MINISTRY OF ENERGY AND MINERAL RESOURCES
Mineral Status and Future Opportunity

DIATOMITE (DIATOMACEOUS EARTH)

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DIATOMITE (Diatomiaceous earth)

1. Introduction

Diatomite is micro-amorphous silica, sedimentary rock consisting principally of the siliceous remains of microscopic unicellular aquatic plant called diatom. A relative of the algae, the diatom is a minute speck of protoplasm that encloses itself in a shell, or frustule, made of silica extracted from the surrounding water. Thus, diatomite has been formed by the induration of diatomaceous ooze, and consists mainly of diatomaceous silica, a form or variety of opal which is first formed in the cell walls of the living diatom. Diatomaceous silica is the preferred name for the principal mineral component of which the rock, diatomite, is composed. The terms Diatomaceous earth and Kieselguhr are used as synonymous with diatomite. The designation of diatomite is for those accumulations of diatomaceous silica that are of sufficient quality, size, and mineability to be considered of potential commercial value.

When diatom dies, it sinks to the bottom of the basin, and the organic matter undergo more or less complete decomposition leaving behind a layer of insoluble siliceous shells. Because diatoms exist in enormous numbers when the environment is favourable, their shells may accumulate by billions. The rate of accumulation is thought to be several millimeters per year. After deposition, such subsequent geologic forces as consolidation, burial under what will be later overburden, regional uplift, and partial erosion come into play to expose the deposit for later discovery and exploitation.

2. Industrial Applications

It is difficult to classify a diatomite deposit as high or low grade since different deposits may yield products highly effective in one specific use while offering poorer performance in others. For example, the diatomaceous deposit in British Columbia, Canada, is a high quality absorbent and is processed for cat litter products, but it is not suitable for filtration aids.

Processed diatomite possesses an unusual particulate structure and chemical stability that lends itself to applications not filled by any other form of silica. For most among these application is its use as a filter aid, which accounts for over half of its current consumption. Low bulk density, high absorptive capacity, high surface area and low thermal conductivity are attributes responsible for its utility as functional filler, thermal insulating, catalyst carrier, and chromatography support.

Worldwide, the major applications of diatomite are:

Filter Aids

The widest use for processed diatomite is in filter aids for the separation of suspended solids from fluids. They do not interfere chemically that the processed of filtration is purely mechanical. The requirements of a good filter aid, provided by diatomite, are suitable particle size and shape characteristics to achieve optimum cake permeability, chemical inertness, lightweight availability in a number of grades, and relatively low cost. Diatomite particulate structure means that the millions of irregularly shaped particles interlock in such way as to leave 85%-90% voids.

More common applications for diatomite filter aids are in the filtration of beer, wine, raw sugar liquors, swimming pool, dry cleaning solvents, chemicals, pharmaceuticals, fruit and vegetable juices, varnishes and lacquers. Major producers of diatomite filter aids manufacture a range of products usually corresponding to increasing flow rate but also possessing different properties.

Filler s

The second largest use of diatomite is as functional filler, where its addition improves the performance of the product. It is used as functional filler in paints, rubber, drugs, toothpaste, polishes, and chemicals. These different applications may be classified under particular properties of diatomite.

Absorption

Diatomite powders have a high absorptive capacity that can absorb up to 2.5 times their weight of water. This property lends them to application in products such as cat litter, pesticide carriers and pitch control in paper manufacturing.

Mild Abrasive

Diatomite possesses hardness sufficient to produce abrasion on metal surfaces. Consequently refined, natural milled products are also in corporate in some silver polish formulation. Flux-calcined grades of diatomite are suitable for use in automobile polishes.

Other Functional Filler Uses

The diatomite structure is useful as a semi-reinforcing agent in certain rubber products and its high silica content makes it suitable for combination with lime in the manufacture of lime-silicate insulation and absorptive calcium-silicate powders.

The Moler products (Danish diatomite-clay mixture), is extensively used in insulation, particularly in the form of bricks. It is also produced in the form of calcined and kiln-dried granules and powders, and is consumed in fertilizers, animal feedstuffs, insecticides, explosives, cement, and industrial and domestic absorbents.

3. Location

The diatomite occurs in two separate horizons in Azraq Mud flat. The area is approximately 110km northeast of Amman and covers an area of more than 150km^2. The area is bounded by the following coordinate (in Palestine Belt): -

East:	**321000 - 340000**
North:	**1125000 - 1145000**

The deposit is easily accessible through asphalted road and tracks. The Qa'a Al Azraq or "Azraq Mud flat" is referred to the whole area where a former lake believed to have been formed in Azraq depression of Miocene time (Fig. 1).

4. Geology of Azraq Mud Flat

Azraq mud flat Qa'a is a flat, closed with an oval shape area. It represents the lowest and the northern part of Azraq depression. The center of the mud flat is 110Km east of Amman.

Azraq depression represents the north western part of As Sirhan-Azraq graben which was developed by two sets of major faults trending NW-SE: the Fulug Fault to the east and As Sirhan Fault to the west. Other system of minor faults was also developed perpendicular to the major faults which contributed in forming the present mud flat (Ibrahim, 1992).

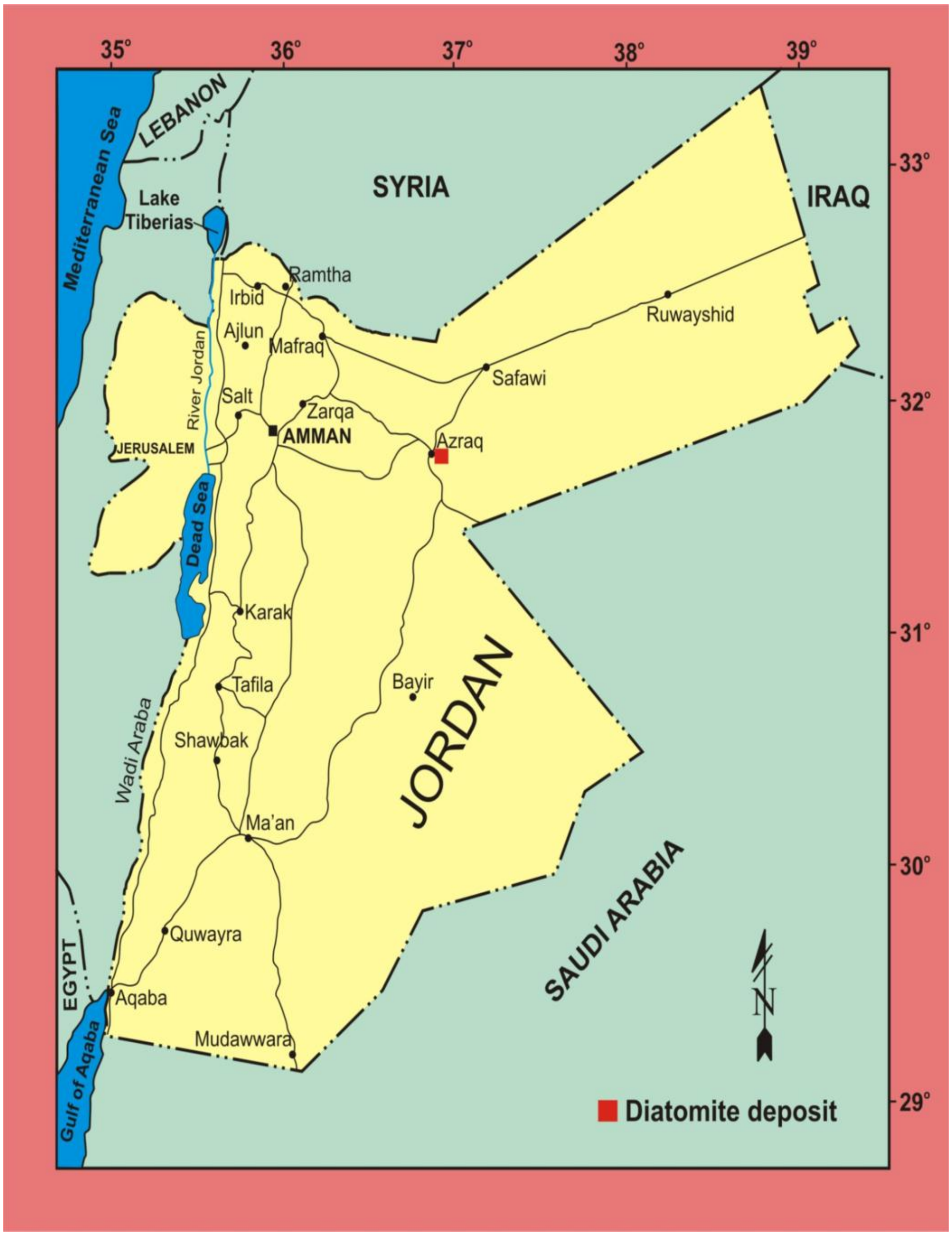


Figure (1): Diatomite deposit location map.

A former lake was believed to have been formed in the depression of Post-Miocene time (Harza, 1956). A thick sequence of clastic sediments, Wadi sediments and evaporites were deposited in the lake. Due to the high rate of evaporation and less supply of water, the lake gradually decreased to its present local shape as mud flat. The Azraq diatomite deposit is mainly composed of diatomite mixed with clay minerals. Illite/smectite mixed layer and kaolinite are commonly present.

Sixty one boreholes were drilled in the mud flat area and the area to the south east along the depression. Thicknesses of the clastic sediments range between 6.5m to 200m. The subsurface data indicate that the clastic sediments belong to Azraq Formation of Pliocene-Pleistocene age. Azraq Formation is composed of clay, silty clay, marly clay, silt, diatomite, evaporites and intercalations of lacustrine carbonates (Alali, & Abu salah, 1993).

Azraq mud flat or Qa'a Al-Azraq can be divided into two sub-areas, the area covered by flood water in winter (current mud flat) and the area to the southeast. The former area contains high concentration of salinity (T.D.S is between 10-30%) and shallow water table (1 to 2m). The latter contains relatively lower salinity to brackish water and the water table gradually deepens eastwards and southeastwards where it reaches 42m in borehole BT-69 (Figure 2).

5. Reserves

The exploration program carried out by NRA reported diatomite in 42 boreholes out of 60 boreholes drilled in the mud flat area. Two diatomite horizons were discovered in the mud flat.

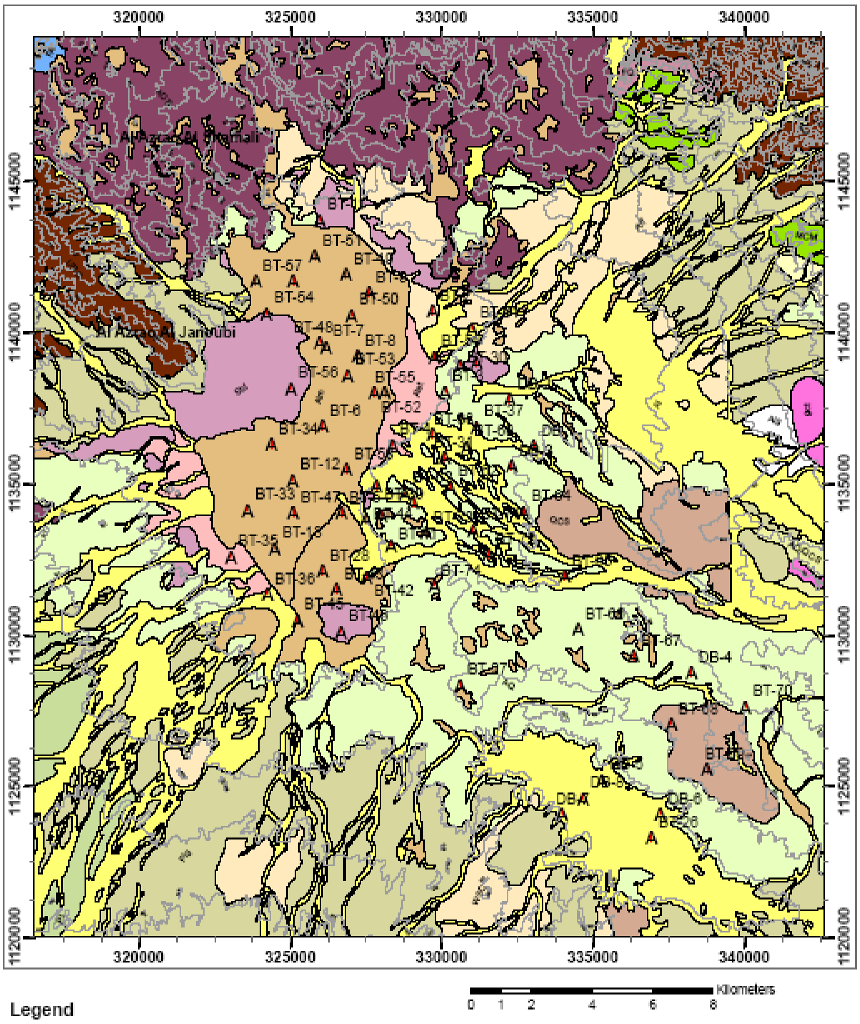
The reserve was calculated for both horizons although the first horizon was considered due to the continuity of the layer through all the 42 boreholes. The stripping ratio was calculated for the first horizon to be between 0.55 and 8.3 (Average 2.7). Reserves calculation was based on average bulk density (dry) of 0.7.

Table (1): Reserve, Diatomite thickness (m) and Overburden (m).

Horizon	Reserve (Mt)	Diatomite thickness (m)	Overburden (m)
First	1042	4.5-31	11-42.5
Second	212	2-20	37-92.5*

❖ *including the first horizon*

Figure (2) Geological Map Showing Diatomite Boreholes Location



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Legend

Geological Formation

- Al — Alluvium And Wadi Sediments
- Alg — Alluvium And Wadi Sediments
- Alm — Mudflat
- Alf — Alluvium fan Sediments
- Als — Alluvium and wadi sediment
- Alst — Alluvuim Silt and Siltflat
- gct — Gypcrete
- Std — Silt Dunes
- Pl — Fluviatil and Lacustrine Gravels
- Plg — Fluviatil and Lacustrine Gravels
- FA — Fahda Vesicular Basalt
- HN — Hassan Scoriaceous
- AQ — Azraq /Qara granite
- MOB — Madhala olivine phyric basalt
- AOB — Abed Olivin Basalt
- QCS — Qirma Calcareous Sandstone
- WSC — Wadi shallala chalk
- FQ — Fuluq Porcellanite
- URC — Umm Rijam (chert - limestone)
- MCM — Muwaqqar Chalk Marl
- ASL/AHP — AL Hisa phosphorite/ Amman silicifed
- Road < 5 m
- Road 5 - 7 m
- Road > 7 m
- Contour
- A — Diatomite Borehole

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December. 2006

Table (2): Diatomite boreholes drilled in Azraq depression (Alali, & Abu salah, 1993).

Borehole No.	East	North	Borehole No.	East	North
BT-1	329.162.36	1143.964.50	BT-45	325.232.18	1130.504.07
BT-2	329.704.80	1140.715.26	BT-46	326.686.92	1130.113.19
BT-3	330.118.99	1138.076.27	BT-47	325.113.53	1134.054.06
BT-4	328.390.90	1136.311.86	BT-48	325.988.20	1139.693.66
BT-5	326.716.06	1134.060.71	BT-49	326.852.63	1141.935.32
BT-6	326.081.30	1136.932.90	BT-50	327.037.50	1140.600.75
BT-7	326.183.16	1139.537.22	BT-51	325.828.42	1142.539.58
BT-8	327.225.73	1139.252.99	BT-52	327.780.85	1138.024.95
BT-9	327.599.56	1141.335.52	BT-53	326.912.25	1138.624.64
BT-10	325.094.87	1141.725.30	BT-54	324.237.21	1140.661.15
BT-11	325.998.32	1143.733.96	BT-55	328.138.41	1138.028.81
BT-12	325.089.82	1135.138.35	BT-56	325.029.63	1138.173.12
BT-26	336.925.30	1123.312.30	BT-57	323.850.36	1141.727.33
BT-27	330.617.46	1128.353.61	BT-58	326.874.26	1135.489.35
BT-28	326.067.96	1132.149.31	BT-59	329.752.47	1139.218.39
BT-29	331.148.97	1139.029.03	BT-60	330.831.81	1136.230.59
BT-30	330.609.85	1138.927.38	BT-61	331.018.74	1140.165.92
BT-31	330.099.55	1135.895.55	BT-62	330.305.84	1134.917.16
BT-32	329.088.24	1134.394.56	BT-63	328.805.90	1134.708.42
BT-33	323.606.04	1134.151.27	BT-64	332.716.82	1134.080.67
BT-34	324.383.62	1136.318.55	BT-65	334.066.21	1131.963.07
BT-35	323.054.24	1132.595.57	BT-66	334.495.55	1130.220.81
BT-36	324.259.76	1131.373.16	BT-67	336.352.45	1129.326.71
BT-37	331.150.35	1136.893.67	BT-68	337.583.32	1127.081.38
BT-38	329.706.37	1136.659.37	BT-69	338.773.98	1125.569.22
BT-39	327.868.34	1134.942.70	BT-70	340.043.68	1127.658.11
BT-40	328.012.16	1133.989.86	BT-71	331.046.28	1133.468.44
BT-41	328.332.79	1132.967.43	BT-72	331.541.56	1132.678.49
BT-42	327.532.55	11131.939.33	BT-73	329.500.00	1133.400.00
BT-43	326.542.71	1131.538.08	BT-74	329.750.00	1131.650.00
BT-44	327.503.00	1133.836.37			

6. Mineral Properties

6.1. Mineralogical Properties

The Azraq diatomaceous clay is composed mainly of diatoms mixed with clay. The diatom frustules are composed of disordered, highly amorphous Opal-A. The other mineral constituents are: kaolinite, illite, quartz and halite with traces of pyrite, dolomite and albite. Mineralogy of the clay fraction confirms the presence of mixed-layer (Illite/smectite), Kaolinite, mica and Palygorskite minerals.

Scanning electron microscope examination confirms the presence of the diatomaceous frustules. Figure (3) shows two main types of frustules, the cylindrical and the centric.

Many frustules were found preserved and filled with clay, others were broken and reworked. The Mineralogical evidence of clastic supply and the presence of broken shells suggest that part of the Azraq diatomite was deposited in a relatively non-quiet sedimentary environment.

6.2. Chemical Properties

The important of diatomite comes from its properties; some of them consider being unique. Since these properties vary between and within individual deposits, the final product may only be applicable to a specific range of uses.

Diatomite is amorphous opaline silica or hydrous silica in composition ($SiO_2.nH_2O$) associated with it a small amount of alumina, iron, organic and inorganic components. Lesser amounts of other elements, a small part of which may be secreted in the diatom skeleton, comprise the balance of the total chemical composition. Diatomite also contains an unusual amount of free water which may vary from 10 - 60%.

Diatomite, chemically, is inert and insoluble in most reagents. Although diatoms appear amorphous under the light microscope, x-ray studies show untreated diatomite to have a broad halo in the region of the principal cristobalite peak. Upon calcination to 950^{o}C, the amorphous silica is converted to a-cristobalite.

Low bulk density, low wet density, and high surface area may be visualized as examples of derived or secondary properties. The loose weight and wet density are functions of the skeletal structure and specific gravity. The ultimate hardness of the diatom skeleton is 4.5 to 5 on the Mohs' scale. After calcination or flux calcination. The hardness is increased to 5.5 to 6. The friability, or the tendency of the skeleton to break down, rather than to abrade, renders a measurement of hardness meaningless without a consideration of particle size. The specific gravity ranges from 2.0 for natural milled powder to 2.3 for flux calcined powder. Refractive index is variable between 1.4 and 1.46 for natural earth, and increase to 1.49 for flux calcined.

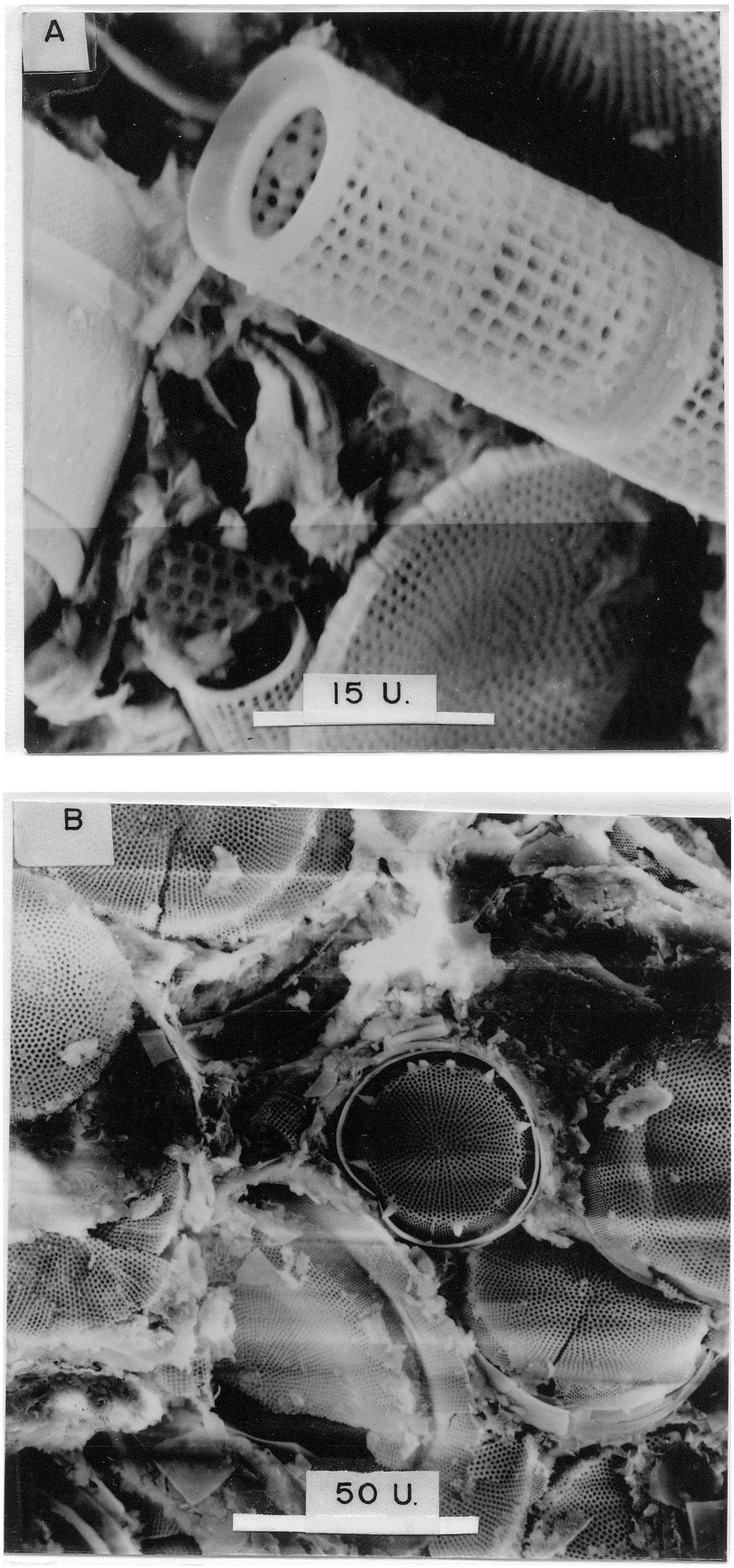

Figure (3): SEM photographs showing diatoms frustiles

Calcination burns off any organic residues and shrinks and hardens the particles, sintering some of them into microscopic cluster. Although the true specific gravity of opaline silica is 2 to 2.3, the powder packs so loosely that its apparent density may be as low as 0.6.

Calcinated products are generally pink owing to oxidation of iron. White grades may be produced through the addition of soda ash or salt at about 1150^{o}C. Since most of the apparent volume of the powder consists of microscopic interconnected voids, the material has very high absorptive capacity for liquids, an extremely large surface area, and low thermal conductivity.

The bulk chemical composition shows that silica and alumina are the major oxides with relatively high values of iron and sodium oxides. The results of the chemical analysis of the Jordanian diatomite could be summarized as in table (3).

Table (3): Average chemical analyses of Jordanian diatomite from boreholes samples (Alali, & Abu salah, 1993).

Component	**SiO_2 %**	**Al_2O_3%**	**Fe_2O_3%**	**MgO%**	**Na_2O%**	**K_2O%**	**TiO_2, MnO&P_2O_5**
	41-70.7	10-18	2.3-10	1.6-2.3	2.4-10	1-3	traces

Table (4): The comparison between Jordanian diatomite and Moler as follows (Alali, 1991).

Components %	**Jordanian Diatomite**	**Moler**
SiO_2	41-70	68-80
Al_2O_3	10-16	8-10
Fe_2O_3	2.35 - 9.9	5-7

Moler: Danish Diatomite

6.3. Physical Properties:

Physical properties were investigated by Al'ali in his M.Sc. thesis in 1991. The results indicated that the specific gravity values are variable and slightly high depending on amount of impurities present. The high dry density of the samples compared with Molar (Danish diatomite) value indicated the high clay content of small particle size and more close packing.

Oil absorption values are acceptable compared with the values (60-100 gm of oil/100 gm of sample) of diatomite for paint filler in British Standard-BS 1795 (1976). pH values are nearly neutral or slightly alkaline which represent alkaline environment. The surface area values are higher than some commercial diatomite and even some clay except montmorillonite clay (85m2/gm) determined by the same method. Explanation of high surface area in many of the tested samples is due to the high clay content, particularly the presence of smectite clay.

Table (5): Some physical properties of Jordanian diatomite from boreholes samples.

Oil Absorption	ph	Surface area m^2 gr.	Dry density kg/m^3	Specific gravity
47-72gr/100gr	6.2-8.1	23-64	666-791	2.27-2.63

The particle size distribution analysis indicated that 93 to 99% of the particle sizes are less than 20μ and at least 82% are less than 10μ for all tested samples.

Table (6): Results of the particle size distribution: -

Grain size	2μ>	10μ>	20μ>
Wt%	9.4 -16.3	82.02-94.5	93.3-99.5

7. Background

- Natural Resources Authority carried out detailed exploration and evaluation study of Azraq mud flat and revealed the presence of diatomite deposit within the smectitic clay and palygorskite during the period 1989-1993 (Alali & Abu Salah, 1993). The diatomite was reported by Khoury in 1990 when samples from BH-2 were sent to the University of Jordan and examined under the SEM.

- El-Harithi (1990) studied some selected samples and concluded that the diatom frustules were deposited in a shallow marine outer shelf depositional environment. Alali (1991 & 1994) evaluated the physical and chemical properties of the diatomite and concluded that the Jordanian diatomite is similar to the Danish diatomite (Molar) product. Alali & Abu Salah, (1993) and Qararah and Alali (1995) investigated the deposit and recommended a detailed evaluation. They concluded that the high saline water is the most important hindrance for mining and utilizing the Azraq diatomite and that the diatomite layers are under the water table in the depression. Qa'adan (1992) carried out detailed mineralogical and chemical investigation in Azraq mud flat.

- Scientific experiments carried out by researchers at the University of Jordan indicated that Azraq diatomite has been found to be effective at removing toxic metals from contaminated water (Kakish, 1992), (Al-Digs, 1994), (Kamal, 1996), (Al-Qassem, 1996) and (El-Shiekh, 1996). Geoindustria Company (2000) evaluated some samples of the Jordanian diatomite deposits.

8. World Resources and Production

World resources of crude diatomite are adequate for the foreseeable future, but the need for diatomite to be near markets because of transportation costs encourages development of new sources for the material.

The amount of domestically produced diatomite sold or used in 2013 increased 5% compared with that of 2012. Apparent domestic consumption increased 4% in 2013; table

(7), exports increased by 6%. Filtration (including the purification of beer, liquors, and wine and the cleansing of greases and oils) continued to be the largest end use for diatomite. Other applications include the removal of microbial contaminants, such as bacteria, protozoa, and viruses, in public water systems, and the filtration of human blood plasma. Diatomite filter aids have been successfully deployed in about 200 locations throughout the United States for the treatment of potable water. Emerging applications for diatomite include pharmaceutical processing and use as an insecticide that is nontoxic to humans.

Table (7): World Mine Production, Reserves, and Reserve Base

*Country	Mine production ('000t)		Reserves (million t)
	2012	2013	
United State	735	770	250
China	420	420	110
Argentina	55	60	NA
Denmark (processed)	338	325	NA
France	75	75	NA
Japan	100	100	NA
Mexico	85	85	NA
Peru	81	80	2
Spain	50	50	NA
Other countries	181	180	550
World total (rounded)	**2120**	**2145**	**362**

* (Source: USGS, 2012)

9. Investment Opportunities

No investment in diatomite deposit has been recorded so far. The mineral is open for investment and mining/exploration companies are invited on the basis of detailed exploration, evaluation, and exploitation.

The assessment of Azraq diatomaceous clay is basically based on the chemistry, mineralogy and physiochemical properties of the material, compared with the nearest commercial type in properties 'Moler' the Danish diatomite product. Azraq diatomaceous clay is not recommended for use as filter-aids or functional fillers unless otherwise is washed from salinity and upgraded. However, such applications require high-grade diatomite (SiO_2 >85%, Fe2O3 <1.5% and CaO < 1%) and require appropriate flow rate and permeability and chemical inertness.
Industrial applications of Azraq diatomaceous clay should accept this natural mixture as raw material taking into consideration the relatively high salt content as a bad contaminant in many applications. However, the diatomite in the area southeast of the mud flat has been found of low salt content.

According to the chemical and physical properties, the Jordanian diatomite could be used in the following industrial applications after simple treatments:

9.1. Liquid Absorption

The high absorption capability of the raw and calcined diatomite indicated that could be used absorbent powders for liquid such as oil, fuel oil, liquid chemicals and transported toxic chemicals used in industrial applications.

9.2. Adsorption of Toxic Pollutants

Scientific experiments carried out by researchers at the University of Jordan pointed out that Azraq diatomite has been found to be effective at removing toxic metals from contaminated water. Investigations showed that the Jordanian diatomite or diatomaceous earth has good sorptive properties for various pollutants such as Cr, Pb, Cu, Cd, Hg, PO4, NO3, and phenolics (Khoury, 2003). Samples were taken from different diatomite intervals of different boreholes in Qa' El Azraq. The tests were performed on raw samples (Kakish, 1992), modified and surface modifications samples to improve the adsorption properties (Al-Digs, 1994, Kamal, 1996, Al-Qassem, 1996 and El-Shiekh, 1996). The presence of amorphous silica, structure and type of frustules of the diatoms and the smectite clays were the main reasons for such properties.

9.3. Mild Abrasive and Polishes

Due to the delicate structure of the diatomite shells, Diatomite possesses hardness sufficient to produce abrasion on metal. It could be used as a mild abrasive on such surfaces.

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