وزارة الطاقة والثروة المعدنية

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MINISTRY OF ENERGY AND MINERAL RESOURCES

## Mineral Status and Future Opportunity

# ZEOLITIC TUFF

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# CONTENTS

## List of Figures



## List of Tables



## List of Appendices

# 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$Km^2$ 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 compromises 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.

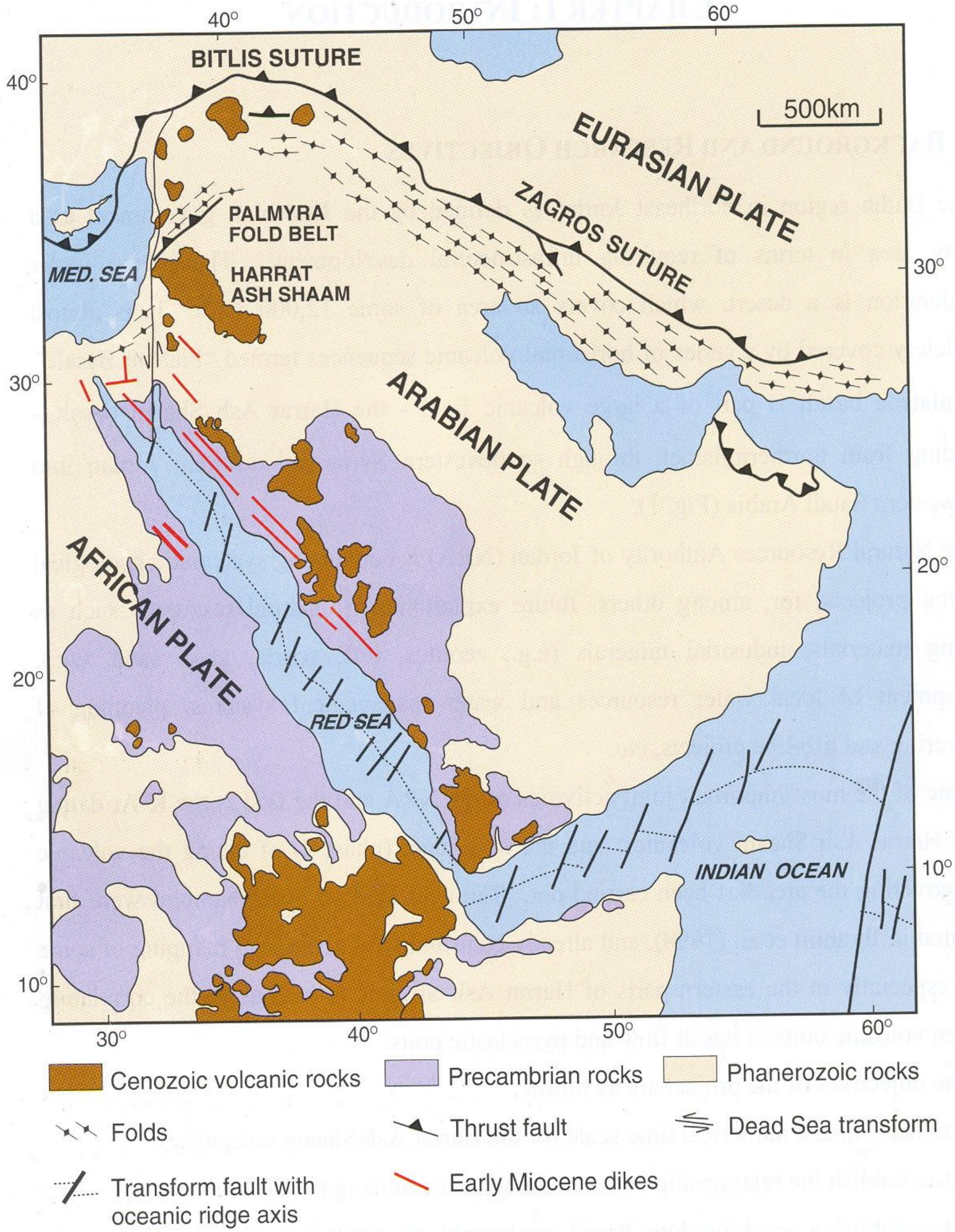


**Figure (2)**: Location of volcanic fields in the Arabian Plate (Camp and Roobol, 1989).

### 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 digenetic 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 Abdlehadi, 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 | % $SiO_2$ | $Al_2O_3$% | $Fe_2O_3$% | % MgO | % CaO | % $K_2O$ | % $Na_2O$ |
|---|---|---|---|---|---|---|---|
| **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 consumed in pozzolanic cement industry. The rest in agricultural sector, i.e. soil amendment, ammonia control and animal nutrition and few 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 tuffacious materials, Jordan is considered as an excellent source for such aggregates. Many trail 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. | Cement | Water | Strength | Strength | Mix. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19mm kg/m$^3$ | 14mm kg/m$^3$ | 9mm kg/m$^3$ | 0.5mm kg/m$^3$ | g/m$^3$ | kg/m$^3$t | Lt. | 7days | 28days | S. gravity | Mix. Absorption | Av. Density |
| 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 )