# MINISTRY OF ENERGY AND MINERAL RESOURCES
## Mineral Status and Future Opportunity

# HEAVY MINERALS

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# Heavy Minerals

## 1. Introduction

Zirconium and hafnium are part of the heavy minerals group and they are curious elements because they are almost found together in nature. Most commonly they form as the silicate sometimes containing iron, calcium, manganese, and other elements. Less commonly they are found as oxides in combination with titanium, thorium, calcium and iron. Zirconium was discovered by Klaproth in 1789 and isolated 35 years later by Berzelius. Because hafnium's chemical properties are so close to those of zirconium, it was not discovered until 1923. These elements occur almost commonly in nature as the mineral Zircon ($ZrSiO_4$) and less commonly as oxide Baddelyite ($ZrO_2$). Zircon was identified as a component in alluvial and beach sands in 1895, but it was not produced in any quantity until 20 years later. Zircon is always a co product from TiO2 mining and processing. Zircon holds a unique position as an industrial mineral because it is used for both physical and chemical properties as well as an ore of zirconium and hafnium metals. Zircon resistance to weathering; therefore it is often present in ancient beach sands and placer deposits. Although resistant to alteration from external sources, it is vulnerable to internal alteration as the result of thorium and uranium substituting for zirconium either in the zircon lattice or in solid solution. Alteration to the metamict state takes place as radioactive from these elements disorder the crystal lattice, accompanied by hydration, reduction in specific gravity, and change in color.

## 2. Location

The Wadi Al Mezrab area (Dubaydeb Sheet 1:50,000) and Al Qannasiya area are considered the main areas contained heavy minerals deposits which are located about 350 km south of Amman and 100 km north of Aqaba (Figure 1). They can be defined respectively by the following coordinates (Palestine belt):

| East | North |
|---|---|
| 222000 – 228000 | 0866000 – 0879000 |

## 3. Geological Setting

The exposed rocks in Wadi Al Mezrab area are composed of sedimentary in origin which belong to the Middle and Upper Ordovician age. The rock sequence is a succession of sediments of a fluvial environment overlain by shallow marine sediments of the Tethyan Ocean (mainly sandstone and siltstone).

Heavy minerals deposited in the middle member of Dubaydib Sandstone Formation (DB2) which has an age of the Middle Ordovician. This member consists of very fine grained sandstone (brown to dark brown color) with thin beds of reddish brown siltstone. The thickness of the bed bearing heavy minerals ranges from 1.5 – 4.2m. The base of this member is considered the base of huge channel filling sand bar deposits and it is well exposed in the middle of the graben. The base of the channel is composed of micaceous, pink to tan siltstone bearing sabellarifex burrows. The DB2 member is overlain by dark tan siltstone followed by reddish brown sandstone and the total thickness of this member is ranging from 80 – 90m.

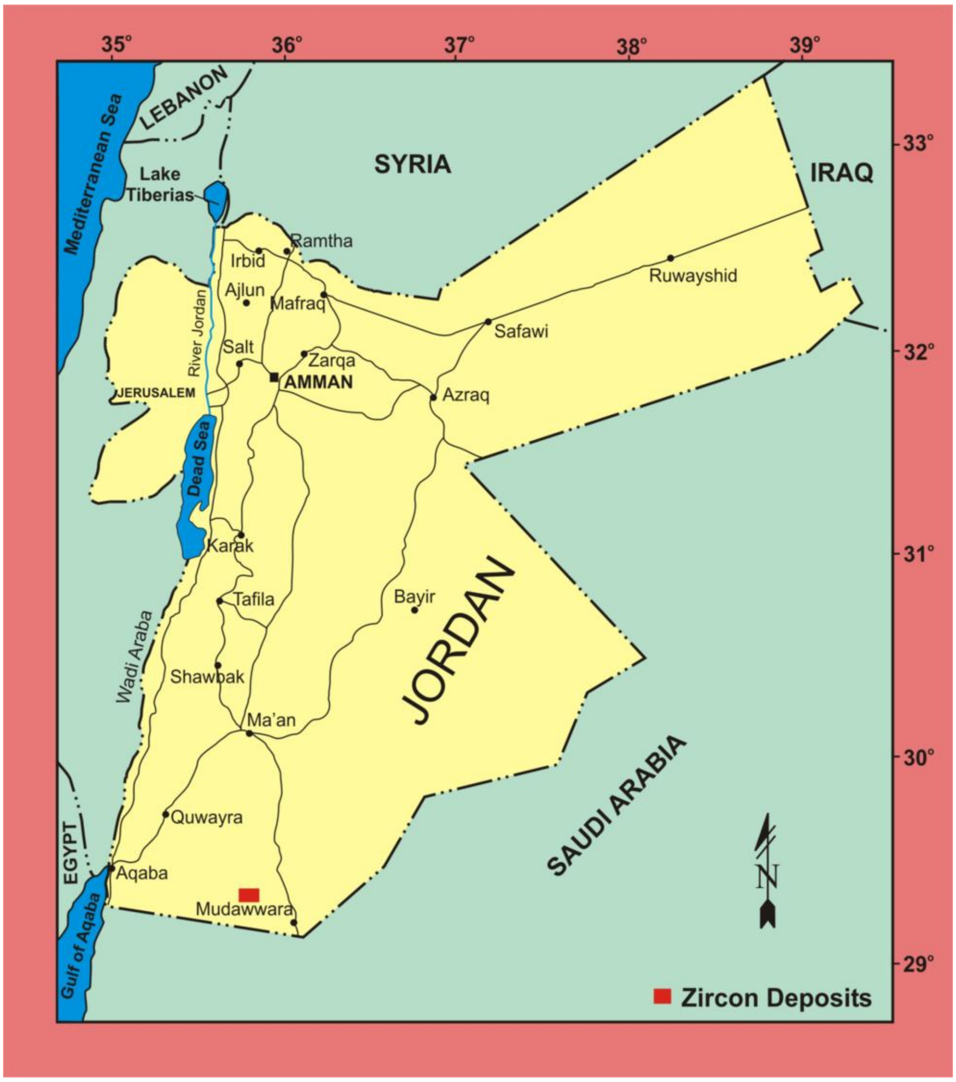



**Figure (1):** Location map of heavy minerals deposits.

## 4. Uses of Heavy Minerals

### 4.1. Uses of Zircon

Zircon sands are used in range of industrial applications and in a variety of markets ranging from foundry moulding sands to zirconium-metal manufacture. The ground flour of zircon is commonly used in refractory paint for coating the outer surface of moulds. In steel production, zircon sands are used in order to produce ladle brick, coatings, mortars and as ladle-nozzle fill. Zircon sands can be fused to make refractory bricks and blocks that are widely used in line kilns, glass melting furnaces and in hearths for containing molten metals due to its resistance to melt in high temperatures (zircon completely melts at 2760°C). Zircon sand is used to produce zirconia and alumina-zirconia abrasive materials and to clean turbines in electrical generating plants. A flour or micronized zircon has replaced more expensive tin as an opciefier in ceramic glazes and vitreous enamels. Zircon is also used in Tv. Face plate glass and Zirconium metal is used as fuel cladding and structural material in nuclear reactors.

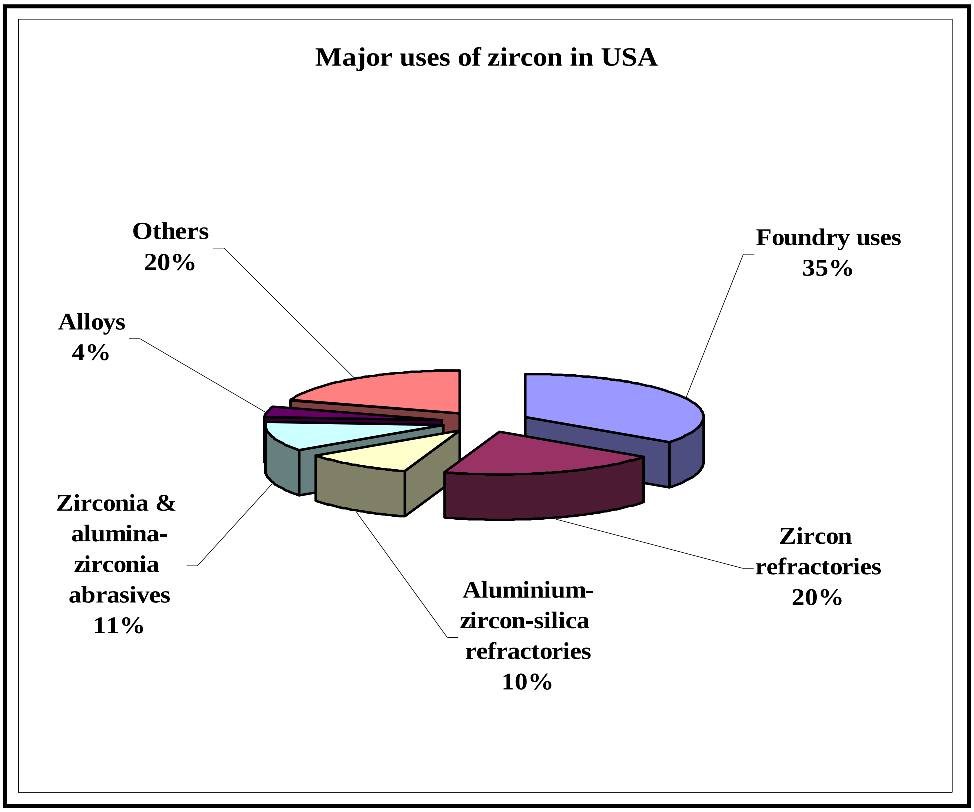



**Figure (2):** Major industrial applications of zircon in the United States.

### 4.2. Uses of Hafnium

- It used for control rods in nuclear reactors.
- It used in photographic flash bulbs.
- Hafnium oxide is used in optical glass.
- Hafnium oxide is used as an opacifier in enamels or as high temperature insulator.
- Hafnium nitride can be used for heat and wear –resistant parts.

### 4.3. Uses of Titanium Minerals (Rutile and Ilemenite)

- Titanium dioxide used in pigments manufacture.
- In paper industry.

## 5. Exploration Activities

### 5.1. Geochemical Exploration

- **Dubaydib Sheet:**

The area is defined by the coordinates (35° 45´ to 36° 00´ E and 29° 15´ to 29° 30´ N). A total of (103) heavy mineral samples and (33) rock samples were collected from this sheet area. All of the geochemical samples analyzed for (32) elements, among them were the Zircon (Zr). The concentration and the distribution of zircon are demonstrated by figure (1&2 appendices). It can be seen that the highest zircon value is (1883) ppm. Equal (1.9 kg/ton) in rock samples and (32941 ppm); Equals (3.2 kg/ton) in heavy mineral samples.

- **Al-Qannasiya Sheet**

The area is defined by 35° 30´ to 35° 45´ E and 29° 30´ to 29° 45´ N. A total of (195) stream sediment samples and (146) heavy mineral concentrate samples were collected from Al-Qannassiya sheet area; all of the samples were analyzed for (32) multi elements including zircon. The concentration and the distribution of (Zr) are demonstrated in figure (3&4 appendices). The highest value of the stream sediment samples was (10609) ppm. Equals 10.6 kg/tan while in the heavy mineral samples was (11473) ppm. Equals 11.5 kg/tan. Further detail geochemical study is highly recommended to evaluate the zircon.

### 5.2. Drilling

The area of Wadi Al Mezrab was subjected to detailed exploration program by Natural Resources Authority (NRA) during 1997-1999 phases 1. In this phase the NRA drilled and cored 39 boreholes and dug 7 exploration trenches in the bed bearing heavy minerals. In the second phase (2004), the NRA drilled and cored 37 boreholes and dug 6 exploration trenches and 7 pits. The attachment map (Appendix- 5) shows the location of the boreholes, trenches and pits.

### 5.3. Gamma Ray Logging

The sandstone of Dubyadib Formation (middle member) is highly radioactive due to its content of U and Th. Therefore, Gamma ray logging was extensively used in order to determine the heavy minerals bearing bed. The explorations indicate a positive relationship between the radioactive (thorium) and presence of zircon Table (1).

## 6. Reserves

The estimated reserves are about 96.000 metric tons. (Phase 1), in phase 2 the reserves are not determined yet.

**Table (1):** Results of gamma rays logging of boreholes (Phase I).

| B.H. No. | Gamma ray (CPS) | Depth (m) | B.H. No. | Gamma rays (CPS) | Depth (m) |
|---|---|---|---|---|---|
| Zr-1 | 3400 | 11-15.5 | Zr-19 | 2600<br>1600<br>2600 | 2.0-3.0<br>3.0-3.6<br>3.6-4.2 |
| Zr-4 | 5000 | 1.2-4.2 | Zr-20 | 2000<br>4400 | 2.8-3.6<br>4.4-5.0 |
| Zr-5 | 6200 | 14.5-18 | Zr-21 | 1950<br>3500 | 1.8-2.8<br>3.2-4.0 |
| Zr-7 | 3000 | 0.0-1.8 | Zr-22 | 1250<br>2350 | 5.9-6.4<br>6.8-7.8 |
| Zr-8 | 4500 | 18.5-21.5 | Zr-23 | 3000 | 6.5-9.0 |
| Zr-9 | 3600 | 2.0-5.6 | Zr-26 | 5200 | 4.5-7.0 |
| Zr-11 | 2000<br>1200 | 2.5-4.0<br>4.6-5.3 | Zr-30 | 2500 | 4.8-7.6 |
| Zr-12 | 3000 | 6.6-8.0 | Zr-31 | 1600 | 7.3-10.5 |
| Zr-13 | 2500<br>1600 | 3.0-4.3<br>4.9-6.0 | Zr-32 | 3400 | 3.0-6.4 |
| Zr-14 | 3400<br>1150 | 1.8-3.8<br>4.3-4.8 | Zr-33 | 3800 | 1.0-4.0 |
| Zr-15 | 2220 | 2.4-4.2 | Zr-34 | 4750 | 1.4-4.2 |
| Zr-16 | 3600 | 0.9-3.8 | Zr-35 | 4200<br>1250 | 0.0-0.8<br>1.2-1.6 |
| Zr-17 | 2600<br>3600 | 2.6-4.2<br>4.6-5.3 | Zr-36 | 2000 | 8.5-11.4 |
| Zr-18 | 1350<br>2600<br>1600 | 8.8-9.2<br>9.6-10.2<br>11.2-11.6 | Zr-37 | 3600 | 7.0-10.4 |

## 7. Thickness and Overburden

The thickness of heavy minerals bearing bed ranges from 1.5-5 m as indicated by gamma rays logging and ICP analysis. The penetrated layers showed that the overburden is consisting mainly of sandstone, light to brown and the thickness ranges from zero (Borehole Zr-7) to 18.7 m (Borehole Zr-8) Table (2). The highest thickness of overburden can be explained as a result of faults, which can be noticed in the area of boreholes Zr-5 and Zr-8. Generally, the thickness of overburden increases towards northeast as the dip of the exposed rocks between 3-5 degrees towards east and northeast (boreholes Zr-16 to 23 and Zr-30 to Zr-38).

**Table (2):** Thickness of heavy minerals bed and thickness of overburden.

| B. H. No | Interval of zircon bed (m) | Thickness of zircon bed (m) | Thickness of overburden (m) |
|---|---|---|---|
| **Zr-1** | 12.7 – 17.0 | 4.30 | 12.70 |
| **Zr-4** | 2.10 – 4.80 | 2.70 | 2.10 |
| **Zr-5** | 16.2 – 18.6 | 2.40 | 16.20 |
| **Zr-7** | 0.0 – 1.20 | 1.20 | 0.0 |
| **Zr-8** | 19.30 – 21.10 | 1.80 | 18.70 |
| **Zr-9** | 1.80 – 6.0 | 4.20 | 6.0 |
| **Zr-11** | 1.0 – 6.0 | 5.0 | 1.0 |
| **Zr-12** | 6.3 – 8.85 | 2.55 | 6.30 |
| **Zr-13** | 2.0 – 5.90 | 3.90 | 2.0 |
| **Zr-14** | 0.5 – 4.40 | 3.90 | 0.50 |
| **Zr-15** | 2.0 – 5.0 | 3.0 | 0.70 |
| **Zr-16** | 0.0 – 3.5 | 3.50 | 0.0 |
| **Zr-17** | 2.30 – 5.30 | 3.0 | 2.30 |
| **Zr-18** | 8.8 – 12.10 | 3.30 | 8.80 |
| **Zr-19** | 1.50 – 4.5 | 3.0 | 1.50 |
| **Zr-20** | 2.20 – 4.0 | 1.80 | 2.20 |
| **Zr-21** | 1.60 – 4.30 | 2.70 | 1.60 |
| **Zr-22** | 6.20 – 7.70 | 1.50 | 6.20 |
| **Zr-23** | 6.50 – 8.90 | 2.40 | 6.50 |
| **Zr-26** | 5.0 – 6.50 | 1.50 | 5.0 |
| **Zr-30** | 4.80 – 7.80 | 3.0 | 4.80 |
| **Zr-31** | 7.90 – 10.80 | 2.90 | 7.90 |
| **Zr-32** | 2.70 – 6.30 | 3.60 | 2.70 |
| **Zr-33** | 1.0 – 3.70 | 2.70 | 1.0 |
| **Zr-34** | 1.10 – 4.20 | 3.10 | 1.10 |
| **Zr-35** | 0.0 – 1.60 | 1.60 | 0.0 |
| **Zr-36** | 8.70 – 11.40 | 2.70 | 8.70 |
| **Zr-37** | 7.0 – 9.50 | 2.50 | 7.0 |
| **Zr-38** | 2.70 – 5.40 | 2.70 | 2.70 |

## 8. Heavy Minerals Properties
### 8.1.Chemical Properties

**Table (3):** Chemical composition of bulk heavy minerals bearing sandstone

| | | |
|---|---|---|
| **Zircon** | $ZrSiO_4$ | 0.67-3.75% |
| **Cerium** | Ce | 499-2168 ppm |
| **Lanthanum** | La | 224-1065 ppm |
| **Titanium** | $TiO_2$ | 1.61-4.91 ppm |
| **Yttrium** | Y | 75-232ppm |
| **$P_2O_5$** | $P_2O_5$ | 1117-4618 ppm |
| **Thorium** | Th | 400 ppm |

### 8.2. Mineralogical Properties

Thin sections and X-ray diffraction revealed zircon ($ZrSiO_4$), which appeared as elliptical-rounded grains forming the dominant heavy minerals followed by Monazite, rutile, brookite, anatase, ilmenite and epidote. Quartz, iron oxides, mica, kaolinite and feldspar are the main constituents as gangue minerals. The cementing materials are composed of iron oxides, calcite and kaolinite.

## 9. Beneficiation of Heavy Minerals

The main objectives of mineral processing are to release (liberate) and concentrate the target (valuable minerals) to a higher grade with maximum recovery from their associated gangue minerals. The first step of mineral processing is comminution of consolidated sandstone samples and examines the distribution of mineral values with particle size. In General, most of heavy minerals sand deposits in the world are found in beach sand (loose sand), so mineral sands mining are a comparatively simple process compared with underground mining. Many technical studies were carried out to concentrate and separate the heavy minerals from south Jordan. Nawasreh, (2001) studied the processing characteristics of ten borehole samples from Wadi Al Mezrab Area using different methods of gravity separation and the other was carried out by the Egyptian Geological Survey and Mining Authority. The following steps are the ideal processing method for Jordanian heavy minerals (Nawasreh, 2001).

The heavy minerals bearing sandstone are consolidated therefore, it should subject to crushing and grinding and the products of comminution are usually treated using a hydrocyclone to eliminate fine clay materials. The cumulative undersize and frequency distributions of the particle size for borehole samples after wet grinding indicated that the bulk of the sample mass was retained between the -90 μm to +63 μm sieves representing from 67 % to about 79 % of the total sample. All the borehole samples have a similar distribution of the metal values with particle size. These results show that by simple sizing it is possible to obtain primary concentrates of all the metal values. The underflow of the hydrocyclone can then be treated by gravity separation to produce pre concentrate heavy minerals which can be further concentrated and enriched by a second stage of gravity separation. An examination of the quantitative distribution of elemental values with size revealed that the majority of all values (Zr, Ce and La) were concentrated within a size range from +20–53 μm with the exception of $TiO_2$. Approximately 80% of the Zr, Ce and La values occurred within this size fraction with the reminder fairly evenly distributed in the coarser particle size range. The $TiO_2$ was found to be more evenly distributed over the particle size range rising steadily to a maximum at a particle size of 32 μm for all borehole samples. Elemental distribution with size has been found to be very similar for all borehole samples examined.

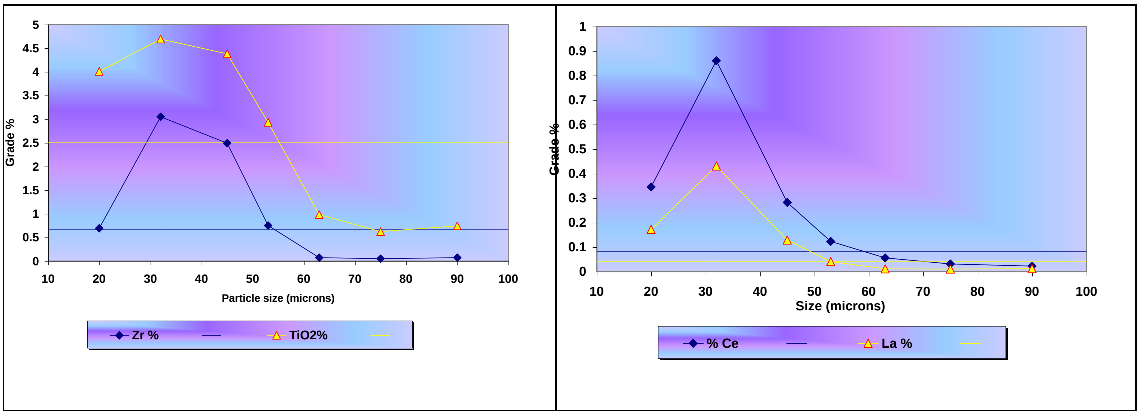



**Figure (3):** Distribution of Zr, $TiO_2$, Ce and La in size fraction (Nawasreh, 2001).

The results of the separation of a milled borehole sample Zr-4 as an example showing the percentage mass within 3 size fractions are illustrated by Table 4. It can be seen that virtually no concentration of values occurs for the +90 μm size fraction.

**Table (4):** Distribution % by mass of heavy mineral and rare earth elements obtained from the separation of borehole Zr-4.

| **Fraction +90 μm** | **Weight %** | **Zr %** | **$TiO_2$ %** | **Ce %** | **La %** |
|---|---|---|---|---|---|
| **Tailings** | 86.13 | 71.42 | 75.22 | 50.60 | 58.57 |
| **Middling** | 3.97 | 3.87 | 3.97 | 6.45 | 5.56 |
| **Concentrate 1** | 9.00 | 18.66 | 15.36 | 33.75 | 30.60 |
| **Concentrate 2** | 0.9 | 5.84 | 4.07 | 11.03 | 8.10 |
| **Total Recovery Concentrate** | 9.90 | 24.50 | 19.43 | 44.78 | 38.70 |

| **Fraction-90 +63 μm** | **Weight %** | **Zr %** | **$TiO_2$ %** | **Ce %** | **La %** |
|---|---|---|---|---|---|
| **Tailings** | 41.88 | 22.34 | 35.14 | 53.85 | 30.15 |
| **Middling** | 20.80 | 6.24 | 11.64 | 14.86 | 11.65 |
| **Concentrate 1** | 35.10 | 23.40 | 34.36 | 20.06 | 28.08 |
| **Concentrate 2** | 2.22 | 48.99 | 18.32 | 15.86 | 30.19 |
| **Total Recovery Concentrate** | 37.32 | 72.39 | 52.68 | 35.91 | 58.27 |
| **Fraction +20 μm** | **Weight %** | **Zr %** | **$TiO_2$ %** | **Ce %** | **La %** |
| **Tailings** | 29.05 | 0.64 | 5.89 | 5.81 | 0.00 |
| **Middling** | 8.64 | 0.32 | 2.27 | 1.76 | 0.72 |
| **Concentrate 1** | 54.32 | 29.74 | 59.64 | 18.11 | 10.58 |
| **Concentrate 2** | 7.99 | 68.64 | 35.09 | 75.37 | 88.56 |
| **Total Recovery Concentrate** | 62.31 | 98.38 | 94.72 | 93.48 | 99.14 |

A small amount concentrating effect can be observed for certain values in the –90 μm +63 μm fraction but a well defined concentration of values can be observed for the –63 μm+20 μm material.

The appearance of a typical gravity concentrates is illustrated by Figure 4 which is an SEM electron micrograph recorded with a back scatter electron detector. This highlights particles containing elements with a high atomic number so they appear to be brighter. It can be seen that the mineral grains are rounded and not fractured being typical of weathered sedimentary particles. The range of mineral compositions of typical concentrates produced experimentally is listed in Table 5.

**Table (5):** Mineral composition of concentrate products after gravity separation.

| **Mineral** | **Composition range of gravity concentrates** |
|---|---|
| Zircon | 26-40% |
| Rutile/Brookite | 18-36 % |
| Monazite | 4-9 % |
| Iron Oxide | 6-13 % |
| Quartz | 16-32 % |

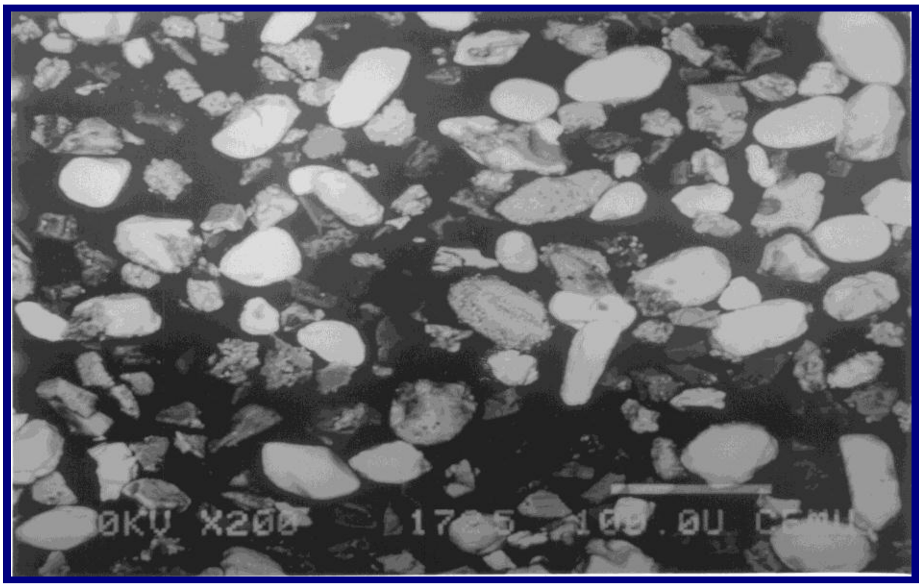



**Figure (4):** SEM micrograph of heavy mineral concentrate.

Pure zircon is obtained from the mixture of heavy mineral primary concentrate product by applying magnetic and high-tension electrical separation techniques. The target mineral zircon, in contrast to rutile and brookite, is non-magnetic and non-conductive and can be separated by magnetic and electrostatic methods. Heavy minerals-rich tailing materials are subjected to further separation using gravity techniques to eliminate remaining light minerals such as quart. Monazite has a slight magnetic susceptibility and can be separated from zircon by high intensity magnetic separation Figure 5 (Nawasreh, 2001).

Within the cooperation programe between Natural Resources Authority and the Egyptian Geological Survey and Mining Authority, a bulk sample (500kg) represents 7 trenches from the Wadi Al Mezrab area (South Jordan) was prepared and sent with the ideal.

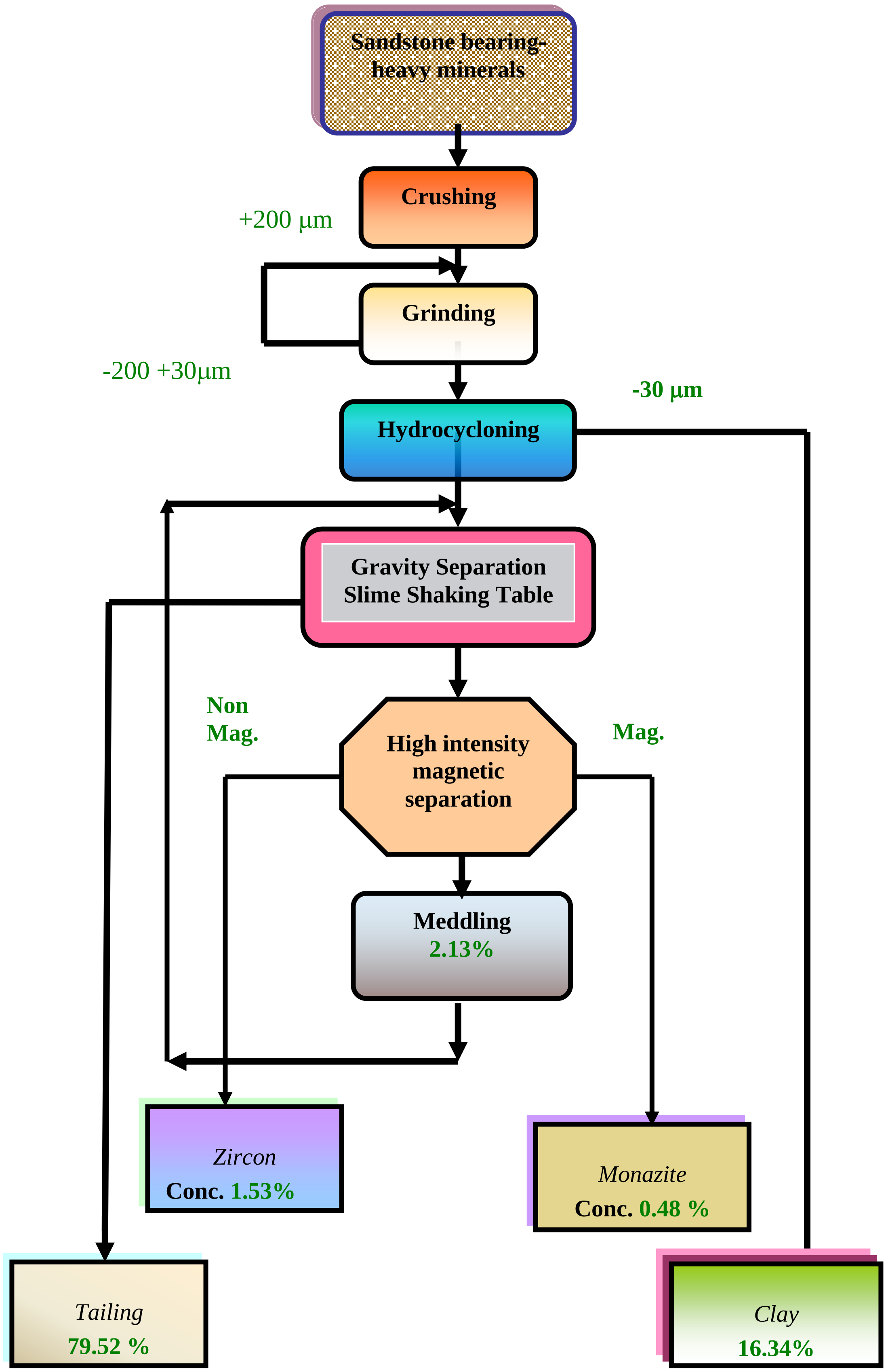



**Figure (5):** Flowchart of processing sandstone bearing heavy minerals from South Jordan.

Processing route to the Egyptian Geological Survey in order to study the possibility of separate zircon and other heavy minerals in semi industrial scale. The results of this study are presented in the following table:

**Table (6):** Processing results of heavy minerals bearing sandstone from Wadi Al Mezrab Area (Egyption Geological Survey).

| Products | Weight % | $ZrO_2$ % | Recovery % |
|---|---|---|---|
| **Bulk sample** | 100 | 1.274 | 100 |
| **Zircon concentrate** | 1.53 | 55.00 | 66.07 |
| **Monazite concentrate** | 0.48 | 1.26 | 0.48 |
| **Meddling** | 2.13 | 7.21 | 12.06 |
| **Tailings** | 79.52 | 0.32 | 19.98 |
| **Clay materials** | 16.34 | 0.11 | 1.41 |

## 10. Background

Several studies were carried out by NRA, these studies are as follows:

- In 1987 and within the Uranium exploration project, many samples were collected from the Dubaydib Sandstone Formation and sent to the BGR to analysis.The results of these analysis indicated the presence of zircon with good percentage.

- Masri, in 1988 produced a geological map of Wadi Al-Mezrab area scale 1:10.000 which encompassed the area of zircon deposits.

- Perrin in 1989, within the Uranium exploration project, and from the radiometric and geological evaluation of radioactive anomalies in the Ordovician sandstone, it was found that there is a positive relationship between Th, U and zircon.

- In 1997 NRA carried out an exploration program for zircon and heavy minerals include drilling 39 boreholes and 7 trenches, sampling and reserve determination.

- In 1999 many samples were sent to the international laboratories for analysis and the results indicate the presence of zircon and REE with acceptable percentage.

- In 2002, bulk sample (500kg) were prepared and sent to Egypt for processing, the result of this study indicated that it can be separate zircon with 80% purity.

- In 2004, NRA carried out an exploration program in new localities and this study is still under evaluation.

## 11. World Zircon, Occurrences and Global Market

### - Domestic Production and Use

The zirconium-silicate mineral zircon is produced as a coproduct from the mining and processing of heavy minerals. Typically, zirconium and hafnium are contained in zircon at a ratio of about 50 to 1. Two firms produced zircon from surface-mining operations in Florida and Virginia. Zirconium metal and hafnium metal were produced from zirconium chemical intermediates by two domestic producers, one in Oregon and the other in Utah. Zirconium chemicals were produced by the metal producer in Oregon and by at least 10 other companies. Ceramics, foundry applications, opacifiers, and refractories are the leading end uses for zircon. Other end uses of zircon include abrasives, chemicals, metal alloys, and welding rod coatings. The leading consumers of zirconium metal and hafnium metal are the nuclear energy and chemical process industries.

**Table (7):** Salient U.S Zirconium Statistics (Metric tones).

| **Zircon:** | **2008** | **2009** | **2010** | **2011** | **2012** |
|---|---|---|---|---|---|
| **Production, zircon ($ZrO_2$ content)** | W | W | W | W | W |
| **Imports** | | | | | |
| Zirconium, ores and concentrates ($ZrO_2$ content) | 22.300 | 9.370 | 14.900 | 17.200 | 26.000 |
| Zirconium, unwrought, powder, and waste and scrap | 318 | 451 | 727 | 485 | 370 |
| Zirconium, wrought | 715 | 526 | 424 | 365 | 280 |
| Zirconium oxide | 5.060 | 2.810 | 2.920 | 3.020 | 5.000 |
| Hafnium, unwrought, powder, and waste and scrap | 12 | 5 | 8 | 10 | 23 |
| **Exports:** | | | | | |
| Zirconium, ores and concentrates ($ZrO_2$ content) | 27.400 | 25.700 | 30.800 | 15.800 | 21.000 |
| Zirconium, unwrought, powder, and waste and scrap | 591 | 223 | 519 | 675 | 551 |
| Zirconium, wrought | 2.080 | 2.080 | 1.540 | 1.330 | 1.200 |
| Zirconium oxide | 2,970 | 3.050 | 5.630 | 6.710 | 6.000 |
| Consumption, zirconium ores and concentrates, apparent ($ZrO_2$ content) | W | W | W | W | W |
| **Prices:** | | | | | |
| Zircon, dollars per metric ton (gross weight): | | | | | |
| Domestic2 | 788 | 830 | 860 | 2.650 | 2.650 |
| Imported, f.o.b.3 | 773 | 850 | 870 | 2.500 | 2.500 |
| Zirconium, unwrought, import, France, dollars per kilogram4 | 41 | 51 | 74 | 64 | 110 |
| Hafnium, unwrought, import, France, dollars per kilogram4 | 225 | 472 | 453 | 544 | 530 |

[r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Data are rounded to no more than three significant digits.
[2]Includes insignificant amounts of baddeleyite.
[3]Defined as production plus imports for consumption minus exports plus or minus government shipments plus or minus stock changes.
[4]Excludes foundries.
[5]Excludes intermediate oxides associated with metal production.
[6]Includes germanium oxides and zirconium dioxides.

### - Mine Production and Reserves

World primary hafnium production data are not available. Hafnium occurs with zirconium in the minerals zircon and baddeleyite. Quantitative estimates of hafnium reserves are not available.

**Table (8):** Zirconium mine production and reserves

| Country | Zirconium mine production (thousand metric tons) | | Zirconium reserves (thousand metric tons, $ZrO_2$) |
|---|---|---|---|
| | **2011** | **2012** | |
| United States | Withheld to avoid disclosing company proprietary data. | Withheld to avoid disclosing company proprietary data. | 500 |
| Australia | 762 | 610 | 21.000 |
| China | 150 | 150 | 500 |
| India | 39 | 40 | 3.400 |
| Indonesia | 130 | 60 | NA |
| Mozambique | 44 | 47 | 1.200 |
| South Africa | 383 | 400 | 14.000 |
| Other countries | 110 | 109 | 7.200 |
| **World total (rounded)** | **1.620** | **1.420** | **48.000** |

- **Zirconium Prices**

After a sharp increase in 2011, the 2012 yearend published price range of standard-grade bulk domestic zircon concentrate remained unchanged from that in 2011 at $2,550 to $2,750 per metric ton (table 2). According to U.S. Census Bureau data, the average unit value of imported zirconium ore and concentrates was $2,580 per ton at yearend 2012, a 19% increase from that at yearend 2011.

No published prices were available for zirconium metal. In 2012, the average unit value of imported unwrought powder from France was $92 per kilogram, a 44% increase from that in 2011. The average duty-paid unit value of imported unwrought hafnium (including sponge and powder) from France was $507 per kilogram, a 7% decrease from that in 2011.

**Table (9) U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY[1]**

| | | | 2009 | | 2010 | |
|---|---|---|---|---|---|---|
| | | | **Quantity** | **Value** | **Quantity** | **Value** |
| **Class and country** | | **HTS[2]** | (metric tons) | (thousands$) | (metric tons) | (thousands$) |
| **Ore and concentrates:** | | 2615.10.0000 | | | | |
| Belgium | | | 6.580 | 6.850 | 657 | 1,000 |
| China | | | 2.630 | 1.430 | 359 | 223 |
| Germany | | | 870 | 1.240 | 1.790 | 4.500 |
| Italy | | | 156 | 232 | 18.200 | 15.800 |
| Japan | | | 11.600 | 6.520 | 1.470 | 3.080 |
| Korea, Republic of | | | 2.320 | 2.060 | 2.080 | 1.870 |
| Mexico | | | 4.010 | 4.140 | 3.560 | 3.970 |
| Netherlands | | | 9 | 53 | 5.280 | 4.610 |
| Spain | | | 4.430 | 3.900 | 2.000 | 1.660 |
| United Kingdom | | | 1.540 | 2.470 | 1.660 | 3.350 |
| **Total** | | | **34145** | **28895** | **37056** | **40063** |
| **Ferrozirconium:** | | 7202.99.1000 | | | | |
| Canada | | | 54 | 122 | 109 | 276 |
| Mexico | | | 490 | 983 | 395 | 791 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Total** | | | **544** | **1105** | **504** | **1067** |
| **Unwrought zirconium, powder:** | | 8109.20.0000 | | | | |
| China | | | 5 | 158 | 61 | 2.570 |
| France | | | 37 | 1.730 | 75 | 3.260 |
| Germany | | | 11 | 356 | 52 | 1.670 |
| Mexico | | | 3 | 12 | 35 | 1.270 |
| Russia | | | 73 | 4.000 | 65 | 3.230 |
| United Kingdom | | | 24 | 730 | 109 | 2.650 |
| **Total** | | | **153** | **6986** | **397** | **14650** |
| **Zirconium waste and scrap:** | | 8109.30.0000 | | | | |
| Canada | | | 27 | 1.590 | 42 | 2.570 |
| France | | | 12 | 208 | 5 | 45 |
| Japan | | | - | - | 7 | 192 |
| Netherlands | | | - | - | 10 | 107 |
| Sweden | | | 16 | 266 | 10 | 118 |
| **Total** | | | **55** | **2064** | **74** | **3032** |
| **Other zirconium:** | | 8109.90.0000 | | | | |
| Canada | | | 442 | 37.200 | 420 | 33.600 |
| China | | | 680 | 62.700 | 328 | 33.800 |
| France | | | 149 | 11.600 | 41 | 3.220 |
| Japan | | | 205 | 17.500 | 62 | 5.490 |
| Korea, Republic of | | | 287 | 26.100 | 176 | 23.500 |
| Spain | | | 83 | 14.300 | 89 | 14.400 |
| Sweden | | | 109 | 9.280 | 143 | 13.000 |
| **Total** | | | **1955** | **178680** | **1259** | **127010** |

| |
|---|
| Revised. -- Zero. |
| 1Data are rounded to no more than three significant digits; may not add to totals shown. |
| 2Harmonized Tariff Schedule of the United States. |
| 3Less than - unit. |
| Source: U.S. Census Bureau. |

**Table (9):** ZIRCONIUM MINERAL CONCENTRATES: WORLD PRODUCTION, BY COUNTRY1, 2

| Rank | Country | World Production, By Country (Metric tons) Estimate 2009 |
|---|---|---|
| 1 | Australia | 476,000 |
| 2 | South Africa | 392,000 |
| 3 | China | 130,000 |
| 4 | Indonesia | 63,000 |
| 5 | Ukraine | 35,000 |
| 6 | India | 31,000 |
| 7 | Brazil | 18,134 |
| 8 | Viet Nam | 7,000 |
| 9 | Malaysia | 7,000 |
| 10 | Russian Federation | 5,000 |

## 12. Investment Opportunities

No activities of mining to exploit heavy minerals are carried out neither in the past nor at the present. Heavy minerals are open for investment and mining/exploration companies are invited on the basis of detailed exploration, evaluation, processing and exploitation. Heavy minerals package are including zircon (usually associated with hafnium), monazite (rare earth elements) and titanium ($TiO_2$) minerals. It is important to pay attention to evaluation the overall deposits, which possessing high economic value.

## 13. References

Al Dalou, et. al., 2001. Geochemical Prospecting for Minerals Jabal Ladghayn Dubaydib Sheet Area and Jabal Al Qannassiya Sheet Area. NRA. Int. Report.

Brian, M. Coope, 1983. Zircon-in good Shape after a Turbulent Decade, Industrial Minerals, Dec. 1983.

Itamar, A. and et. al., 1999. Mineralogical and Geochemical Characteristics of Rare Earth Elements bearing ordovicians sandstones from Jordan.
Karine pearson, 1999. Grinding & bearing it, a zircon market in sight, industrial minerals May 1999, pp 25-35.

Langtry, E. Lynd, 1985. Zirconium and Hafnium, in Mineral facts and Problems, pp. (1045-1060).

Madanat, M. and Mehyar, N., 1999. Occurrences of Zircon in Wadi Al-Mezrab Area. NRA, 45p.

Manning, D. 1995. Zirconia and zircon in introduction to industrial minerals, pp. 194 – 195.

Masri, A., 1988. The Geology of Wadi Al- Mezrab, Int. report, NRA.

Nawasreh, M., 2001. Investigation of Jordanian Industrial Minerals. PhD thesis, Cardiff University, U.K.

Perrin, C. 1989. Radiometric and geologic Evaluation of Radioactive Anomalies in the Ordovician (Sabllerifex) Beds Rep. 89 - 04.

Yao Shaode, Li Jiye. 1996. Chinese Zircon, in Industrial Minerals, July 1996.

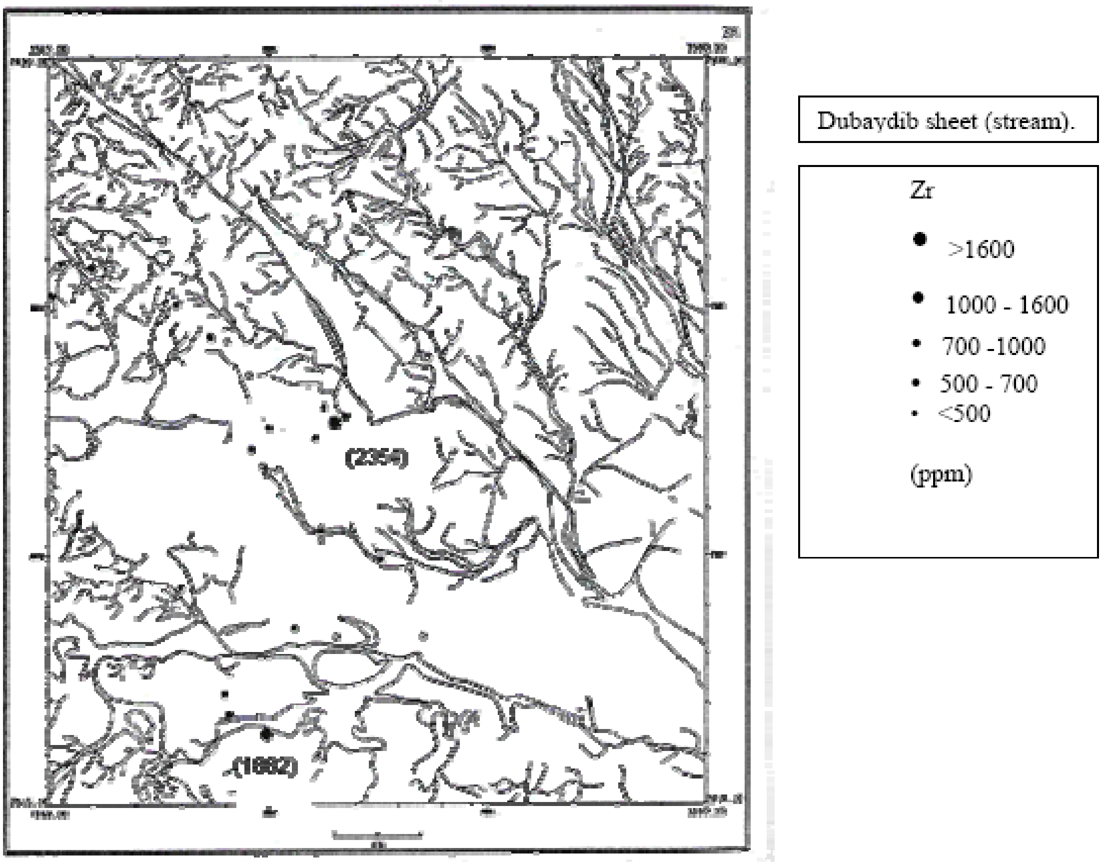
النمري، فواز- دعنا، جمال- الزعبي،هاشم-ابو بكر،عاصم، 1996. الزركون والعناصر الارضية النادرة في منطقة الدبيديب.

وجدي عبد القادر، 1995. مقترح لتنفيذ مشروع تنقيب عن خامات الزركون ومعادن التيتانيوم في جنوب المملكه.

وجدي عبد القادر، 1996. تقرير موجز عن تواجد خامات الزركون ومعادن التيتانيوم (الروتيل وغيره) في جنوب المملكه (تقرير مقترح عمل استطلاعي - متابعه اوليه).

## Appendices

**Appendix (1):** Zr (ppm) Distribution in rocks samples.
**Appendix (2):** Zr (ppm) Distribution in heavy minerals samples.
**Appendix (3):** Map of Zr anomalies from sediments samples.
**Appendix (4):** Map of Zr anomalies from heavy minerals samples.
**Appendix (5):** Heavy minerals deposits.




**Appendix (1):** Zr (ppm) Distribution in rocks samples.

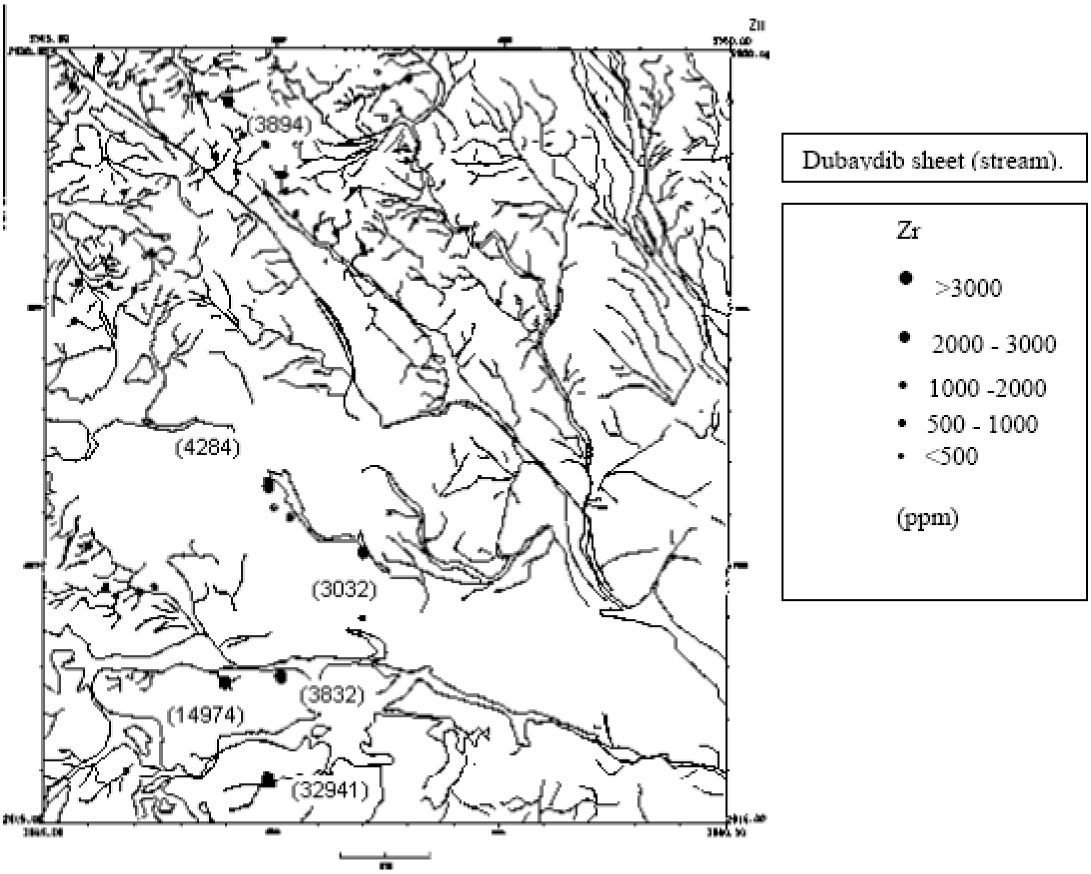
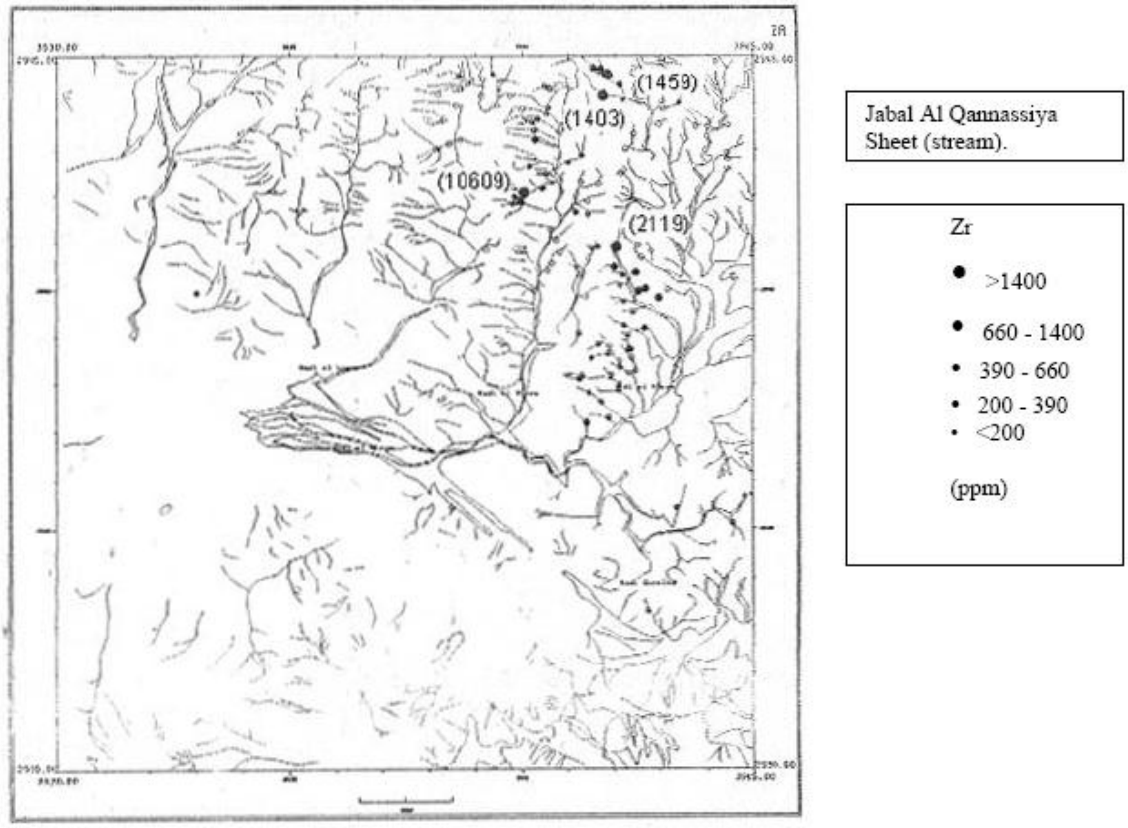
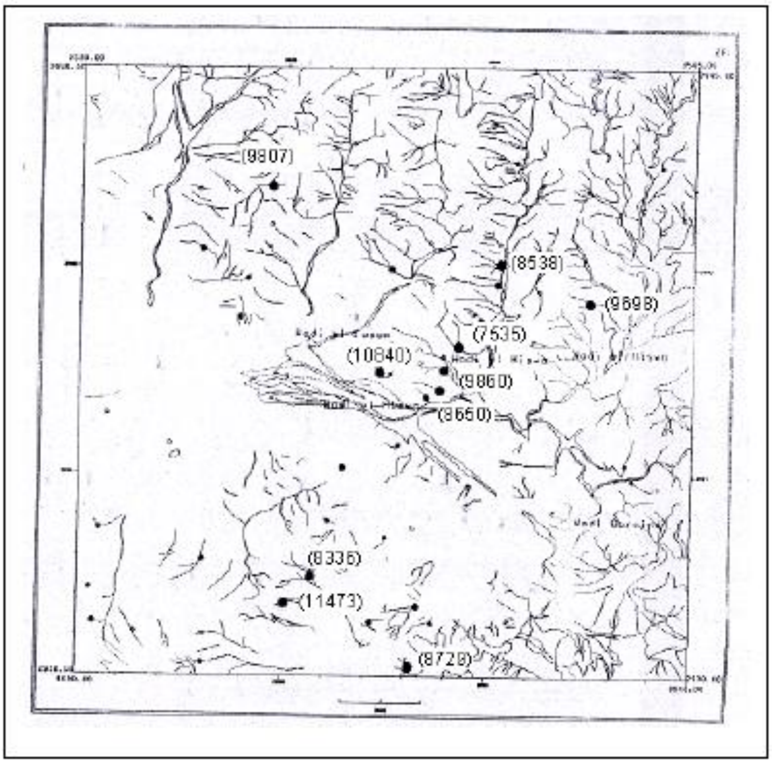



**Figure (2):** Zr (ppm) Distribution in heavy minerals samples.




**Appendix (3):** Zr (ppm) Distribution from heavy minerals samples.




Jabal Al Qannassiya Sheet (stream).

Zr

- >7500
- 5000 - 7500
- 2500 - 5000
- 2000 - 2500
- <2000

(ppm)

**Appendix (4):** Map of Zr anomalies from heavy minerals samples.

Appendix (5) Heavy Minerals Map