics for HLW are concentrated mainly in the northeast, middleeast and southeast parts of the country. The following rock types: granite in the south, basalt in the north and marl limestone in the middle were considered as candidate host rock this conclusion is simmeller to that found by (Nizar Abu-Jaber 2011).

Geological Setting:

Basalt Rock

One of the target areas that have been selected for the proposed project is the basalt in northeast Jordan, 30 Km north of Safawi city. Basaltic flows comprise the majority of the study area, and cover approximately 658 km2. Generally, the basaltic rocks in northeast Jordan has been subdivided into 5 groups based on detailed geological, mineralogical and petrographical studies (Ibrahim 1993).. These are Wisad, Safawi, Asfar, Rimah and Bishriyya. The maximum recorded thickness of the basaltic succession as recorded in the north of Safawi area from one of the boreholes that have been drilled for petroleum purposes is about 478m.

The Abed Olivine Phyric Basalt is the dominant formation in the Safawi area, and covers the majority of northern and southern parts of the study area. It is exposed along the Wadi El Abed in the central part of the area and across the Safawi-Baghdad highway. The Abed Basalt exposed as a series of flows seen in vertical section in the northern part, whereas thin flows are present including randomly distributed boulders. (Tarawneh, 1996, Tarawneh, 2003). The Abed Olivine Phyric Basalt comprises thick and massive flows (up to 100 m thick) in Qitar El Abed ridges.

Petrography and Mineralogy

Flow units of the Abed Olivine Phyric Basalt are melanocratic, holocrystalline and medium-grained with a porphyritic texture. Microvesicles are filled with calcite or zeolites. Olivine is mostly altered to iddingsite, and in some cases shows clustering texture. Plagioclase and pyroxene are present in the groundmass.

Petrographic studies indicate that the basalt consists of meshwork of plagioclase, olivine, pyroxene and iron oxides. The average modal composition of this formation is 50-53.5% plagioclase; 20-25.4% olivine, 18.3-21% pyroxene, 0.5-1% calcite and 2.5-4.5% opaque minerals.

Geochemistry of the Basalt

Fifteen representative basalt samples were collected from the study area and examined in the laboratory of NRA.. The results of the chemical analyses show that the SiO2 content varies from 41.68 to 46.96%. TiO2 content varies from 1.54 to 2.46%, whereas MgO varies from 8.13 to 12%. There results reflected the olivine megacrysts and microphenocrysts content in the basalt.

Limestone

Field Characteristics

The second area that has been selected for our project is the limestone rock. The limestone in the study area belongs to the Umm Rijam Chert- Limestone Formation (URC), which represents the uppermost unit of the Belqa Group. Limestone has a wide distribution throughout Jordan. It extends from north Jordan until south Jordan (Ras En Naqab area) and can be found in many deep geological formations and near the surface. The URC is unconformable overlain by superficial deposits. This formation is predominantly composed of bedded chert, chalk and limestone that produce distinctive landform with gentle slopes. Generally, the study area is strongly influenced by geological structure. The maximum thickness of the URC in the Ma'an area is around 50 (Tarawneh, 2007).

A prominent bed of 15 m thick marks the lower part of this formation consisting of chalk, chalky limestone, marly limestone and clayey marl, whereas the middle part consists of limestone, chalk, chalky limestone, phosphatic limestone, thin beds of chert, limestone and chert concretions.

Petrographic and Mineralogical Studies

More than 15 representative limestone samples were taken from 4 type localities (southeast of Jebl Es Semneh, Jebel El Wheheida, Jebel El Jitheh and El Jazera area). They studied by using polarizing microscope type Leitz Laborlux 12 pols. In hand specimen limestone is characterized by different degree of coloration. It is mostly white to grey white in Jebel El Jitheh, reddish to white reddish in Jebel El Whehieda and in Es Sateh area, while in the Jazera area is mostly with white color. Generally there is a big similarity of the internal texture and structure of the study limestone. The result of mineralogical and petrographic studies shows that the rock consists of the following particles: micrite to sparatic calcite, and micro-fossils. Most of the fossils are foraminifera that are composed of micritic calcite. The matrix consists of micrite, sparite to microsparite with little blue-stained ferrous calcite cement.

Geochemistry of limestone

The limestone is rich in calcium carbonate. The CaO is reach up to 55%, with small amounts of other impurities of oxides (Table 1).

Table 9 Chemical composition of selected sample from Ma'an area

Sample	Fe_2O_3 Wt%	CaO Wt%	SiO_2 Wt%	Al_2O_3 Wt%	MgO Wt%	Na_2O Wt%	MnO Wt%	TiO_2 Wt%	K_2O Wt%	SO_3 Wt%	Cl Wt%	L.O.I Wt%
1	0.15	55.00	0.73	0.12	0.02	0.019	0.008	0.001	0.013	0.06	0.02	42.70

Granitic Rocks

Field characteristics

The third area that has been selected for our project is the granitic rocks from Aqaba area. Granite rocks are part of the basement rocks of southwest Jordan that represents the northern extension of the Arabian Nubian Shield (ANS). The exposed basement rocks in Jordan comprise igneous and metamorphic suites, predominantly of late Proterozoic age, classified into two lithostratigraphical complexes, the oldest is the Aqaba Complex and the youngest is the Araba Complex. Both complexes are separated by a regional unconformity represented by the Saramuj Conglomerate Formation. The Aqaba Complex consists mainly of calk-alkaline plutonic igneous and metamorphic rocks of an age ranges between 570 and 800 Ma, whereas the Araba Complex comprises the Safi Group, Feinan Granitic Suite, Qrienifat Volcanic Suite and Ahaymir Volcanic Suite. The Yutum Granites and Urf Porphyritic suites have been considered as a target areas and potential sites for repositories for high- and medium- level radioactive wastes. The granite rocks which belong either to Abu Jadda granite (582±4Ma), Imran monzogranite (589±5Ma) and the Mulghan granodiorite Unit (630-570 Ma) are also considered as potential sites.

Petrography and Mineralogy

Selected samples from granite have been studied by polarizing microscope to identify petrographic relationship and mineralogical composition of these samples. These studies revealed that the granite is an equigranular, medium to coarse grained, red weathering and partially characterized by the presence of small vugs or cracks that are filled with iron oxides. Euhedral quartz overgrowths, clusters of quartz and hornblende are also present. Sometimes the granite is cross cut by veins of calcite. Minerals assemblage are composed of orthoclase, plagioclase, quartz, and accessory minerals of biotite, muscovite, chlorite and iron oxides. The orthoclase forms about 18% and microcline 10% by volume of the rock. Plagioclase forms about 20 to 30%, while quartz from 30 to 45%. The mafic minerals content is up to 10%. The grain size of minerals ranges between 0.5 and 3.5 mm. X-ray Diffraction Analysis indicate that the main essential minerals are orthoclase, plagioclase, microcline and quartz, while the accessory minerals are zircon and biotite

Chemical Characteristics

According to their chemical composition granite are divided into four chemically distinctive subgroups: potassium feldspar (orthoclase, KAlSi3O8), sodium feldspar (albite, NaAlSi3O8), and calcium feldspar (anorthite, CaAlSi3O8). Four samples of granite have been collected from different localities of the Aqaba Complex to investigate the chemical composition of the granite from the areas of Wadi Al-Jaishieh, Ayn Al Hashim, Wadi Sader Mulghan and Wadi Sader Ash Shuqayri. All samples were analyzed by X-ray fluorescence (XRF) method at the laboratories of Natural Resources Authority, Jordan. The standard chemical composition of granite are (.K2O ranging from 3.9-4.9, Na_2O from 3.2-3.64, CaO ranging from 2.11-2.65, AL_2O_3 ranging from 18.1-19.3 and SiO_2 ranging from 69.8-71.2.)

Geomechanical analisys of the sellected rocks

The knowledge of thermo-mechanical properties of rocks is required to understand and model nuclear waste disposal behaviour. Thermo-mechanical properties of the proposed rocks were determined in the laboratory. The range of temperature used in this study was up to 200^{o}C, keeping in view the highest temperatures expected in underground nuclear waste repositories.

These properties are the uniaxial compressive strength using the indirect method of Point load test and tensile strength using Brazilian method and rock porosity.

Description of rock samples

Four types of rock were investigated in this study: two Limestone rock types, granite and Basalt. Several blocks of each rock type were collected from the outcrops. Limestone rocks were collected from the central and southern parts of Jordan. Granite rocks were collected from the south and basalt rock from the northern east part of the country.

Sample preparation

Cylindrical cores Specimens were prepared as per the International Society for Rock Mechanics (ISRM) recommendations (: Brown 1981) for Point load test, Brazilian tensile strength and porosity. The samples were cored from carefully selected blocks , which were dominated by a similar angle of lamination. Cylindrical samples were drilled in a vertical orientation using a diamond core drill with water lubrication. All specimens were approximately 54.4mm in diameter (NX size). Core samples having visible cracks or any defect were discarded. After drilling the core (with water cooling), both ends were flattened. Subsequently the cores were air dried at room temperature for at least one week before testing.

Heat treatment programme

Rock samples were heated in a laboratory oven to a desired temperature. In order to avoid provoking thermal shocking, the cores were heated slowly at a rate of 1oC/min. After attaining the testing temperature, the samples were heated at this temperature for 48h. Then the oven was cooled down to room temperature at a lower rate than heating rate in order to maintain a homogeneous temperature state in the sample and to avoid thermal shock during heating and cooling. Laboratory tests were carried out following the cooling process. Four specimens were tested at each temperature, i.e. room temperature, 75 ^{o}C ., and 200 ^{o}C .

Physical and mechanical properties tests

Density

The Dry density (ρd) for each rock type is calculated from the mass of the dry specimen, Ms)(g) and the bulk volume V (cm3). The bulk volume of the specimen prepared in the form of regularly shaped cylinders is calculated by means of Vernier calliper measurements. The resultant value of the dry density (g/cm3) is then defined by the respective equation

$$\rho_d = \frac{M_s}{V}$$

The resultant values for each rock are given in Table 2

Table 10 Dry density of tested rocks

Rock Type	Dry Density (g/cm^3)
Yellow Limestone (Limestone_1)	2.38
White Limestone (Limestone_2)	2.62
Granite	2.55
Basalt	2.90

Porosity

The porosity of the rock is calculated using saturation and Vernier calliper technique. This method is only used for non-friable, coherent rocks that can be machined and do not appreciably swell or disintegrate when oven dried or immersed in water.

In this method, the specimen bulk volume V is calculated from an average of several calliper readings for each dimension. The specimen is saturated by water immersion in a vacuum of for a period of 1 hr. The specimen is then removed and surface dried using a moist cloth, care was taken to remove only surface water and to ensure that no fragments are lost. The specimen is dried to constant mass at a temperature of 105°C, allowed to cool for 30 min in desiccators.

The resulted porosity of the tested rock at various temperature are shown in Figure (3). The result shows that the porosity of all tested rock is decreases with the increase in temperature. This may have similar explanation as (Dwivedi et. Al. 2008). He found that this reduction on porosity may be attribute to the widening of pre-existing micro-cracks took place at 65 oC. These gaps of cracks marginally reduced at temperature 100–125 oC. On further heating to 160 oC, he state that the pre-existing micro-cracks closed considerably. Development of new micro-cracks was not observed at any temperature up to 160 oC.

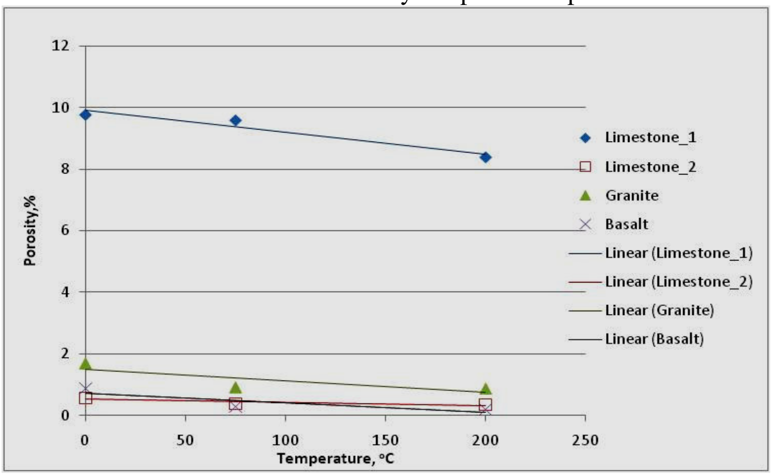

Figure 18 Variation of porosity data depending on heat levels

Point load

The Axial point load test was carried out on cores having a diameter of 54.44mm and a length of 20 mm. The tests were carried out on the samples cored perpendicular to any visible weakness plane and the samples having a weakness plane were discarded. The results were corrected to a specimen diameter of 50 mm (Is(50)) according to the procedure described by the International Society of Rock Mechanics (ISRM,1981). The point load test was repeated four times for each rock type and for each temperature change (i.e. at room temperature, 75oC and 200 oC. The test results are listed in Table (3).

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Table 11 Point load testing results for all rocks at various temperature values

Rock Type	Sample NO	At room temperature, °C			At 75°C			At 200°C		
		Max.load, kN	$Is_{(50)}$, MPa	UCS, MPa	Max.load ,kN	$Is_{(50)}$, MPa	UCS, MPa	Max.load kN	$Is_{(50)}$, MPa	UCS MPa
Limeston_1	1	10.16	5.33	128.02	7.15	3.76	90.16	7.66	4.02	96.53
	2	7.52	3.95	94.80	7.93	4.16	99.93	6.98	3.66	87.95
	3	7.08	3.72	89.21	6.32	3.32	79.63	8.10	4.26	102.14
	4	11.36	5.97	143.18	7.84	4.12	98.86	7.82	4.11	98.65
Limestone_2	1	6.70	3.52	84.42	5.98	3.14	75.41	6.04	3.17	76.16
	2	7.70	4.04	97.03	6.90	3.63	87.01	6.04	3.17	76.10
	3	6.07	3.19	76.48	7.85	4.12	98.99	6.91	3.63	87.07
	4	5.15	2.71	64.94	7.55	3.96	95.14	8.34	4.38	105.10
Granite	1	6.86	3.60	86.50	7.80	4.10	98.29	8.45	4.44	106.55
	2	8.55	4.49	107.75	6.00	3.15	75.66	8.30	4.36	104.60
	3	8.71	4.57	109.77	7.00	3.68	88.27	6.15	3.23	77.49
	4	8.46	4.44	106.62	7.20	3.78	90.79	7.55	3.96	95.14
Basalt	1	24.16	12.69	304.59	21.03	11.05	265.12	26.28	13.81	331.38
	2	25.63	13.46	323.12	24.55	12.90	309.57	26.58	13.97	335.17
	3	21.41	11.25	269.91	22.32	11.73	281.45	29.04	15.26	366.19
	4	25.74	13.52	324.51	22.07	11.59	278.23	26.41	13.88	333.02

The relationship between the heating temperature and the uniaxial compressive strength of tested rocks are presented in figure 4. The figures show that there is no significant change in the rock strength after heating. This can be attributed to the fact that heating temperatures were much lower than the dissociation temperature the rocks minerals. Figure (4) shows a slight increase in the uniaxial compressive strength of basalt as a result of temperature increase. This may be attributed to the decrease in the porosity of basalt shown in figure (3) above.

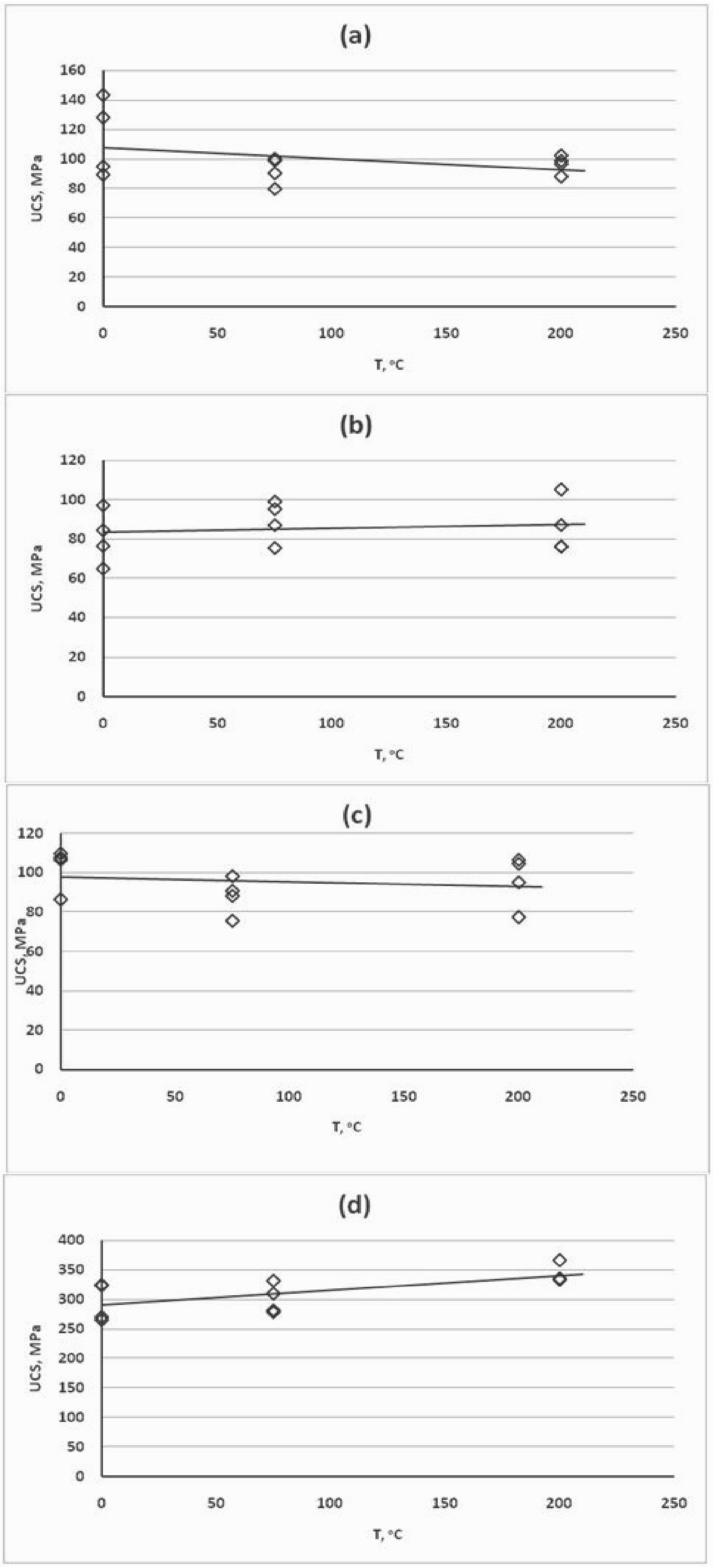

Figure 19 Variation of Uniaxial compressive strength of rocks with increase at different heat levels.

Tensile strength (Brazilian)

The Brazilian test is widely used in engineering practice to indirectly obtain the tensile strength (TB) of intact rock samples obtained from drill cores. The Brazilian test allows the determination of the tensile strength of the rock on disc-shaped specimens,

In this study, Brazilian testing was performed according to the procedure described by the ISRM Standard. The diameter of the samples was 54.4mm, and the thickness was 20 mm.

.The disc is subsequently compressed by load F (kN) in the radial direction between a flat platens of the press till its rupture. During the process of axial compression, some tensile-type fractures of the specimens usually appear, the orientation of which follows the direction of loading. The tensile strength TB (MPa) of the rock was calculated by the formula suggested by the ISRM. The results of tensile strength of the tested rock as function of temperature are listed in Table (4).

Table 12 Tensile strength of the tested rock as function of temperature

Rock Type	Sample NO	At Room temperature		At 75°C		At 200 °C	
		Max.load, kN	T_B, MPa	Max.load ,kN	T_B, MPa	Max.load kN	T_B MPa
Limeston_1	1	12.42	7.27	13.35	7.81	12.65	7.40
	2	10.82	6.33	13.19	7.72	11.33	6.63
	3	10.45	6.12	11.11	6.50	13.14	7.69
	4	12.19	7.14	12.69	7.43	11.90	6.97
Limestone_2	1	11.94	6.99	12.30	7.20	10.06	5.89
	2	8.53	4.99	12.10	7.08	12.09	7.08
	3	12.07	7.06	7.60	4.45	9.79	5.73
	4	10.37	6.07	9.40	5.50	9.91	5.80
Granite	1	9.87	5.78	11.48	6.72	9.59	5.61
	2	7.91	4.63	6.22	3.64	7.41	4.34
	3	7.75	4.54	8.46	4.95	7.75	4.54
	4	7.91	4.63	7.45	4.36	7.79	4.56
Basalt	1	31.87	18.66	33.39	19.55	38.02	22.26
	2	31.60	18.50	36.88	21.59	36.76	21.52
	3	31.74	18.58	30.52	17.87	37.43	21.91
	4			29.61	17.34	35.56	20.82

The effect of temperature increase on the magnitude of the tensile strength of rocks is shown in Figure (5). The figures clearly indicate that the effect of temperature increase on the value of tensile strength of the rocks is insignificant. The reason for this result maybe the same as for the uniaxial compressive strength mentioned earlier.

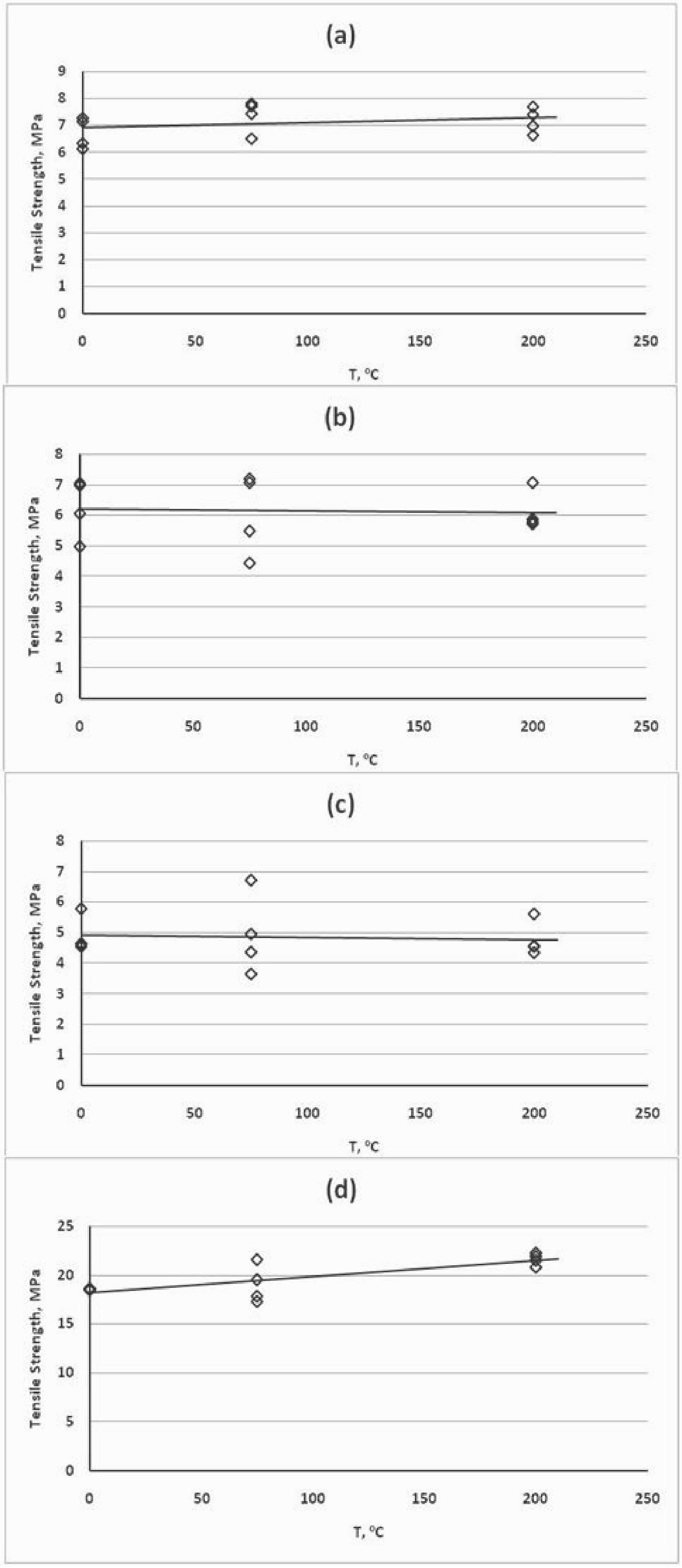

Figure 20 Variation of Uniaxial compressive strength of rocks with increase at different heat levels.

Conclusion and recommendation

Deep disposal ensures that any risk from exposure due to accidental intervention or natural disturbance is reduced to a very low level. A preliminary screening of the territory of Jordan has been performed. Large number of available geological date from previous geological survey, explorations for oil and gas deposits, and water well drilling has been collected, reviewed and analyzed. A map has been created which shows the location of current and potential mineral resources and natural reserve based on the data collected from the NRA. Based on the international criterion, it has been concluded that the regions possessing favourable characteristics for HLW in Jordan are concentrated mainly in the northeast and Middle East and southeast parts of the country. And the following rock types: Granite in the south, Basalt in the north and Marley limestone in the middle were considered as candidate host rocks. A representative rock blocks were collected from the outcrop of the three regions mentioned above. Extensive laboratory tests were conducted using various physical and mechanical laboratory tests. The results from laboratory investigations shows that the heat generated from a proposed nuclear waste will have only small effect on the physical and mechanical properties of the selected rocks. The preliminary study showed that Basalt rocks have the best physical and mechanical properties that will make it the best candidate to host the nuclear waste. More detailed investigation, including boring deep holes, cores from borehole exploration and geo- physical surveys can help to confirm that the rock formations have appropriate properties.

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