MINISTRY OF ENERGY AND MINERAL RESOURCES
Mineral Status and Future Opportunity

OIL SHALE

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1. Introduction

Jordan is one of the developing countries, whose fuel and electricity industries are mostly dependent on imported crude oil. The daily petroleum consumption is around 100,000 bbl*I* day, which becomes a significant load on the GNP and the development of Jordan's economy. So far, the only important indigenous source of energy in Jordan is oil shale.

Oil shale rocks were recognized for the first time since the early time of the Twentieth century in the Yarmouk region north of Jordan near Al-Maqqarin Village. The German Army during the First World War had used it when they installed the first project to produce oil from the Oil Shale to operate the Hijazi Railway. Exploration work started after El Lajjun deposit had been discovered by the German Geological Mission in the 1960s. Intensive exploration activities on oil shale in central of Jordan were carried out during the Eighties as part of the technical cooperation between Natural Resources Authority (NRA) and the German government represented by BGR institute and resulted in delineating other deposits such as Sultani, Hasa and Jurf Ed Darawish. NRA continued its role in exploration and discovered other deposits such as Attarat Um Ghudran, Wadi Maghar, Siwaqa, Khan El Zabib, and El Thammad.

Oil shale is defined as sedimentary rock (mostly carbonates; chalk marl and shale) whose solid immature organic content is insoluble in organic solvents, but forms liquid oil-like hydrocarbons when exposed to destructive distillations of temperatures up to 500-600ºC.

The Jordanian Oil Shale is kerogen-rich, bituminous, argillaceous limestone that was deposited in shallow marine during the Maestrichtian-Danian periods. The origin of the kerogen is the dead plants and animals that found in the ancient seas and lakes during the Upper Cretaceous period and after the burial process, heat and the pressure which caused the change from organic matter to kerogen.

2. Geology of Oil Shale in Jordan

2.1. Origin and Definition

Oil shale is widely distributed in Jordan and can be identified in few outcrops and mostly in the subsurface. The most important Oil shale occurs in the lower part of the Upper Cretaceous Muwaqqar Chalk Marl Formation which outcrops across much of central northern and central southern Jordan. Although the oil shale is widespread, it varies in thickness and oil content. Studies suggest that the hydrocarbons are concentrated in down faulted (graben) elongate basins. Oil shale horizons of less apparent importance occur in the underlying AL Hisa Phosphorite formation and in the overlying Eocene rocks of the Um Rijam Chert Limestone Formation.

Oil shale is defined as sedimentary rock where solid organic content is insoluble in organic solvents, but forms liquid oil-like hydrocarbons when exposed to destructive distillations, i.e. to temperatures up to 500-600 ºC with a minimum oil yield of around 5%.

The Jordanian oil shale are naturally bituminous marls and are varying shade of brown, grey or black with typical bluish light-grey color when weathered. Another characteristic feature is their content of light fine-grained phosphatic xenocrysts.

The organic material of the oil shale consists largely of prebitumen bituminous ground-mass (Huffnagel 1980). This was formed during sedimentation or in the early diagenetic process by mainly microbial influence, from initial plant and animal materials with a lipidic composition.

2.2. Mineralogy and Chemistry of Oil Shale

The principal mineral component of the oil shale is calcite or more rarely quartz together with kaolinite and apatite and, on occasion feldspar, muscovite, Illite, goethite and gypsum as secondary components. Dolomite occurs in some individual carbonate beds as in the Arbid limestone of El-Lajjun.

Table-1 and Table 2 show averages of the chemical analysis, trace and heavy metals of the oil shale rocks in some deposits.

Table (1): Average chemical composition of Oil shale (Modified after Hamarneh, 1998).

Major oxides	Sultani	El-Lajjun	Attarat Um Ghudran
SiO_2%	26.26	16.13	23
TiO_2%	0.13	0.16	0.2
Al_2O_3%	2.87	3.77	2.7
Fe_2O_3%	1.12	1.55	0.9
MnO%	-	0.01	-
MgO%	0.95	0.65	-
CaO%	26.3	30.43	25.6
Na_2O%	0.27	0.1	1.1
K_2O%	1.37	0.00	0.3
P_2O_5%	3.48	3.3	2.4
SO_3%	4.38	4.83	4
LOI%	33.0	38.13	-

LOI: Loss On Ignition

Table (2): Heavy and trace elements in oil shale (Modified after Hamarneh, 1998).

Element (ppm)	Sultani	El-Lajjun
As	17	-
Cu	115	92
Mo	99	73
Ni	139	167
Pb	11	7
Rb	14	10
Sn	235	n.d
Sr	707	1015
Th	10	6
U	25	29
W	10	n.d
Y	27	33
Zn	649	451
Zr	46	36
Ba	45	113
Co	15	9
Cr	267	431
La	28	27
V	268	162

While table 3 summarizes the average analysis of some properties such as oil content, organic matter and physical properties.

Table (3): Summary of Chemical and physical properties

	El-Lajjun	Sultani	Attarat Um El-Ghudran	Wadi Maghar*	Jurf Ed Darawish
Av. oil content (wt%)	10.5	7.5	8	6.8	5.7
Total Organic matt. (wt%)	22.1	21.5	23.16	20.8	18
Calorific value (kcal/kg)	1590	1210	--	780-1270	864
$CaCO_3$ (wt%)	54.3	46.96	52.2	48	69.1
SO_3 (wt%)	4.8	4.4	4.9	4.2	4.3
Bulk density (g/cm^3)	1.81	1.96	1.8	2.03	2.1
Moisture (wt%)	2.43	2.6	1.71	2.9	2.8

* Information is from few boreholes drilled in the area.

Three main formations could be identified in center of Jordan in areas where oil shale deposits were found. They are (from old to young) Al Hisa Phosphorite, Muwaqqar Chalk Marl and Umm Rijam Chert Limestone Formations. The stratigraphic and lithological distribution of these formations is as in the following paragraphs.

Structurally, the area between Siwaqa and Jurf Ed- Darawish forms part of an east Jordanian block-faulted zone. Cretaceous and Tertiary sediments dip gently towards the east and south-east to the El-Jafr basin and are cross cut by a system of faults trending north–west and north –northwest (Bender 1968). The available information from exploratory drilling of the surveyed oil shale deposits suggest that oil shale bodies consist of shall lenses and forming elongated big ones. However, the deposits are bounded by faults to varying degrees.

2.3. Uses and Industrial Applications of Oil Shale

The main utilization and use of oil shale as energy resource is to produce: -

- Oil and gas by surface retorting methods, chemical extraction and in-situ heating process. The oil and/or gas could be upgraded and refined to produce petroleum products or the crude oil could be burned to generate electricity.
- Power generation by the means of direct combustion techniques (i.e. directly burning the ground oil shale).

As by-products, the retorted oil could be utilized in the petrochemical industry to produce plastics, rubbers, chemicals, insecticides, .etc. In case of Jordanian oil shale, a considerable percentage (8-10%) of sulphur exists in the oil and this could be recovered for uses in industry. The heavy metals are significantly enriched in oil shale and mostly returned to the spent shale and ash. These metals could be recovered (i.e. Vanadium, Molybdenum, Chromium, tungsten zinc, nickel, copper, lanthanum and cobalt). Spent shale and ash could be used in the cement manufacturing, road construction, asphalt production, and soil conditioning.

3. Oil Shale Deposits

Jordan possesses a very large energy resource in its vast reserves of oil shale (over 65 billion tons of geological reserves) which is ranked as the **8th** country in the world for its shale oil reserves (Table 5). There are 23 known sites of shallow and deep deposits of oil shale occurrences have been reported in most of the Jordanian districts.

The geological studies and exploration for water, oil, and minerals showed that oil shale is widely distributed in many parts of the country, either cropping out at the surface or encountered in the exploratory wells.

The following are the main localities of oil shale:

A. In Northern Jordan (Irbid District), for example at Yarmouk River, Buweida & Beit Ras villages, and at the Risha Rweished area in the northern east panhandle.
B. In Central Jordan (Karak District), in the area between Husseinieh in the south and Daba'a in the north along the desert highway, and also in the EI-Lajjun area and in Madaba District at Eth Thamad area.
C. Southern Jordan (Ma'an District), at the Jafr area.

From the above-mentioned 23 deposits, Eight of these deposits i.e. El- Lajjun, Sultani, Jurf Ed–Darawish, Attarat Umm Ghudran, Wadi Maghar, Siwaqa, Khan Al – Zabib & Eth–Thamad, were investigated to different degrees (Fig. 1). Among these deposits, El-Lajjun, Sultani, Attarat Um Ghudran and Wadi Maghar deposits are of major deposits of commercial scale interest. They represent the core for any future investment interest in central of Jordan. The following description will highlight these deposits.

3.1. El-Lajjun Deposit

El-Lajjun deposit is located approximately 110 km south of Amman and mid way along the asphaltic road between Karak and Qatrana. The area is 38.4 km^2 and bounded by the following coordinates (Table 4).

The oil shale deposit consists of limestone, marl, cherts, shales and phosphates of Campanian - Maestrichtian. It is situated in a north -south trending graben.

The average thickness of oil shale is 30 m. The average stripping ratio is approximately 1. The proven reserve amounts to 1.2 billion tons of oil shale containing oil content of approximately 115 million tons.

One hundred and seventy three (173) boreholes were drilled during the periods 1968/1969, 1979, and 1982-1985. In further investigation, another 22 boreholes were drilled by Suncor Company during the time of 1998-1999.

In the investigated area the main structural feature is the El-Lajjun graben, controlling a morphological depression bordered from east and west by faults striking generally north – south.

Table (4): The coordinates of El-Lajjun area (Pal. Belt).

Point	East	**North**
1	232 000	1074 000
2	232 000	1072 000
3	231 000	1072 000
4	231 000	1068 600
5	230 200	1068 600
6	230 200	1062 500
7	232 400	1062 500
8	232 400	1065 000
9	234 000	1065 000
10	234 000	1069 000
11	235 000	1069 000
12	235 000	1074 000

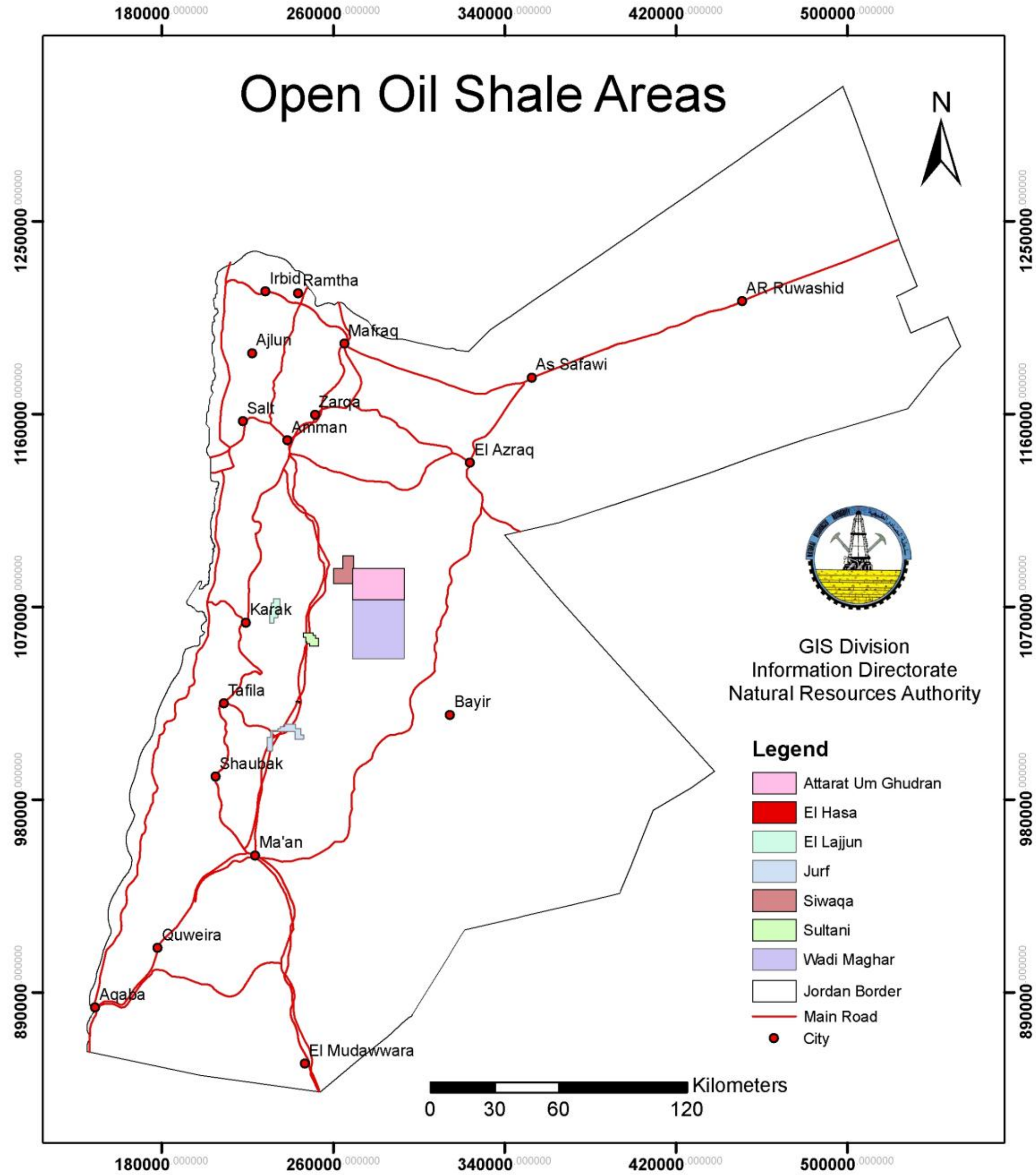

Figure (1): Location map of the major oil shale deposits.

Table (5): World Shale Oil Reserves (Qian, 2003).

No	Country	Shale Oil Reserves Million Tons
1	USA	304000
2	Russia	39000
3	Zaire	14310
4	Brazil	12000
5	Morocco	7739
6	Canada	6300
7	Australia	4080
8	**Jordan**	**4000**
9	China	2483
10	Estonia	2457
11	Italy	1431
12	France	1000
13	Thailand	857
14	Egypt	816
15	Israel	714
16	Ukraine	600
17	Sweden	450
18	Kazakhstan	400
19	England	500
20	Burma	286
21	German	286
22	Yugoslavia	220
23	Mae Sot	200
24	Turkey	147
25	Belgium	100
26	Luxemburg	100
27	Argentine	57
28	Armenia	44
29	Mongolia	42
30	Spain	40
31	New Zealand	35
32	South Africa	19
33	Bulgaria	18
34	Hungary	8
35	Poland	7
36	Madagascar	5
37	Chile	3
TOTAL		**404754**

3.2. Sultani Oil Shale Deposit

The area was first geologically mapped at a scale of 1:25.000 by Heimbach (1962 & 1964) and was included also in the phosphate exploration project carried out by the NRA and United Nations (Sunna', 1974). Sultani deposit was also included in the NRA and BGR exploration studies of oil shale (Huffnagel 1980). In 1987, NRA carried out a further detail drilling program to delineate the deposit in the area (Project Staff, 1987).

The deposit is located at about 115kms south of Amman just adjacent to the desert highway. It is situated in a NNW - SSE oriented graben structure 8 km long and 2-5 km wide bounded and transected by faults mostly of the same orientation. The area is 31.2 km^2 and bounded by the following coordinates (Table 6).

Table (6): The coordinates of Sultani area (Pal. Belt)

Points	East	North
1	246 000	1058 000
2	246 000	1056 000
3	247 000	1056 000
4	247 000	1054 000
5	247 600	1054 000
6	247 600	1053 000
7	248 800	1053 000
8	248 800	1051 800
9	253 000	1051 800
10	253 000	1055 600
11	251 600	1055 600
12	251 600	1057 000
13	250 400	1057 000
14	252 000	1058 000

The overburden composes of Cretaceous, Tertiary and Quaternary formations. The type of rocks are limestone, phosphates, chalk marl, cherts, basalts, wadi and mud flat sediments of Campanian Maestrichtian, Paleocene and Holocene ages.

The characteristics of the Sultani oil shale deposit are summarized in Table 7.

Table (7): Sultani oil shale deposit.

Area of the deposit	31.2 km^2
Geological reserves	1130 Mt
Indicated reserves	989 Mt
Thickness of Oil Shale	2 -65 m
Average thickness	31.6 m
Thickness of overburden	34 – 86 m
Average OB	49.3 m
Stripping Ratio (Average)	1.6 (0.9-3.2)
Oil content	3.2 - 10.2%wt
Average oil cont.,	7.5 %wt.
Oil density (15^0C)	0.964
API	15

The calcareous bituminous marl (oil shale) of Sultani is generally gray, gray brown, and brown. It is thin bedded and laminated and has a distinct bituminous smell, phosphatic material is present. The oil shale is calcareous marl with calcite as main component and varying amounts of quartz, clay and occasionally phosphatic material.

Table (8): Chemical Composition and trace elements of Sultani oil shale deposit (Project Staff, 1987)**.**

Component.%	Average	Min.	Max.
SiO_2	26.26	6.31	60.45
TiO_2	0.13	0.04	0.26
Al_2O_3	2.87	1.10	6.48
Fe_2O_3	1.12	0.53	2.33
MgO	0.95	0.09	7.54
CaO	26.3	10.81	43.34
Na_2O	0.27	0.04	0.93
K_2O	0.37	0.17	0.62
P_2O_5	3.48	1.37	8.42
SO_3	4.38	2.05	6.27
LOI	33.0	15.95	42.66
As (ppm)	17	15	34
Cu	115	59	319
Mo	94	12	217
Ni	139	55	252
Pb	11	<5	143
Rb	14	8	25
Sn	22	20	27
Sr	707	404	1131
Th	10	5	17
U	25	14	40
W	10	5	49
Y	27	150	1339
Zr	46	29	94
Ba	46	29	94
Co	15	2	32
Cr	267	120	385
La	28	2	173
V	268	78	596

3.3. Attarat Umm Ghudran Oil Shale Deposit

During the exploration activities of the geological mapping project carried out by NRA, the oil shale deposit was for the first time reported by Sunna' in 1985.A detailed report with drilling campaign was prepared to delineate the deposit by Haddadin & Abu Qudireh in 1988.

This large oil shale deposit is located 40 km east and southeast of Qatrana. An asphalted road (27) km branching off the desert highway from a point at a distance 70km from Amman reaches the western border of the ore body.

The area is located within the Upper Cretaceous chalk marl belt. The rocks forming the overburden and the deposit are Marl chalk, limestone and chert.
The thickness of oil shale varies from 10 to 60+ in and the thickness of overburden varies from 45 to 80+m.

The deposit features low mining costs and it is suitable for open pit/ cast mining: This shallow deposit render favorable conditions for further exploitation both for retorting and direct combustion.

The depth of the drill holes varies from 85 to 145 meters. However, current investigations carried out by NRA indicate thicker oil shale bed and reached more than 90m in one of the boreholes (Verbal communications with project staff). The spacing between the boreholes ranges from 4 to 6 km throughout the investigated area. The area is about 348 km^2 and bounded by the following coordinates (Table 9).

Table (9): The coordinates of Attarat Umm Ghudran area (Pal. Belt).

Point	East	North
1	269 000	1088 000
2	269 000	1073 500
3	293 000	1073 500
4	293 000	1088 000

The chemical analysis was carried out on the core and cutting samples. The oil content varies between 4-13% with average oil content of about 8.1%. The sulphur content varies from 1.93 to 5.3% and the moisture content varies from 0.4 to 2.3%. X-Ray analysis indicates that the main components of the oil shale are; calcite and quartz and the secondary mineral apatite. The calcium carbonate content ranges from 21 to 55%. The organic carbon ranges from 9 to 19 **%.**

The characteristics of the Attarat Um Ghudran oil shale deposit are summarized in table 10.

Table (10): Characteristics of Attarat Um Ghudran oil shale deposit.

Area	348 km^2
Thickness of oil shale	10 – 90+m
Average thickness of Oil shale	45m
Thickness of overburden	45 – 62+m
Average thickness of overburden	53.2m
Stripping Ratio (Average)	1.2
Geological reserves	-
Indicated reserves	24500 (Mt)
Oil content of indicated reserves	1960 (Mt)
Number of drilled boreholes	53 + (22*)
Average oil yield	8%
Moisture content,	1.7%
Ash content	53.2%
CO2	18.9%
Sulphur	2.6%

* Current drilling campaign.

3.4. Wadi Maghar Oil Shale Deposit

The deposit is located approximately 35 km south east of Qatrana town. This deposit is the extension of Attarat Umm Ghudran to the south. This deposit shows even larger reserves of oil shale, but rather of lower quality than Attarat Umm Ghudran. The area is about 660 km^2 and bounded by the following coordinates (Table 11).

Table (11): The coordinates of Wadi Maghar area (Pal. Belt).

Point	East	North
1	269 000	1073 500
2	269 000	1046 000
3	293 000	1046 000
4	293 000	1073 500

The area is located within the Upper Cretaceous Chalk Marl Formation. This oil shale was explored during the geological mapping activities (Sunna' 1985). NRA made further and detailed investigations of the deposit (Haddadin & El Khatieb, 1986). The thickness of the oil shale varies from 10 - 61 m. The thickness of overburden ranges from 32.5 to 50 m. The rocks forming the overburden and the deposit are: Marl, chalk, limestone and chert. The estimation of the reserves was based on the information derived from cuttings of boreholes covering a huge area. The characteristics of the Wadi Maghar oil shale deposit are summarized in table 12.

Table (12): Characteristics of Wadi Maghar oil shale deposit.

Area of the deposit,	660 km^2
Oil shale Geol. Reserve (Mt)	31600
Shale oil (Mt)	2148
Oil shale Indicated Reserve(Mt)	21500
Shale oil (Mt)	1462
Thickness of oil shale (m)	10 - 61
Average thickness of Oil shale (m)	40
Thickness of overburden (m)	32.5-50
Average thickness of overburden (m)	40.5
Stripping Ratio (Average)	1
Average oil yield	6.8 %
Moisture content,	2.7 %
Ash content	57.5 %
CO2	19.9%
Sulphur, wt%	0.9-3.5
Av. Sulfur	2.4%

3.5. Khan Az Zabib Deposit

The deposit is located approximately 45 km south-south east of Amman. The area is about 116 km^2 and delineated by the following coordinates (Table 13). The oil shale of this deposit is relatively deep when compared to first four deposits. Only six boreholes were drilled in this area by Shell Company in 1996.

Table (13): The coordinates of Khan Az Zabib area (Pal. Belt).

Points	East	North
1	245 000	1110 500
2	261 000	1110 500
3	261 000	1104 000
4	251 000	1104 000
5	251 000	1102 000
6	245 000	1102 000

3.6. Jurf Ed Darawish Deposit

The deposit is located approximately 145 km south of Amman and close to the Jurf Ed Darawish town and crossing the main high way to Aqaba. The deposit was explored by NRA and BGR exploration studies (Huffnagel 1980). The area is about 90.2 km^2 and delineated by the following coordinates (Table 14). Average oil content is 5.7% and average thickness of oil shale and overburden is 68 and 47m respectively. Sulphur content is the lowest of all other deposits or close to Maghar deposit with average calorific value of 864 Kcal/kg.

Table (14): The coordinates of Jurf Ed Darawish area (Pal. Belt).

Points	East	North
1	237 300	1015 400
2	237 300	1014 300
3	235 300	1014 300
4	235 300	1013 350
5	234 000	1013 350
6	234 000	1012 400
7	230 600	1012 400
8	230 600	1009 300
9	229 200	1009 300
10	229 200	1003 000
11	233 400	1003 000
12	233 400	1010 500
13	240 100	1010 500
14	240 100	1008 400
15	246 200	1008 400
16	246 200	1010 500
17	244 700	1010 500
18	244 700	1013 350
19	242 400	1013 350
20	242 400	1015 400

3.7. Siwaqa Deposit

The deposit is located approximately 70km south of Amman. The area is about 102.5 km^2 and delineated by the following coordinates (Table 15).

Table (15): The coordinates of Siwaqa area (Pal. Belt).

Points	East	North
1	269 500	1094 000
2	264 500	1094 000
3	264 500	1088 000
4	260 000	1088 000
5	260 000	1081 000
6	269 500	1081 000

3.8. El Hasa Deposit

The deposit is located approximately 135km south of Amman and crossing the main high way to Aqaba. It is very small deposit and close to the El Hasa town. The area is about 1.3 km^2 and delineated by the following coordinates (Table 16).

Table (16): The coordinates of El Hasa area (Pal. Belt).

Points	East	North
1	242 600	1026 250
2	242 600	1025 900
3	243 700	1025 900
4	243 700	1025 200
5	244 400	1025 200
6	244 400	1026 250

3.9. Eth Thamad/ Madaba Area

The deposit is located approximately 45km south-south west of Amman. The deposit is actually west of Khan Ez Zabib deposit. The area is about 65.6km^2 and delineated by the following coordinates (Table 17).

Table (17): The coordinates of Siwaqa area (Pal. Belt).

Points	East	North
1	245 000	1110 500
2	240 900	1110 500
3	240 900	1112 500
4	228 200	1112 500
5	228 200	1109 000
6	233 600	1109 000
7	233 600	1108 000
8	245 000	1108 000

4. Summary of Previous Technical Activities

The Natural Resources Authority (NRA) has done extensive geological studies to delineate the oil shale reserves at El-Lajjun, Sultani, Attarat Umm Ghudran, and Wadi Maghar deposits. In addition, the Government of Jordan contacted and commissioned different foreign governmental institutes and companies for technical assistance in order to study, test and exploit oil shale for power generation and crude oil production.

In 1980, NRA commissioned a study by the BGR (German Federal Institute) for the evaluation of El-Lajjun, Jurf Ed-Darawish, El-Hisa and Sultani deposits in central Jordan, and a techno-economic pre-feasibility study for an oil shale retorting complex using Lurgi -Ruhrgas Process.

The results of this study indicated that EL-Lajjun oil shale deposit shows continuity over an area of 18 km^2 with about 1.2 billion tons of oil shale reserves containing some 115 million tons of shale oil. The deposit was suitable for open cast mining and could support a 50,000 bbls/day oil shale retorting complex for about 25 years.

In October 1980. NRA commissioned Phase I of the two pre-feasibility studies for:

- An oil shale complex using the Lurgi-Ruhrgas (LR) process for extracting 50,000 bbls/day of shale oil.

- Installation of a power plant of 300 MW capacity utilizing El-Lajjun oil shale by means of Lurgi's circulating fluidized bed combusting process (CFB).

The studies were completed in 1982 and concluded that both options were technically viable.

In 1985, another agreement was signed with the China Petrochemical International Company (SINOPEC) to carry out a proving test in order to determine whether a Fushun- Type retort would be technically feasible for processing El-Lajjun oil shale. The final report of the proving test was submitted in 1986 and the results emphasized that the Fushun - Type retort was quite suitable for processing E1-Lajjun oil shale and that the results were promising.

SINOPEC International proposed the installation of a 100 tons/day Fushun-Type retort at a cost of US $6 million. Cooperation with SINOPEC was halted due to high operation costs.

In March 1986, NRA contracted with the German Consortium Lurgi-Klockner to revise and update the previous study. The update study consisted of a revised geological study, revised prefeasibility study, performance of retorting pilot tests, CFB combustion tests on 200 tons of El-Lajjun oil shale sample in Germany, and hydrogeological studies for water resources. In addition, Lurgi-Klockner also undertook an assessment of the possibility of burning the spent shale in the electric power generation plant of 350 MW by adopting Lurgi's CFB process.

Since 1986, the Jordan Electricity Authority (JEA) and NRA together with the assistance of USAID and CIDA (Canadian) and Brown Boveri and Company (Swiss), has been investigating the possibility of exploiting Sultani oil shale for direct combustion for power generation. That effort was to utilize the state of the art Circulating Fluidized Bed (CFB) technology. Performance tests on Sultani oil shale carried out by B.B.C, Lummus/Combustion Eng. and Bechtel Pyropower (funded by CIDA and USAID) had demonstrated that Sultani oil shale was suitable as fuel for direct combustion in CFB power plants.

Although oil shale retorting has a long history, the research conducted by the Americans and the Europeans after the 1973 oil crisis resulting high prices led to further research and development of modern oil shale retorting processes. Lurgi technology and other processes based on tar sands in USA and Canada has proven the technology on a pilot scale and the current lower level of oil prices has rendered commercial development and operation of such plants uneconomic.

As regards to CFB technology, in the Eighties of last Century more than 60 plants were operating on low calorific value fuels. However, none of these plants have been operated on oil shale. Further, the technical problems involved in the disposal and the utilization of spent ash have not been analyzed in detail. In 2004 Foster Wheeler Company commercial and proven constructed and installed CFB boilers at Narva plant in Estonia.

5. Mining Aspects

There are many issues that should be considered when time comes to start mining and extraction of oil shale. All data and information gathered from the geology, topography, geochemistry, mineralogy, drilling, engineering properties of the rocks, surface and underground water situation, climate, infrastructure, and the environment on the surrounding areas of the deposit should be compiled and studied in order to design, proceed and maintain a successful mining plan.

5.1. Overburden

All rocks overlying the oil shale are considered as the overburden. Most of the rocks of the overburden consist of the upper sequence of the Muwaqqar Formation in addition to a few meters of gravel and wadi sediments and some places of the remnants of Umm Rijam Chert Limestone formation.

The upper Muwaqqar sequence mainly consists of chalk, chalky limestone, marl and marly limestone with some concretions of limestone. These materials are soft to moderate in hardness. At the topmost of the overburden, gravels of Pleistocene and wadi sediments consist of limestone, chert, basalt are present in thickness ranging between 2-10m at the most (see Figs. of El-Lajjun outcrop and Sultani open pit).

The thickness of overburden ranges from 15–62 meters at El-Lajjoun, 34–86 meters at Sultani, 45–62 meters at Attarat Umm Ghudran, and 32.5 –50 meters at Wadi Maghar.

5.2. Ore Body of the Oil shale

Based on the detailed geological information gained from El- Lajjun, Sultani, Attarat Umm Ghudran and Maghar deposits, the oil shale ore bodies are in the shape of elongated big lenses. Although the upper and lower surfaces of these lenses are undulated, but lay as a horizontal bed-like.

The chalk and chalky marl rocks become hard to moderate hard due to bituminization. However, there is a proportional relationship between hardness and organic carbon content in the oil shale ore body.

The average thickness of oil shale deposits vary from 30 m in the El-Lajjun area to nearly 100m in the Attarat Um Ghudran area.

5.3. Reserves

Reserves have been delineated and estimated based on core and cutting samples from exploratory boreholes drilled in the areas. It could be stated that El-Lajjun and Sultani deposits are ranked as calculated reserves while Umm Ghudran, Wadi Maghar and Jurf Ed Darawish deposits are considered indicated and inferred reserves (Table 18).

Table (18): Estimated and calculated reserves of the oilshale deposits.

	El-Lajjun	Sultani	Attarat El-Ghudran	Wadi Maghar	Jurf Ed Darawish
Area (km^2)	20.4	24	348	660	90.6
Av. thickness oil shale (m)	29.6	31.6	45	40	63.8
Av. thickness of OB (m)	28.8	69.3	53.2	40.5	47.3
Stripping Ratio (average)	1	1.6	1.2	1	-
Geological reserves (Mt)	1196	1130	(24500)*	31600	8000
Calculated & Indicated reserve (Mt)	1170	989	(24500)*	21600	2500

* NRA current investigation indicates substantial amount than this.

5.4. Mining Method

A geological estimate of oil shale reserves of the five deposits is **66.4** billion tons, while the calculated and indicated reserves are **50.7** billion tons (See Table 18). It is obvious that there is huge reserves exist, but most important is the mineable reserves in these deposits with favorable characteristics for large-scale economical development. The deposits are characterized by the following criteria:

- Favorable conditions for surface mining such as low stripping ratio (1:1 in general), minimal overburden, absence of significant structural disturbances, and absence or limitation of intrusive rock bodies.

- Properties of oil shale, relatively high oil content and calorific value, low moisture content, and acceptable properties for processing.

- Adequate reserves to justify a commercial processing plant.

- Located in remote or thinly populated areas and have good roads connected with asphalted highways.

- The availability of adequate amounts of deep ground water underneath the deposits for the industrial utilization.

- Among the deposits in central Jordan El-Lajjun and Sultani were selected for feasibility studies.

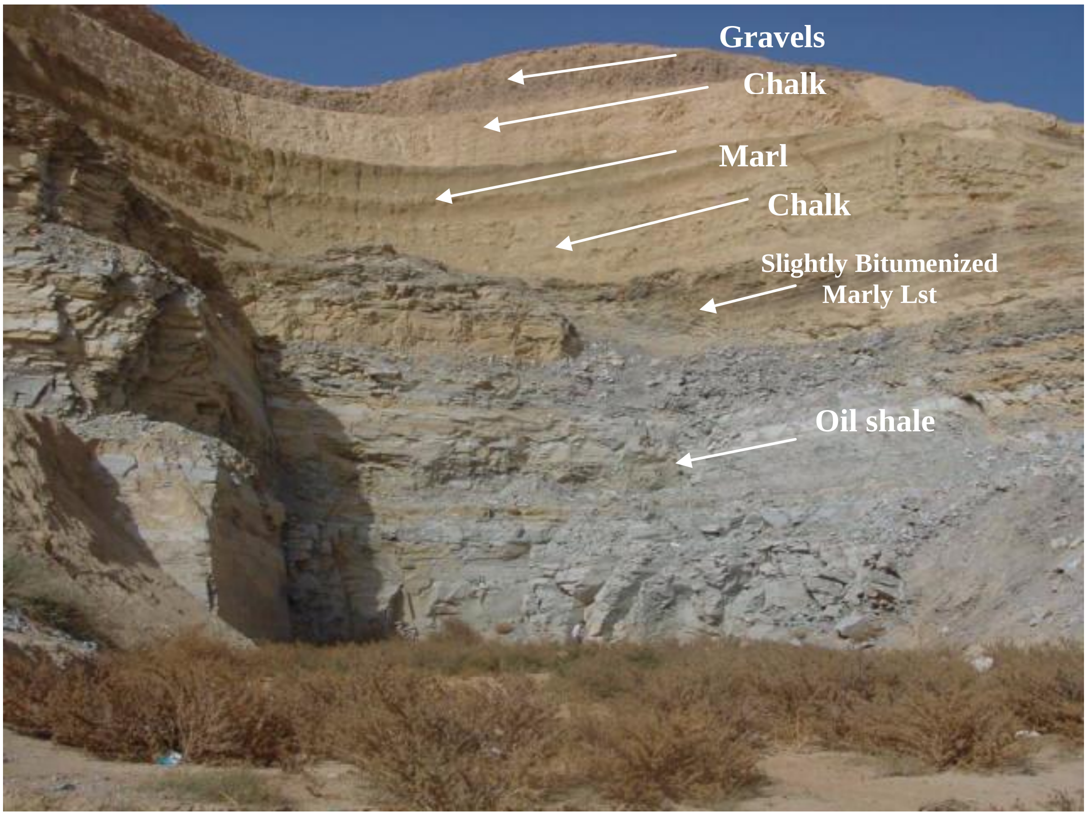

Figure (2): Oil Shale outcrop in El-Lajjun deposit.

Figure (3): Open pit in Sultani deposit.

Since the stripping ratio is low (1 in general, 1.6 only in Sultani deposit), beds are horizontal and structurally undisturbed, and the topography is slightly flat or little undulated, surface mining could be adapted and the cost effective mining method will be Open cast method for such deposits.

This method will require removal of the material in strips that could be designed in perpendicular to the elongated side of the deposit. The removed material of the second strip could be back filled into the one before. However, the initial stage of the overburden removal should be transferred to outside site in order to reserve room for the second strip removal.

Draglines are recommended for overburden removal similar type of work in Jordan Phosphate mines (Close to Sultani and Maghar deposits). These machines are capable of removing huge quantities in short time since the overburden rock types are soft to moderate in hardness.

The oil shale will be mined by drilling and blasting operations. Bulldozers and excavators could be used to extract the oil shale rocks with the help of big shovels and back trucks for transporting the oil shale material to the conveyer belts. In the initial stages, the mined oil shale should be stockpiled to maintain enough material to the processing plant.

The processing plant for retorting the oil shale should not be far from the mining site. The run-off mine oil shale is transported by the conveyer belts to the oil shale stockpile site or supply directly the crushing plant and then to the processing plant.

Spent shale (shale rocks after oil extraction) should also be stockpiled in a place close to the mine area. It could be used in the cement manufacturing, road construction, asphalt production, soil conditioning and possible heavy metals extraction. The rest of the spent shale should be back filled to the excavated area and covered by the overburden material.

6. Oil shale Technologies and Exploitation Worldwide

As stated from the uses of oil shale as source of energy, the two main basic categories have been defined: producing crude oil and generating electricity. More than 100 years, oil shale has been used as fuel and source of oil in small quantities and in few countries in the world. Technologies to exploit oil shale for both uses have been slowly and partially developed compared to other industries such as conventional oil industry. This is due to many reasons such as the cost of the produced oil from oil shale compared to the conventional oil, historically low price of oil and the environmental issues.

6.1. Crude Oil Production

There are many types of technologies being used or tested in the world. Few countries such as Russia, Estonia, Barzil, China and USA have developed several oil shale retort technologies. The most matured retorts are the Estonian Kivitar and Galotar retorts, Brazilian Petrosix retort and Chinese Fushun retort. Other developing one is the Alberta Taciuk Process (ATP). A different type of process is the In-situ conversion technique, which involves heating underground oil shale rocks for a period of time to a certain temperature in order to convert the kerogen into liquid oil and gas. This process is still under investigation.

In the following is a list of these technologies:

Technology	Country	Status
Fushun retort	China	Matured + developing
Kiviter retort	Estonia	Matured + developing
Galoter retort	Estonia	Matured
Petrosix retort	Brazil	Matured + developed
Taciuk (ATP) retort	Canada	Developing
In-situ conversion process	USA	Under Testing

Table (19): The following table shows oil quantities produced from oil shale in year 2002 (Qian, 2003).

Country	Plant	Retort	Shale Oil (tpa)
China	Fushun Bureau Huadian Sunde	80 Fushun (100/d) 1 Fushun (100t/d)	100,000 3,000
Estonia	Viru Keemia Kohtla Jarve Kivioli Estii Power Plant	2 Kiviter (1000t/d) & 45 Generator (100t/d) 8 Generator (100t/d) 2 Galoter Retort (3000t/d)	200,000 20,000 80,000
Russia	Slantsy Syzran	36 Generator (100t/d) 8 Generator (30t/d)	200,000 2,000
Brazil	Petrobras	1 Petrosix (2200t/d) 1 Petrosix (6200t/d)	160,000
Australia	SPP Stuart	1 ATP (6000t/d)	200,000

6.2 Power Generation

Oil shale is used for direct combustion to produce steam and electricity. Development in the direct combustion utilizing oil shale was much better than that in the retorting. Currently, commercial burners and boilers could be produced and could work safely and environmentally in Europe.

Three technologies have been utilized in the world:

1. Pulverized Combustion (PC): Four power stations have been operated in Estonia; Estonia power plant (1600MW), Baltic power plant (1290MW), Kohtla Jarve power (37MW) and Ahtma power (30MW) for many years. Estonia is self sufficient in electricity from its oil shale power plants.

2. Fluidized Bed Combustion (FBC): Particulate commercial fluidized bed combustion plant has been operated in Germany for many years. The oil shale is burned and the ash is used for cement production.

3. Circulated Fluidized Bed (CFB): Two new burners have been installed in Estonia Power Plant by Forster Wheeler Company. These commercial power burners have been installed and used in China and Isreal.

Table (20): Commercial production of power generation using oil shale in the world 2002 (Qian, 2003).

Country	Power Plant	Oil Shale t/y	Capacity KW	Type of Tech.
China	Huadian PP	300,000	12,000	CFB
Germany	Dotternhausen Cement Work	270,000	7,500	FBC
Estonia	Baltic PP Estonia PP Kohtla Jarve PP Ahtma PP	5,000,000 5,000,000	1,290,000 1,600,000 37,000 30,000	PC PC + CFB PC PC
Israel	Pama	400,000	40,000	CFB

7. Investment Opportunities and Outlook

Oil shale in Jordan is considered to be one of the good oil shale in the world in terms of oil content and other conditions. However, oil shale in central of Jordan is characterized by: -

- Huge reserves relatively close to each other
- Good quality in terms of oil content and type of host rock.
- Offering favorable mining conditions:
  - Shallow and suitable for surface mining.
  - Low Stripping ratio (Av. 1:1 in general).
  - Beds are horizontal and structurally undisturbed.
  - Soft to moderate overburden rocks.
- Located in remote or thinly populated areas
- Have good roads connected with asphalted highways.

Interested companies in utilization oil shale are welcomed on the following basis:

a) Express interest by writing to Natural Resources Authority (a governmental entity).

b) Provide solid evidence of financial and technical capabilities.

c) MOU could be signed with the company to carry out the necessary investigations to determine the vitality of the project.

d) Apply for a mining concession under the “Mineral Agreement” provided the successful technical and feasibility studies of the project.

e) Approval of the Ministry of Energy and Mineral Resources (MEMR).

f) The Board of Ministers approves the final concession agreement.

g) Approval of the House of Parliament.

Currently, the government has started to implement a comprehensive strategy for oil shale development. This is due to many facts such as the dramatic rise of the global oil prices which has directly affected the government's budget and Jordan's GNP and the willingness of interested investors and companies whom approached MEMR to exploit oil shale for producing crude oil and power generation. The main features of this strategy are in the following:

7.1. Crude Oil Production

A specialized technical team has been set up in MEMR to gather, collect, prepare and digitize all the technical studies and data of all oil shale occurrences in Jordan. The aim is to facilitate and to provide technical support for investors and interested companies in oil shale.

The Board of Ministers has assigned a Special Tender Committee in order to call proposals from interested companies in the oil shale utilization, negotiate, and sign memorandum of understanding (MOU) and commercial agreements.

A comprehensive feasibility study on all types of oil shale technologies has been started by a well known American consultant company and commissioned by the government through a technical grant from the United State Development Agency (USTDA).

Starting negotiation and signing MOU with Shell Company that leads to granting a concession through a commercial agreement using in-situ process to utilize oil shale for crude oil production. The concession will be on deep oil shale occurrences in Jordan excluding the shallow occurrences in central of Jordan, which is allocated for surface mining and retorting techniques (Fig. 4). The Shell process is called In-situ Conversion Process (ICP), which basically is based on heating the rocks in place (underneath the ground) in order to convert the Kerogen into gas and oil that could be pumped through production wells.

Call for proposals were sent to 14 interested companies whom actually approached NRA previously for oil shale. MOU's were signed with three qualified companies on specific three areas in Lajjun oil shale deposit using surface retorting for crude oil production (Fig. 5). The MOU's will last for 12-20 months started from November 2006. The companies are:

- Jordan Energy and Mining Ltd. Area –A (Lajjun).
- International Corporation for Oil Shale Investments. Area –B (Lajjun).
- Oil Shale Energy of Jordan. Area –C (Lajjun).

7.2. Direct Combustion

An MOU was signed with Jordan Cement Factories Company to burn oil shale as a source of energy and at the same time using the ash in the cement manufacturing process.

Although priority has been set for oil production in Jordan, oil shale could be utilized for power generation using CFB direct combustion technique is open for investment since this technology has been commercially approved in countries like Estonia.

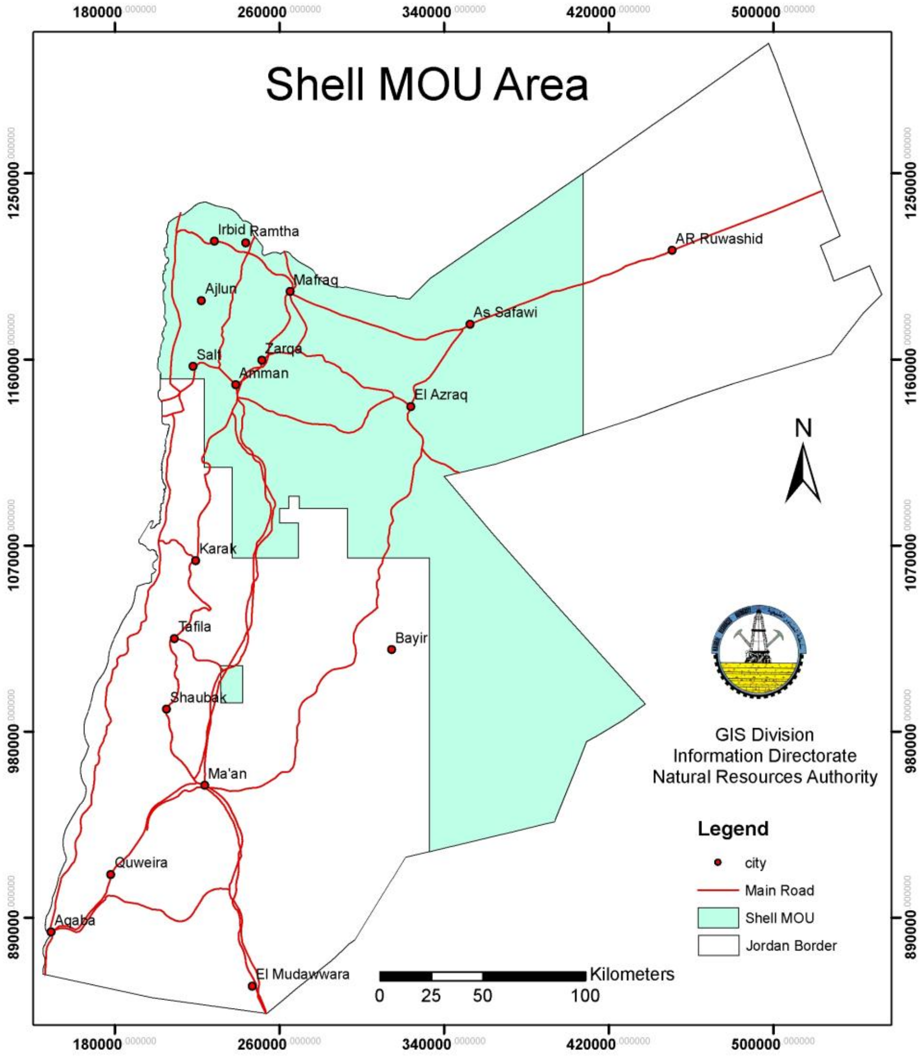

Figure (4): Location map of the MOU of Shell Company.

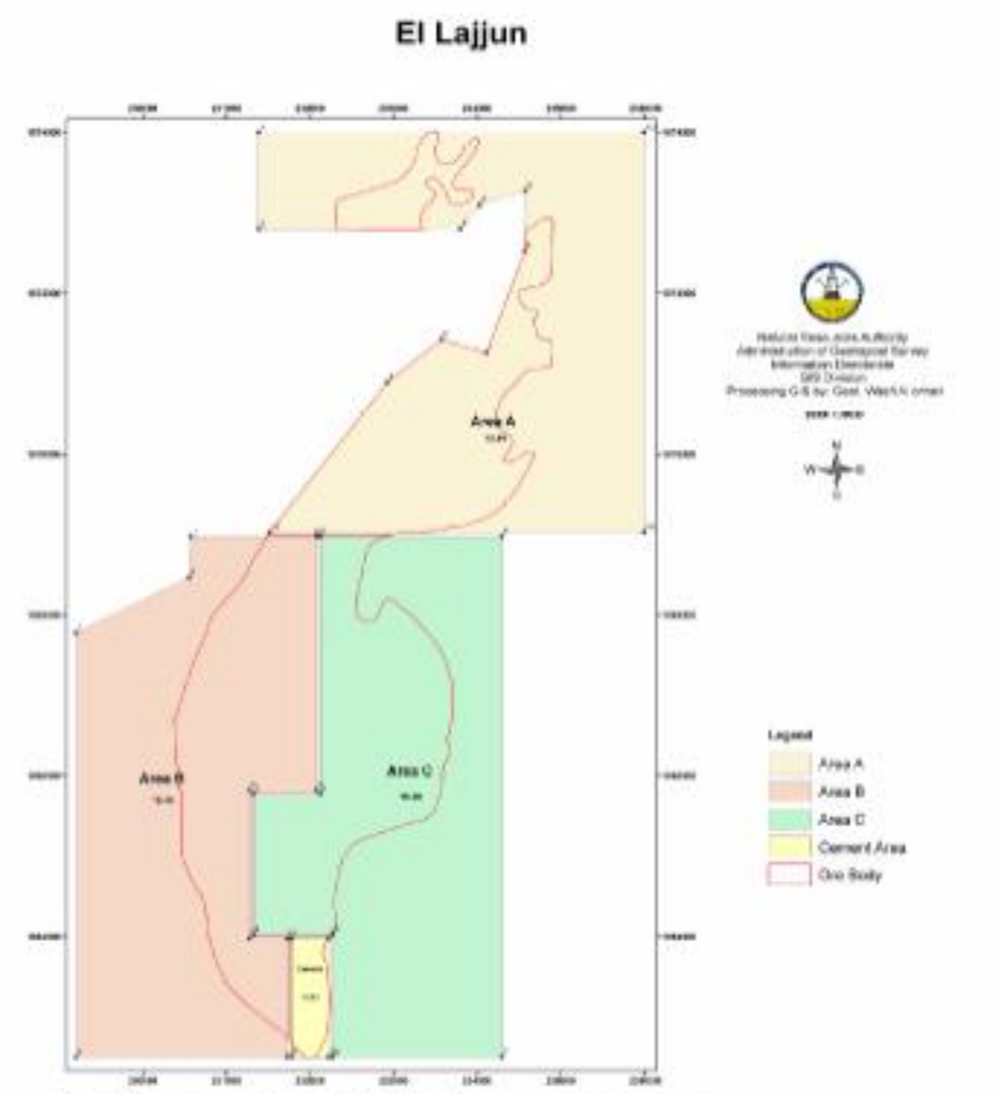

Figure (6): Location map of the three MOU's for the three companies in Lajjun deposit.

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