



MINISTRY OF ENERGY AND MINERAL RESOURCES

Mineral Status and Future Opportunity

ZEOLITIC TUFF

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Zeolitic Tuff

1. Introduction

Zeolites a suite of hydrated framework aluminosilicates of the alkali and alkaline earth elements and consist of infinitely three-dimensional frameworks of AlO_4 and SiO_4 tetrahedra, called the primary building units, which are linked to each other by sharing all oxygen's. Their unique structure gives rise to remarkable physical and chemical properties, which have allowed the group to play a vital role in many industrial and agricultural technologies. Zeolite occurs as a cementing material to volcanic tuff granules.

2. Location

2.1 North East Jordan

Zeolitic tuffs are located at Jabal Aritayn (30km NE of Azraq), Tlul Al-shahba (20km E of Al safawi), Tell-Rimah (35km NE of Al Mafraq) and many other areas (App. 1).

2.2 Central Jordan

Promising areas in central Jordan are:
Makaur and AL-Zara
Wadi AL-Hydan and wadi AL-walah

2.3 Southern Jordan

Promising areas in southern Jordan are in table (1).

Table (1): Volcanic tuff deposits in south Jordan.

Tell Johera	Tell Burma
Jabal Gerana	Tell AL-Amer
Jabal Oneiza	Tafellah AL-DaJaneh
Wadi AL-Hasa	

3. Geological Setting

The volcanic field of the Harrat Ashaam is one of several Cenozoic volcanic fields situated on the western Arabia Peninsula (Fig. 1&2). These volcanic fields cover some $11,000\text{Km}^2$ in Jordan with an average thickness of up to 100m. Approximately 200 eruptions with volcanic centers were recorded in northeast Jordan (Malabeh, personal communication). The Neogene-Quaternary volcanism is generally associated with the opening of the Red Sea and with faulting along the Dead Sea Transform (Menzies et al., 1997).

Different types of volcanoes resulted from differences in the chemical composition (amount of silica) and temperature of the magma. The solid particles are produced during explosive eruptions due to the sudden release of superheated gases.

Zeolites in Jordan are usually associated with volcanic tuff and scoria; both of them are belonging to the Rimah Group, which is defined on the basis of its lithotypes only. It comprises volcano-sedimentary and scoriaceous deposits devoid of specific inference as to their magmatic source and age. The Rimah Group comprises two formations.

3.1. Hassan Scoriaceous Formation

This formation is developed from Strombolain-type, non-stratified cinder cones and composite stratovolcanoes which are susceptible to weathering and erosion. The formation gives a smooth ground cover over the cones with weathered surface colors of brown, red brown, black and gray. The scoria cinder cones are typically 30-70m high with relatively low lying hills of sub-circular to conical overall shape within a vast plain area. Flanks of these conical cones have steep angles of slopes up to 35 degree in all directions.

3.2. Aritayn Volcaniclastics Formation

The Aritayn Volcaniclastics Formation consists of bedded, poorly cemented air-fall pyroclastics and is typified by their stratified form and typically cavernous morphology. It includes all of the volcaniclastic deposits developed from the composite cinder stratovolcanic centers. It is characterized by a smooth ground cover surface with variable weathering colors from black, purplish black, brown, reddish brown to yellowish brown and gray color. The formation consists of stratified, weakly to moderately indurate air-fall ash tuff, lapilli tuff, agglomerate and breccia.

4. Estimated Reserve of the Jordanian Zeolitic Tuff

4.1. Areas with Zeolitic Tuff Potential

According to Natural Resources Authority, estimated zeolitic tuff reserves in various areas in Jordan are as follows:

Table (2): Geological reserves of Zeolitic tuff deposits

Area	Geological reserve (million tons)
Tell Rmah	46.0
Al-Aritain	170.0
Tlol Al-Shahba	9.2
North East Areas	472.0
Other areas	1340.0



Figure (1): Location map of Zeolitic Tuff deposits in Jordan.

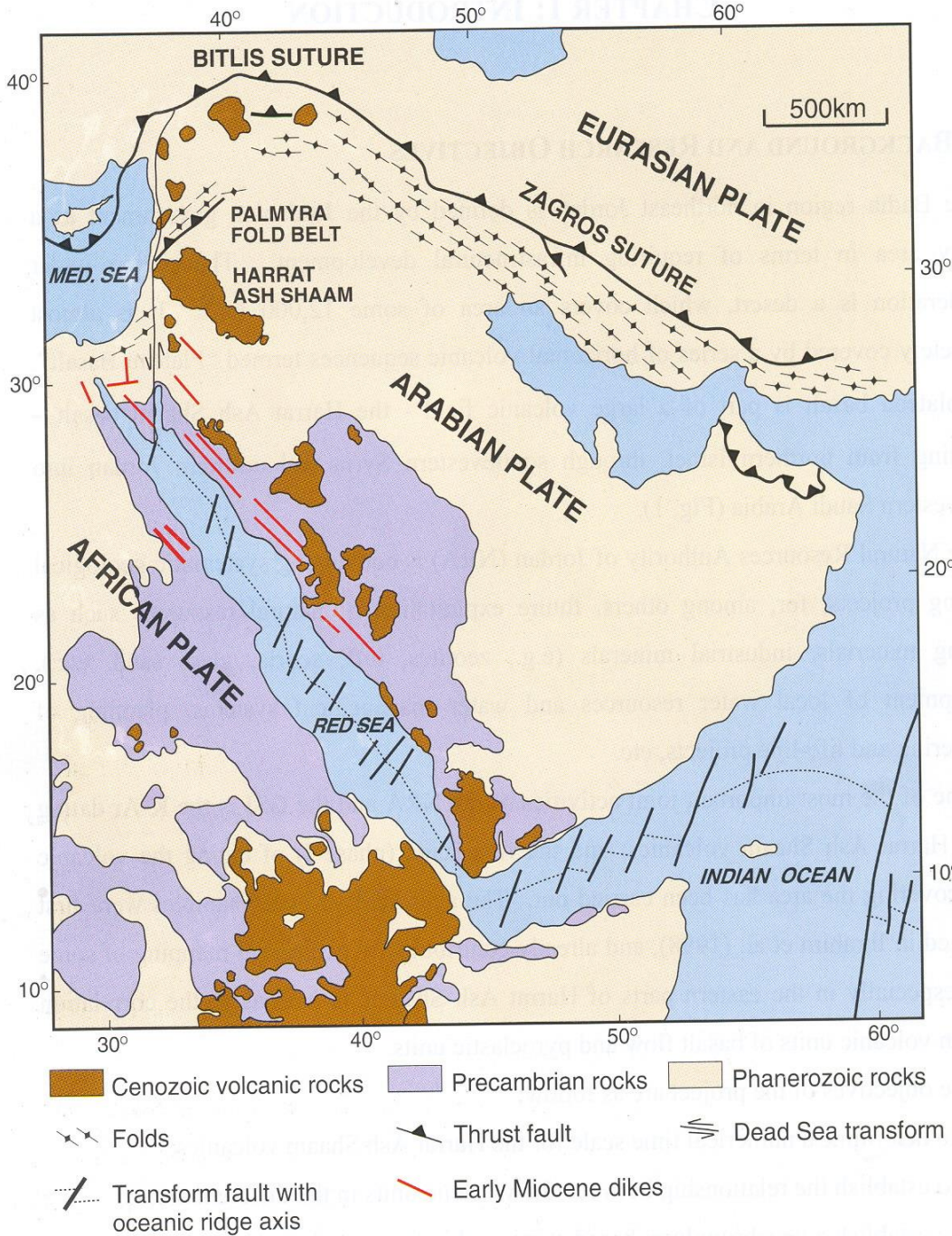


Figure (2): Location of volcanic fields in the Arabian Plate (Camp and Roobol, 1989).

4.2. Current/Potential Mines

According to Jordan's zeolitic tuff companies, their geological reserve are as follows:

Table (3): The Jordanian companies with the geological reserve of Zeolitic tuff.

Company	Geological reserve (tons)
Amanah For Agr. & Ind. Investment	953,700
Green Technologies/Jordan FSD	31,000,000
ASI	7,299,600
Al Jalel	67,500,000

5. Zeolitic Tuff Properties

Many researchers were studied the physical and engineering properties of scoria and volcanic tuff of NE Jordan regardless to the presence of zeolite. Some of the important physical and engineering parameters for these materials are given in tables 6, 13 and 14.

5.1. Mineralogical Properties

Three distinctive diagenetic vertical zones are present within the volcanic tuff and they can be distinguished in the field by their weathering color. They defined with respect to the degree of alteration to the following:

Sideromelane Zone presents at the surface and contains a relatively fresh sideromelane not yet altered to palagonite and has black to light grey colour.

Palagonite Zone it is an intermediate zone which is almost free of zeolite as well and it has dark brown to reddish brown colour.

Zeolitic zone (zeolite zone) rich with zeolite characterized by yellow to light brown colour. XRD analysis of volcanic tuff samples revealed that most samples are composed of phillipsite as major constituents followed by chapazite and faujasite. Each one has own specific gravity and due to that phillipsite, chapazite and faujasite can be separated from each other.

5.2. Physical Properties

Grain size distributions, zeolite percentage, cation exchange capacity, attrition resistance, acid resistance and packed bed density of zeolitic tuff from NE Jordan are considered the most important physical properties. The most important physical parameter for cement industry is the hydraulic factor. The higher of this factor the more suitable is the material. Regarding to the presence of zeolite with the volcanic tuff, it was reported by the Jordan

Cement Company in 1985 that the presence of zeolites with the tuff enhances significantly the hydraulic factor of the pozzolana.

Table (4): Physical properties of the zeolitic tuff after Reshiedat, 1991 and Ibrahim, 1995.

Size fraction mm	Weight %	Zeolite %	CEC (meq/g)	Attrition Resistance Wt loss %	Packed bed Density g/cm ³
-2+1	17	43.19	2.02	N.A	N.A
-1+0.5	16	45.56	2.05	N.A	N.A
-0.5+0.25	28	38.51	1.54	6.2-7.2	0.94-1.07
-0.25+0.063	20	36.95	1.33	4.5-5.4	1.01-1.15
-0.063	9	25.74	0.94	N.A	N.A
Concentrated 0.5-0.125	10	<90	2.88-3.59	4.5-7.2	0.94-1.15

N. A.: not available

Table (5): Physical properties of the pozzolana for cement industry after Jordan Cement Company 1985.

Locality	Hydraulic Factor	Strength (N/cm ²)	S. gravity (gm/cm ³)	Loss on ignition %
J. Fahem	41	1212	1.4	5.6
J. Aritayn	52.5	1190	1.57	6.5
J. Aritayn	31	810	1.85	6.6
J. Ufayhimat	39	1112	1.78	5.8
J. Ufayhimat	37.5	729	1.64	9.7
J. Jilad	22	N.A	1.7	5.8
J. Al Manasif Al Gharbya	41	1005	1.59	2.7
J. Al Manasif Ash Sharqiyya	19	280	1.58	4.7

5.2.1. Engineering Properties of Volcanic Tuff

Due to mass demand for very good quality of concrete for infra and super structures, some researchers were studied the volcanic tuff in order to determine quality and quantity in addition to find out the suitability of these materials in different structural aspects regardless to the presence of zeolite.

Table (6): Engineering properties of Tell Hassan and Jabal Fahem pozzolana after Malabeh, 1993, El-Hamed and Abdlehad, 2001.

Parameters	Tell Hassan	Jabal Fahem
Water absorption	8.53-10.8 %	9.2 %
Colours	grey, grey to brown	brown, grey, reddish brown
Abrasive value	35-43.2 %	52 %
Unit weight	1010 kg/m ³	980 kg/ m ³
Specific gravity	1.56-1.80 gm/cm ³	1.79 g/ cm ³
Void ratio	17.54	N.A
Porosity %	14.93	N.A
Pulse Velocity m/sec	3333-3564	N.A
Surface abrasion mm	27-28	N.A
Soundness %	8-9	N.A
T.D.S ppm	1250-1500	N.A
Elongation	11.09	N.A
Flakiness	22.59	N.A

5.2.2. Processing of Zeolitic Tuff

The conventional mineral processing techniques of Jordanian zeolitic tuff are starting with crushing the materials by Jaw crusher followed by autogenous tumbling mill and then low intensity magnetic and gravity separation. The combined simple of wet and dry processing routs, high grade zeolites can be produced with grade ranges between 80-96% at reasonable recovery (Reshiedat, 1991, Ibrahim, 1996 and Rawashdeh, 1997).

5.3. Chemical Properties:

The following table shows the chemical composition of the Jordanian zeolitic tuff, both exploited and not exploited:

Table (7): Chemical analysis of zeolitic tuff.

Area	% SiO ₂	Al ₂ O ₃ %	Fe ₂ O ₃ %	% MgO	% CaO	% K ₂ O	% Na ₂ O
Exploited							
Tell Rmah	42.0	12.8	12.1	10.1	8.5	0.8	4.0
Mkawer	42.7	13.9	12.7	9.2	9.8	1.9	2.1
Aarityan	38.6	12.8	12.1	9.6	9.3	1.5	2.1
Not exploited							
Shihan	44.0	13.2	8.3	8.6	11.3	1.2	2.0
Tell Jheera	35.0	10.2	11.3	7.6	20.2	0.7	2.4
Jabal Atatah	48.0	10.8	8.1	7.7	10.1	0.5	1.5
Tlul Al-Shahba	41.7	11.8	12.0	10.3	9.4	1.7	2.8
Jabal Onaizah	40.0	7.9	8.8	8.6	15.8	0.9	5.7

6. Background

The first zeolite (Phillipsite) deposit was discovered in Jordan in 1987. The deposit was found in the Quaternary volcanic tuff of the Jabal Al Aritayn Volcano in Northeast Jordan. In 1996, six localities with zeolites deposits were discovered in the volcanic tuff outcrops in Northeast Jordan. NRA carried out detailed studies of the Zeolitic tuff in Tlul Al-Shahba and Ashquf areas during the period of 2002-2004 (Abu Salah et.al., 2002).

7. Global Market

According to the United States Geological Survey, world mine production of natural zeolites currently stands at between 3 and 4 million metric tonnes per annum. It is thought that the majority of this output is used in the production of pozzolanic cement. Global production of natural zeolites for non-pozzolanic applications is more likely to be in the order of 600,000 tonnes per annum.

8. Jordan Market

8.1. Zeolitic Tuff Demand

At present Jordan's four zeolitic tuff producers sell approximately >90% of their combined production to the domestic market. Most of it is consumed in the pozzolanic cement industry. The rest is in the agricultural sector, i.e. soil amendment, ammonia control and animal nutrition and few are exported (see the following tables).

Jordan Cement Factories Company consumption from pozzolana:

Table (8): Pozzolana consumption in cement industry.

	2008	2009	2010	2011	2012
Consumption/ ton	654	123.832	447.490	451.473	845.701

Jordan's total exports are shown in the table below:

Table (9): Quantity (ton) exports of Jordanian zeolitic tuff

	2008	2009	2010	2011	2012
Jordan exports of zeolitic tuff/ ton	-	11.955	30.685	14.209	34.157

8.2. Jordan Prices

In Jordan, current local prices for all zeolitic tuff products average 53 JD/tonne (approx. US\$70/ton), while export prices tend to be around 10 JD higher (ex-works).

9. Investment Opportunities

9.1. Cement Industry

Zeolitic tuff production in Jordan started in 1998, and therefore it is a relatively new sector. Currently around 400000 ton/year of zeolitic tuff consumed by Jordan Cement factories to produce pozzolanic cement. Consuming the deposits it is prospective to be increased due to establishing new cement factories to fulfil the market demands.

9.2. Lightweight Concrete

Volcanic tuff and scoria are the main source for lightweight aggregates. These materials are suitable for producing lightweight concrete which could be used in many structural aspects (El Hamed and Abdlehadi, 2001). Due to the huge reserves of tuffaceous materials, Jordan is considered as an excellent source for such aggregates. Many trial mixes with different materials (normal limestone aggregates, wadi sand, polystyrene, crushed sand) were carried out and the results are listed in Tables (10 & 11).

The compressive strength results of blocks (bricks) made by light weight concrete mixed with polystyrene particles at 15x20x40 dimension (El Hamed and Abdlehadi, 2001) They pointed out that the compressive strength results were not satisfactory due to only technical difficulties.

Table (10): Compressive Strength of Light weight Concrete Blocks after El Hamed and Abdlehadi, 2001.

Dimension	Total area (cm ²)	Pores area (cm ²)	Solid area (cm ²)	Load (Kg)	Strength (Kg/ cm ²)	Weight (Kg)
15x20x40	600	275	325	6630	18.8	15.3
15x20x40	600	275	325	3570	13	15.4
15x20x40	600	275	325	5610	17.3	15.45
15x20x40	400	146	254.4	5100	20	9.5
15x20x40	400	146	254.4	6120	23	9.6
15x20x40	600	146	325	5916	24	9.4
15x20x40	600	275	325	5100	16	12.2
15x20x40	600	275	325	5916	18	12.3
15x20x40	600	275	325	6018	19	12.4
15x20x40	600	275	325	5508	17	12.7
15x20x40	600	275	325	6936	21	12.7
15x20x40	600	275	325	6018	19	12.3

Table (11): Mix results of tuff materials, El Hamed and Abdelhadi, 2001.

Size				Polys. g/m ³	Cement kg/m ³ t	Water Lt.	Strength 7days	Strength 28days	Mix. S. gravity	Mix. Absorption	Av. Density
19mm kg/m ³	14mm kg/m ³	9mm kg/m ³	0.5mm kg/m ³								
413	290	N.A	724	N.A	450	275	140	196	1.9	12.1	2.1
540	290	N.A	724	N.A	450	275	136	179	1.88	11.37	2.12
540	290	N.A	724	N.A	450	275	123	154	1.89	12.1	1.35
540	290	N.A	724	N.A	350	275	113	147	1.75	13.21	2.05
540	290	N.A	724	N.A	300	275	93	132	1.82	12.22	2.01
190	190	190	724	N.A	450	275	160	224	1.87	11.37	2.08
218	217	217	103	N.A	400	275	176	305	1.88	11.48	2.07
190	190	190	N.A	N.A	350	275	132	210	1.85	13.53	2.08
201	201	201	N.A	N.A	300	275	114	176	1.88	11.84	2.07
201	201	201	753	N.A	250	296	114	120	1.52	13.24	2.06
201	201	201	724	N.A	225	275	108	118	1.79	12.12	2.04
1270	N.A	N.A	635	N.A	450	226	108	128	1.84	11.13	1.87
423	N.A	N.A	720	604	450	254	30	67	1.57	7.83	1.72
63	N.A	N.A	N.A	7.2	450	275	13	15	N.A	N.A	1.7
190	190	N.A	64	14.8	450	250	59	82	N.A	N.A	1.84
1270	N.A	N.A	635	N.A	450	381	65	92	N.A	N.A	1.87
381	508	N.A	760	N.A	425	296	96	166	N.A	N.A	1.68

9.3. Agriculture Applications

The total output during 2004 was 1600 tones, produced by three companies and consumed in agricultural applications. Given the size of the agricultural sector in the region, it is estimated that the market potential in these application is large. In terms of Jordan's cultivated land, each two percent increase in land treated with zeolitic tuff would result in an increase in zeolitic tuff demand of 100,000 tones per annum and 50,000 tones per annum in animal feed and odor control. The total expected demand potential is 360,000 tonne per annum depending on previous assumptions. Also it can be used in animal waste treatment and / or as air purification media inside animal houses. It would reduce the odour intensity and ammonia gas concentration within the building, therefore, reduce the air ventilation needs, consequently, reduce the energy consumption. And at the same time creates enhanced conditions for animals to live and for labour to work.

9.4. Wastewater treatment

Zeolitic tuff could be used successfully in removing Cu^{+2} , Cr^{+3} , Ni^{+2} , Pb^{+2} and Zn^{+2} from industrial wastewater.

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Appendices

Appendix (1): Geology of Zeolitic Tuff (mining rights and exploration areas).

Appendix (1) Geology of Zeolitic Tuff (Mining Right & Exploration Areas)

