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EXPLORATION AND EVALUTION INVESTMENT OPPORTUNITIES OF FELDSPAR ORE IN JORDAN

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ABSTRACT. The feldspar deposits in Jordan are belong to the alkali granite rocks type, as leucogranite, feldspar pegmatites and alkali-rich granite, occurring as medium to coarse-grained, light colored igneous rocks such as aplite and alaskite, respectively. They are characterized by granite composition and low content of iron-bearing mafic minerals. The paper aims to evaluate the feldspar of the plutonic rocks in southwest Jordan, particularly in Wadi Sadir Al-Mulghan and adjacent areas, and to shed light on investment opportunities of this ore with aim to be used in building tiles, ceramic, glass and other applications. The feldspar has a lower content of mafic minerals and a higher content of alkalis (K_2O+Na_2O), comparing with the other localities of feldspar ore deposits in southwestern Jordan. A review and interpretation of geology, mineralogy, petrography and chemical composition of the feldspar ore in these areas are discussed in this work.

ЕКСПЛОАТАЦИЯ И ОЦЕНЪЧНИ ИНВЕСТИЦИОННИ ВЪЗМОЖНОСТИ ЗА ФЕЛДШПАТОВА СУРОВИНА В ЙОРДАНИЯ

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РЕЗЮМЕ. Фелдшпатовите находища в Йордания са свързани с алкален тип скали като левкогранити, фелдшпатови пегматити и алкално-обогатени гранити, които се разкриват като средно до едрозърнести светлоцветени магмени скали, например аплити и аласкити. Те се характеризират с гранитен състав и ниско съдържание на желязо-съдържащи мафични минерали. Статията цели да се оцени фелдшпата от плутоничните скали в югозападна Йордания, в частност във Вади Садир ал Мулган и околните райони, както и да се хвърли светлина върху възможностите за инвестиции при тази суровина с оглед нейното използване за строителството, в керамиката, стъкларството и други приложения. Фелдшпатът има едно по-ниско съдържание на мафични минерали и по-високи съдължания на алкални елементи (K_2O+Na_2O), в сравнение с този от други находища в югозападна Йордания. Дискутира се и се интерпретира геологията, минералогията, петрографията и химичния състав на фелдшпатовата суровина в указания район.

Introduction

In Jordan, the feldspars deposits belong to alkali granite rocks, leucogranites, feldspar pegmatites and alkali-rich granites, occurring as medium to coarse-grained, light colored igneous rocks, such as aplites and alaskite. The feldspar ore is characterized by higher content of alkalis and low content of mafic minerals. These deposits belong to the Aqaba map sheet and are located in the following areas: Al-Jaishieh area; Wadi Sadir Mulghan area; Wadi Sadir Ashuqayri area, and Ayn Al Hashim area (Fig. 1).

Geological Setting

Feldspar ore deposits are part of the basement rocks of southwest Jordan that represents the northern extension of the Arabian Nubian Shield (ANS). The exposed basement rocks in Jordan comprise igneous and metamorphic suites, predominantly of late Proterozoic age, classified into two lithostratigraphical complexes, the oldest is the Aqaba Complex and the youngest is the Araba Complex (Fig. 2). Both complexes are separated by a regional unconformity represented by the Saramuj Conglomerate Formation. The Aqaba Complex consists mainly of calk-alkaline plutonic igneous and metamorphic rocks of an age ranges between 570 and 800 Ma, whereas the Araba Complex comprises the Safi Group, Feinan Granitic Suite, Qrienifat Volcanic Suite and Ahaymir Volcanic Suite. The Yutum Granites and Urf Porphyritic suites have been considered as the source rocks for the feldspar ore deposits. The granite rocks which belong either to Abu Jadda granite (582±4Ma), Imran monzogranite (589±5Ma) and the Mulghan granodiorite Unit (630-570 Ma) are also considered as a source rocks for the feldspar ore deposits (Rabba, 1991).

Detailed mineral processing using magnetic and floatation processes were carried out by Natural Resources Authority (NRA) (Rawashidi, Al Batah, 1996; Tahat et al., 2000; Al-Abtah, Louzi, 2002), whereas Barjous (1997, 2000) carried out a study on beneficiation of Jordanian feldspar from unique tectonically crushed granite. Haki (1976) discovered new localities of feldspars in the Aqaba-Quweira area. Beneficiation studies on the medium grained alkali granites of the Aqaba-Quweira area were carried out (Haddad, 1976; Hadad, Barakat, 1988).

Technostone S.P.A. (1984) produced a final report on feldspars in the El Quweira area. A systematic exploration for the exposures of feldspar in the Wadi Sader Mulghan area has been carried out by Ala'a and Shakkour (2007; 2010). Additional study has been carried out by NRA on the feldspar deposits of the monzogranite at Wadi Sadir Ash Shuqayri (southwestern Jordan) during the period 2009-2010. Some of their results are presented in this work.

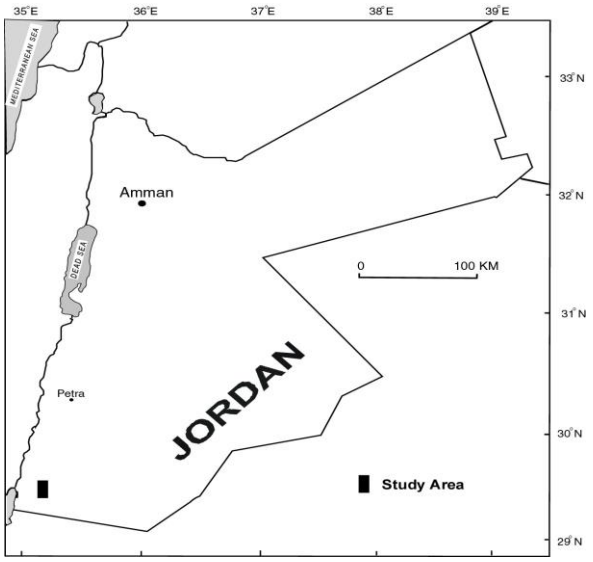


Fig. 1. Location map for the feldspar ore deposits in Jordan

Results and Discussion

Mineralogical Properties

Mineralogical and petrographic studies have been carried out during the last years on feldspar deposits in southwestern Jordan. The main studies on these deposits were carried out by Rabba and Ibrahim (1988), McCourt and Ibrahim (1990), Rabba (1991), Rabba et al. (1996) and Jarrar et al. (2003). Below are brief description on the mineralogy and petrography of the feldspar deposits from some economic localities, that have been studied in this work.

Mineralogy of Feldspar in Wadi Al-Jaishieh Area

Petrographic studies were performed on representative samples from the Wadi Al-Jaishieh feldspar deposits. Minerals assemblage are composed of orthoclase, plagioclase, quartz and accessory minerals of biotite, muscovite, chlorite and iron oxides. The orthoclase forms about 18% and microcline 10% by volume of the rock. Plagioclase forms about 20 to 30%, while quartz from 30 to 45%. The mafic minerals content is up to 10%. The grain size of minerals ranges between 0.5 and 3.5 mm. X-ray Diffraction Analysis indicate that the main essential minerals are orthoclase, plagioclase, microcline and quartz, while the accessory minerals are zircon and biotite.

Mineralogy of Feldspar in Ayn Al Hashim Area

Two representative samples were collected from the pegmatites of the Ayn Al Hashim deposit (Figs. 3A, B). The petrographic and XRD studies revealed that the main minerals are feldspars, albite, microcline and quartz, while biotite, calcite and smectite are secondary minerals.

Mineralogy of Feldspar in Wadi Sader Mulghan Area

Petrographic studies showed that the feldspar has perthitic and microperthitic, poikilitic, rare micrographic intergrowths and local consertal and myrmekitic textures (Fig. 4A). Quartz occurs as medium-grained, anhedral with suture outlines giving consertal texture or irregular boundaries. In some places quartz occurs as fine-grained like rods enclosed by feldspar. Quartz forms about 25% of the volume of the rock. Plagioclase occurs as large to medium grains with euhedral to subhedral elongated crystals showing well-developed albite twinning and forms about 45% of the rock. The crystals partially altered to sericite at the centre of the mineral. Orthoclase occurs as well-developed crystals showing perthitic texture and Carlsbad twinning, while the perthite exhibits alteration along the albite lamellae (Fig. 4B). Microcline, also present and showing cross-hatching twinning altered to clay minerals. It forms about 25-30% of the rock. Biotite and muscovite are present as flakes and forms about 2%. (Figs. 4A, B). XRD indicated the presence of feldspar minerals (microcline and albite), while the calcite and smectite are trace minerals.

Mineralogy of Feldspar in Wadi Al Bayyara Area

Seventeen representative samples from monzo- and granodiorite outcrops. Petrographic studies indicate the presence of feldspar, plagioclase, quartz and mafic minerals of biotite and muscovite (Figs. 4C, D). The results of XRD indicated that the major minerals of the most samples are quartz and feldspar (orthoclase, albite and microcline) and minor minerals – muscovite and biotite (Fig. 5).

Chemical Characteristics

According to their chemical composition feldspars are divided into four chemically distinctive subgroups: potassium feldspar (orthoclase, $KAlSi_3O_8$), sodium feldspar (albite, $NaAlSi_3O_8$), calcium feldspar (anorthite, $CaAlSi_3O_8$) and barium feldspar ($BaAl_2Si_3O_8$). The standard chemical composition of feldspar minerals are shown in Table 1.

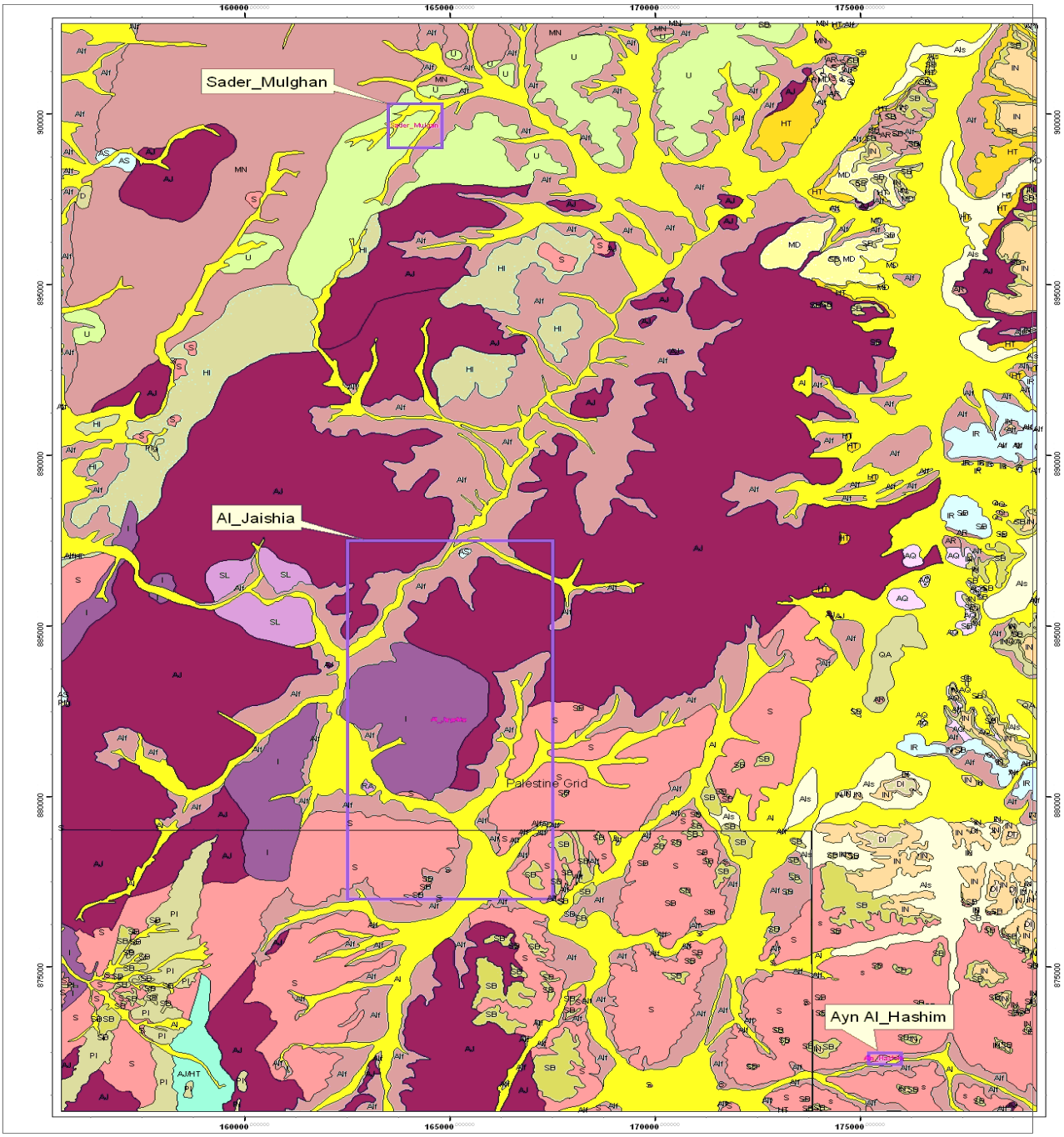
Table 1. *Chemical composition of feldspar minerals (%)*

Feldspar	K_2O	Na_2O	CaO	AL_2O_3	SiO_2
Microcline	16.9	_	_	18.4	64.7
Orthoclase	19.9	_	_	18.4	64.7
Albite	_	11.8	_	19.4	68.8
Anorthite	_	_	20.1	36.6	43.3

The samples of feldspar ore have been collected from different localities of the Aqaba Complex to investigate the chemical composition of the feldspar from the areas of Wadi Al-Jaishieh, Ayn Al Hashim, Wadi Sader Mulghan and Wadi Sader Ash Shuqayri (Figs. 3C, D, E, F). All samples were analyzed by X-ray fluorescence (XRF) method at the laboratories of Natural Resources Authority, Jordan.

Chemical composition of feldspar of Wadi Al-Jaishieh

Four representative samples were collected from three localities at the Wadi Al-Jaishieh Feldspar deposit. Results of the major elements presented in Table 2. The K_2O content varies from 2.30 to 4.34% and Na_2O from 3.92 to 5.54%, while the SiO_2 content is from 71.33 to 74.49%. Some variations in the content of alkalis is due to the heterogeneous distribution of the feldspar minerals that present in the original granitic rocks.



Legend

Geological Formation:

- Umm ishrin sandstone
- Abu jadda granite
- Azraq /Qara granite
- Ar Rashidiyya Aplite
- Abu saq'a schist
- Alluvium And Wadi Sediments
- Alluvial fan
- Mudflat
- Aeolian Sand and Sand Dunes
- Duheila Hornblendic
- Disi Sandstone
- Lake Deposit
- Humrat granite
- Imran Monzogranite
- Irkheim/ saham /Ishaa monzogranite
- Janub metamorphic
- Marsad porphyry
- Ma'in Sandstone
- Fluviatill and Lacustrine Gravels
- Quraynifat volcanic
- Azraq /Qara granite
- Rahma Foliated
- Sabil Granodiorite
- Salib Arkusic Sandstone
- Silal
- Urf porphyritic
- Study Area

Natural Resources Authority
Administration Of Geological Survey
Information Diroctority
GIS Division
November 2006
GIS Processing By: Basima Al_Karasneh

Map scale 1: 75,000
Palestine Grid

Fig. 2. Complied geologic map shows the distribution of feldspar ore deposits

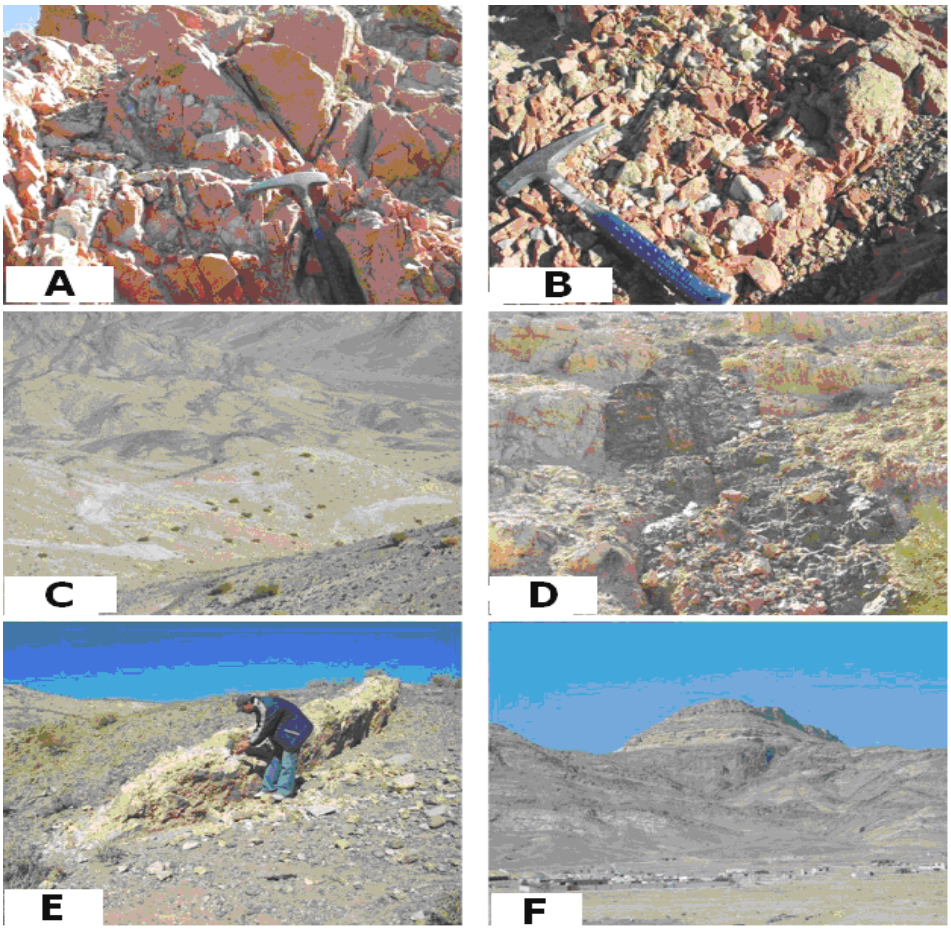


Fig. 3. A-B – pegmatites with coarse grained texture mainly composed of quartz and alkali feldspar; C – dolerite dike intruded the study area, the main strike directions of the dykes are NE-SW; D – monzogranite intruded by a dolerite dyke; E – calcite vein intruded the monzogranite rocks; F – the unconformity between the Precambrian igneous rocks and the overlying lower Cambrian sandstone

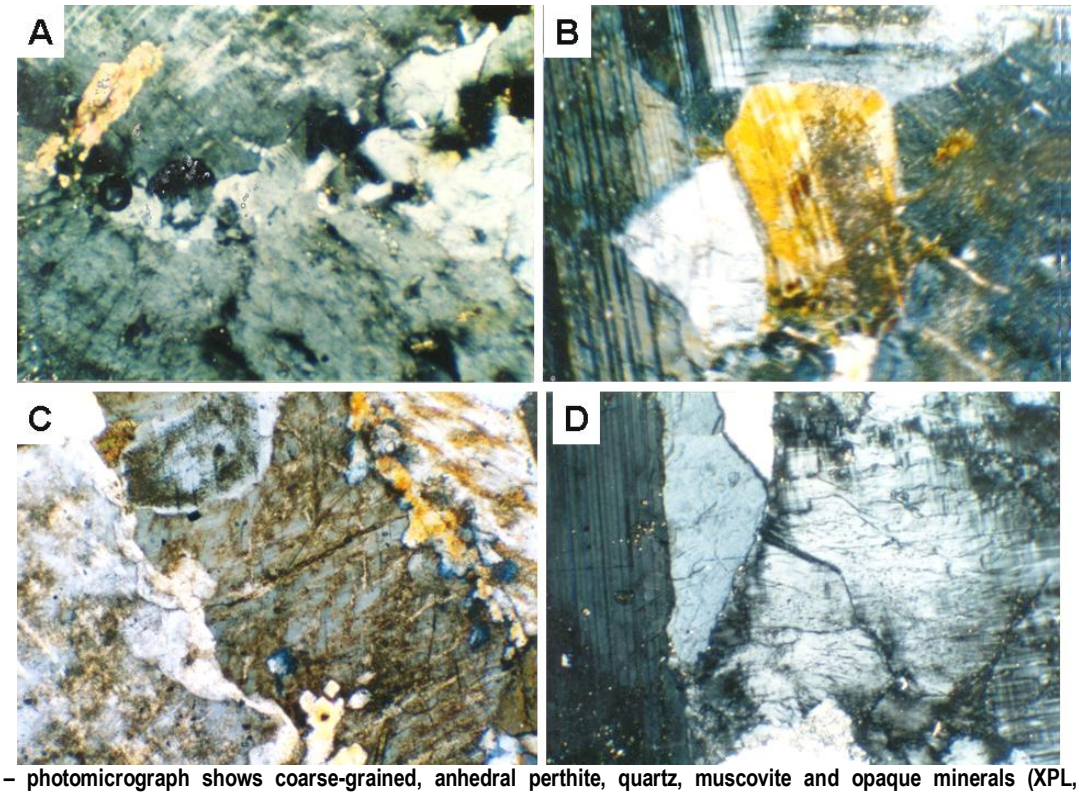


Fig. 4. A – photomicrograph shows coarse-grained, anhedral perthite, quartz, muscovite and opaque minerals (XPL, 40X); B – photomicrograph shows euhedral to subhedral plagioclase with albite twining and selective alteration of plagioclase (XPL, 40X); C – photomicrograph shows anhedral coarse-grained crystals of perthite intergrowth of orthoclase and lamellae of albite; zoned plagioclase occurs and quartz is present as fine grains (XPL, 40X; D – photomicrograph shows plagioclase, occurs as elongated subhedral crystals with albite twining, fractured microcline shows cross-hatching twining and quartz is also present (XPL, 40X)

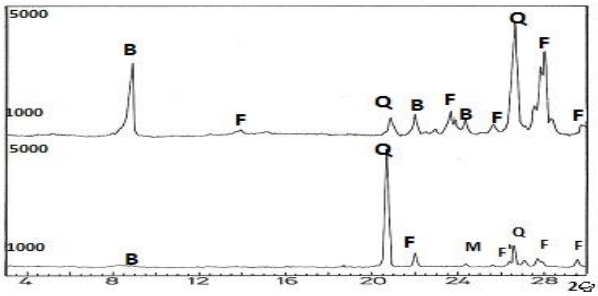


Fig. 5. XRD patterns of the major minerals of granite rocks (B: biotite; F: feldspar; Q: quartz; M: muscovite)

The iron oxides occurred with low content in and vary from 0.81 to 2.28% which are thought to be produced from the chemical alteration of the mafic minerals.

Table 2. *Chemical analysis of feldspar ore deposit in Wadi Al-Jaishieh (%)*

Area	SiO_2	CaO	Fe_2O_3	Al_2O_3	Na_2O	K_2O
J/North	71.46	1.05	1.02	13.98	5.53	4.29
J/Area1	71.72	1.04	1.37	13.63	5.34	4.34
J/Area2	74.49	1.62	2.28	13.25	3.92	4.28
J/South	71.33	3.22	0.81	12.90	5.54	2.30

Chemical composition of feldspar of Ayn Al Hashim

Two samples have been analyzed from the Ayn Al Hashim Feldspar deposit. The results are shown in Table 3. Comparing these results with those from other localities, it can be noticed that the SiO_2 content is less than 70%, whereas the Al_2O_3 and K_2O content is higher in samples from other localities, and the content of iron oxides is changeable (0.22-1.45%). This reflects the heterogeneous character of the magma and the processes of chemical weathering.

Table 3. *Chemical analysis of feldspar in Ayn Al Hashim (%)*

Area	SiO_2	CaO	Fe_2O_3	Al_2O_3	Na_2O	K_2O
Hashim/1	66.7	0.03	0.22	18.8	4.06	11.0
Hashim/2	69.0	0.60	1.45	14.8	2.64	8.60

Chemical composition of feldspar of Wadi Sader Mulgan

Three representative samples were analyzed from the feldspar ore of Wadi Sader Mulghan. The results revealed that the total alkalis (Na_2O+K_2O) varies from 9.77 to 10.24%, while the average content of iron oxides is 0.51%. All the results are presented in Table 4.

Table 4. *Chemical analysis of feldspar at Wadi Sader Mulghan area (%)*

Area	SiO_2	CaO	Fe_2O_3	Al_2O_3	Na_2O	K_2O
Wsader/1	72.99	0.61	0.65	14.29	4.13	5.64
Wsader/2	72.90	1.20	0.58	14.20	5.25	4.99
Wsader/3	73.69	1.37	0.30	13.02	6.05	3.73

Chemical composition of feldspar of Wadi Sader ash shuqayri

The results of the samples collected from different localities from this area revealed that total alkalis (Na_2O+K_2O) varies from 8.41 to 8.84%, which is considered to be a good source for feldspar deposits, and Fe_2O_3 ranges from 1.44 to 1.86%, which is considered low. These results are shown in Table 5.

Table 5. *Chemical analysis of major oxides at Wadi Sader Ash Shuqayri in percent (%)*

Area	SiO_2	CaO	Fe_2O_3	Al_2O_3	Na_2O	K_2O
1	70.27	1.45	1.44	15.67	4.48	4.36
2	66.44	2.76	1.86	16.06	4.94	3.52
3	67.27	2.78	1.82	15.43	4.53	3.88

Chemical composition of feldspar of Wadi Al Bayyara area

The results of the collected samples from this area show content intermediate to high alkalis (K_2O+Na_2O), which ranges from 6.03 to 9.47 %, with an average of 8.51%. The iron oxides in these samples have an acceptable amount with an average of 1.96%. These mafic minerals could be reduced by different simple processing mechanisms such as flotation and magnetic separation processes.

Table 6. *Average of five samples of major oxides from different localities at Wadi Al Bayyara area (%)*

Area	SiO_2	CaO	Fe_2O_3	Al_2O_3	Na_2O	K_2O
WB	67.48	2.27	1.96	15.87	4.81	3.70

Average chemical composition of feldspar in Jordan and other countries

Compared the results of the total alkalis (Na_2O+K_2O) of Jordan feldspars with other countries it can be noticed that the total alkalis of (Na_2O+K_2O) in Sweden is 8.83%, in Norway is 8.9% and in Japan is 7.44%, whereas in Jordan is 9.36% (Table 7).

Table 7. *Average chemical analysis of the feldspars in other countries compared with Jordan feldspar*

Oxides %	Turkey	Norway	Japan	Jordan
MgO	1.10	0.0	0.8	0.36
Na_2O	3.19	4.3	3.39	4.28
K_2O	4.49	4.6	4.05	5.08
SiO_2	66.03	75.30	77.14	70.70
CaO	1.98	0.9	0.5	1.47
Al_2O_3	16.83	14.90	14.12	14.67

Evaluation and Investment Opportunities

The future opportunity of the feldspar deposits in south-western Jordan should be related to many aspects that will be take into consideration. Among these is the mineral and chemical composition, purity of the ore, type of mining and exploitation, mineral processing and recovery of the ore, in addition to the infrastructure at the study area. NRA indicated a total of 15 promising localities that have been identified. Thirteen of these localities have been inspected and sampled. The feldspar areas can be followed on map sheets of 1:50000 scale in Jabal al Mubarak, Ayn Al Hashim, Umm Ishrin, Aqaba and Wadi Rahma. On the basis of the technological results and dressing tests it can be noticed that the most convenient areas for feldspar production are Al Jaishiah within Jabal al Mubarak, Wadi Sader Mulghan and Wadi Sader Ash Shuqayri. These localities are more accessible and also more suitable from an extraction and mining viewpoint.

Al Jaishiah feldspar ore deposit

The deposit is located 6km south of Aqaba within Jabal al Mubarak and Aqaba sheet maps. The area is restricted between two major faults, almost parallel to each other. This area is largely affected by tectonic movements and caused of many

minor faults on the intersection and crushed zone. The deposit is characterized by easy accessible, lack in dikes and has high alkali content. This area could be with low costs of mining and beneficiation. The most suitable mining method at the Al Jaishiah ore deposit which should be applied for exploitation of the crushed granite is the selective open pit mining method (Haddad, 1976). The reasons for applying the mentioned method are as follows: 1) the northern part is very extensive traversed with dikes; 2) distribution of the mafic minerals content along the crushed granite is variable; 3) the alkali-group in the ore is variable, 4) the surface crushed granite is with coarse-medium blocks and the interior crushed granite is friable and with fine-grained blocks, and the silica content in the Al Jaishiah feldspar ore deposit is also changeable.

Wadi Sader Mulghan, Wadi Sader Ash Shuqayri and Wadi Al Bayyra feldspar ore deposit

The feldspar deposits are located north of Aqaba. The studied area is located in the Aqaba and Wadi Rahma sheet maps, scale 1:50000. NRA studied the area in full exploratory program during the period 2005-2010 in order to estimate the alkali content and the mineralogical components of feldspar deposits. The feldspar deposits are present in Mulghan Monzogranite to Granodiorite units and the thickness is ranging from 10 to 25 m. The estimated reserve of the deposit is about 55 million ton (Ala'a, Shakkour, 2010). Comparing with the Al Jaishiah feldspar ore deposit, the feldspar at the Wadi Sader Mulghan, Wadi Sader Ash Shuqayri and Wadi Al Bayyra areas is more favourable for exploitation due to the following reasons: 1) less ferro-magnesium minerals; 2) higher alkali content; 3) less dikes; 4) ea1sier exploitation, better accessible and suitable for mining. For these reasons, the open pit mining method was found suitable to be the cheapest method and will give the highest recovery and safest method.

Ayn Al Hashim feldspar ore deposits

The deposit is located 45 km southeast of Aqaba, east of Titten village. NRA studied the area during 2010. Several samples were collected and analyzed from the pegmatite exposure, which is hosted by the Sabil Granodiorite Unit that belongs to the Rumman Tonalitic (Abu Baker, 2005). The length of the pegmatite intrusion is about 26 m, with 16 m width and 8.0 m thickness. Depending on previous diminutions of the ore, the estimated reserve will be between 10000-12000 tons, including small pockets of pure quartz that are present in the core of the pegmatite exposure (Abu Baker, 2005).

Conclusions

Feldspar ore deposits belong to the basement rocks of southwest Jordan which represents the northern extension of the Arabian Nubian Shield (ANS). The feldspar deposits are found in alkali granite rocks, leucogranites, pegmatites and alkali-rich granites, occurring as medium to coarse-grained, light colored igneous rocks, such as aplites and alaskite. They have a granite composition and are characterized by low content of mafic iron-bearing minerals. These deposits are located at Al-Jaishieh, Wadi Sadir Mulghan, Wadi Sadir Ashuqayri, Wadi Al Bayyra and in Ayn Al Hashim areas. Petrographic studies shows that the feldspar has perthitic and microperthitic, poikilitic, rare micrographic intergrowths and local consertal and myrmekitic textures. Quartz occurs as medium-grained forms with about 25% of the volume of the rock. Plagioclase forms about 25-45% of the rock and occurs as large to medium grains, euhedral to subhedral elongated crystals showing well-developed albite twinning, partially altered to sericite. Orthoclase forms about 25-35% and occurs as well-developed crystals, showing perthitic texture and Carlsbad twinning, with perthite exhibits alteration along the albite lamellae. Microcline forms about 25-30% of the rock, showing cross-hatching twinning altered to clay minerals. Biotite and muscovite are present as flakes and forms about 2%. Biotite is altered to iron oxides or chlorite. XRD analysis indicate that the main minerals are orthoclase, plagioclase, microcline, albite and quartz, while the accessory minerals are iron oxides, muscovite, biotite and zircon. On the basis of the results of mineral processing and dressing tests it can be noticed that the most convenient areas for feldspar production are Al Jaishiah within Jabal al Mubarak and Aqaba sheet maps, Wadi Sader Mulghan within the Aqaba sheet map, and Wadi Sader ash Shuqayri. The feldspar in these areas are characterized by high alkali content and less mafic minerals. The studied areas are better accessible and also more suitable from an extraction and mining viewpoint.

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