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Evaluation of some granitic rocks of the Algerian coast as a source of feldspar raw material

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ABSTRACT

Feldspar, a mineral group found in the Earth's crust, is crucial for the glass and ceramics industries. Traditionally extracted from pegmatites, it is now increasingly extracted from various deposits, predominantly alkaline and high calc-alkaline granitic rocks. Despite the significant global demand for feldspar and Algeria's rich reserves and diversity of feldspar-bearing rocks, the country has yet to fully exploit these resources. Among the magmatic formations of Algeria, there are numerous high calc-alkaline granitic rocks. Petrographic studies have classified these rocks into granite, microgranite, and pegmatite, each consisting predominantly of potassium feldspar (orthoclase and microcline), plagioclase feldspar (albite and andesine), quartz and micas (biotite and muscovite), with hematite as a minor component. Secondary minerals such as sericite, calcite, and chlorite were identified, and X-ray diffraction studies also revealed the presence of additional secondary minerals, namely smectite and kaolinite. Geochemical analysis indicated sodium oxide (Na_2O) content ranged from 2.61 to 4.91 wt%, averaging 3.45 wt%, potassium oxide (K_2O) from 3.40 to 5.11 wt%, averaging 4.45 wt%, iron (III) oxide (Fe_2O_3) from 0.34 to 3.08 wt%, averaging 1.68 wt%, and titanium dioxide (TiO_2) from 0.02 to 0.37 wt%, averaging 0.17 wt%. These chemical profiles highlight the high calc-alkaline nature of the rock bodies with a low magnetic phase content and position these Massifs as promising feldspar reserves.

Keywords: Algeria; granitic rocks; feldspar; ceramics; glass.

INTRODUCTION

Feldspar, as a common mineral group, makes up approximately 51% of the Earth's crust (Smith, 1974; Smith and Brown, 1988). They occur in many sedimentary deposits and are found in almost all igneous and metamorphic rocks in most countries (Smith and Brown, 1988; Deer et al., 2013). The mineralogical composition of most feldspar minerals can be expressed as a ternary system: orthoclase ($KAlSi_3O_8$), albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$) (Smith, 1974; Smith and Brown, 1988; Bernasconi et al., 2014). Chemically, feldspars are alumina silicates containing sodium, potassium, iron, calcium, barium or combinations thereof (Smith, 1974; 1988; Bernasconi et al., 2014). Traditionally, feldspar was only obtained from pegmatite through manual sorting (Dill, 2015). Thanks to technological development with the new flotation technique, even today it is easy to extract feldspar from various types of felsic plutonic rocks such as granitoids and alkaline intrusive, syenites, leucocratic granites, albitites, alaskites and aplites (Taboada et al., 2002). Granitic rocks have become the main source of feldspar in recent years, which is used in the ceramics and glass industries. Of all granitic rocks, the alkaline and high calc-alkaline rocks are the most important source of feldspar because they contain a high quantity of Na and K (Dill, 2015; Dondi, 2018).

Feldspar is used in a variety of industrial applications. In the glass industry, feldspar is used as a source of alumina and silica to improve the durability and corrosion resistance of glass, increase its viscosity and reduce the temperature of quartz during glass formation (Lee and Iqbal, 2001; Kara et al., 2006; Martín-Márquez et al., 2010; Bernasconi et al., 2014;). In the ceramics industry, it reduces the glass transition temperature of ceramic substrates due to its flow properties. It is also mixed with clay to create a strong ceramic piece (Lee and Iqbal, 2001; Kara et al., 2006; Martin-Marquez et al., 2010; Bernasconi et al., 2014;). The other uses are in plastic, rubber, paint, enamel, household and welding electrodes (Ismail et al., 2007; Ansari et al., 2009; Zhang et al., 2018; Ghalayini, 2020).

In Algeria, feldspar has historically been overlooked when compared to many other countries, even though it's rich in a variety of rock types such as pegmatite, granite, syenite and gneiss and widely used as a source of this mineral worldwide. This neglect persists in Algeria despite the growing domestic and international demand for feldspar. Surprisingly, feldspar mining in the country between 1984 and 1990 only took place in the Ain Barbar region, after which no significant mining activities were recorded (Chaib, 2017).

This study aims to evaluate the potential of granitic rocks in Algeria as useful sources of feldspar. The goal is to identify specific localities that are most conducive to feldspar production in hopes of spurring larger exploration efforts across the country. The study highlights the need for industries and exploration companies to consider a wider range of rock types, particularly given the declining availability of traditional sources. This study includes a detailed petrographic, mineralogical and geochemical analysis of selected granitic samples from the Algerian coastline to determine the economic feasibility of extracting feldspar from these deposits.

Location of the study area

Eight granitic Massifs located in five cities (Tlemcen, Boumerdes, Tizi Ouzou, Skikda and Annaba) are examined. Most of them are concentrated in eastern Algeria. The studied massifs of the eastern part are the Wadi El Anab and Ain Barbar (Annaba), Collo and Filfila (Skikda) massifs. In the central part, the massifs Draa El Mizane, Larba Nait Irathen (Tizi Ouzou) and Naciria (Boumerdes) are examined. The western part is represented by the Nadroma massif (Tlemcen) (Figure 1).

GEOLOGICAL SETTING

The structure of northern Algeria is an extension of the Alpine chain of northern Algeria, called "the Maghrebides chain"; this is the result of a Euro-African Alpine compressive tectonic context and other microplates (Wortel and Spakman, 2000; Rosenbaum et al., 2002; Handy et al., 2010; Carminati et al., 2012). This structure was divided into three domains: (1) the inner domain, (2) the Flyschs domain and (3) the outer or Tellian domain (Figure 1) (Bouillin, 1977; Vila, 1980; Wildi, 1983). In central and eastern Algeria is the inner domain known as the basement represented by the massifs of Tenes, Chenoua, Algiers, Greater Kabylia and Lesser Kabylia. It does not occur in western Algeria. The inner domain consists of high-pressure, high-temperature metamorphic rocks at the bottom and medium to low-pressure rocks at the top crossed by Magmatic rocks. A tertiary-aged sedimentary cover rests locally on the basement of the area (Bouillin, 1977; Vila, 1980; Djellit, 1987; Mahdjoub and Merle, 1990). The Cretaceous flyschs domain, represented by the Massylian (Raoult, 1969) and the Mauritanian flysch (Gélard, 1969) consists mainly of the alternation of a series of claystone and sandstone. The external domain series includes the tellian series, the allochthone series and the autochthon series (Vila, 1980). All studied massifs are located in the inner domain, except the Nadroma massif, which is in the outer domain in the Oranie sector.

Magmatic Events

The Algerian coast has been influenced by several magmatic events in different geological periods (Eocene-Miocene). These events allow for the formation of many types of magmatic rocks along the coast from west to east. Tertiary magmatic rocks are important and widespread along the Algerian coast (Figure 1). These rocks were formed by two magmatic events, an orogenic magmatism with high-K calc-alkaline products from the Miocene ages, and an anorogenic alkaline magmatism from the Plioquaternary age (Louni-Hacini et al., 1995; El Azzouzi et al., 2003; El Bakkali et al., 1998; Maury et al., 2000; Coulon et al., 2002; Duggen et al., 2005). Magmatic events began in the central-eastern Algeria. It consists of plutonic and volcanic rocks with calc-alkaline affinity, rich in potassium, and consists mainly of metaluminous and peraluminous granitoids with andesite and dacites and some gabbros and basalt (Maury et al., 2000; Fourcade et al., 2001). At the end of the Miocene, these calc-alkaline magmatic events extend toward the Oranie sector to the west and transition to alkaline products (Maury et al., 2000). The source of the peraluminous granitic rocks is metasedimentary, while the metaluminous granitic rocks are of crustal origin (Fourcade et al., 2001). Alkaline magmatic rocks are formed by minor melting of the Earth's mantle at a depth of 70 km (El Azzouzi et al., 2003). In the eastern part of Algeria, magmatic rocks occur mainly in the Iron Cap and Edough, Collo-Cap Bougaroun, Filfila, Al Aouana and Bejaia-Amizour regions. It is represented

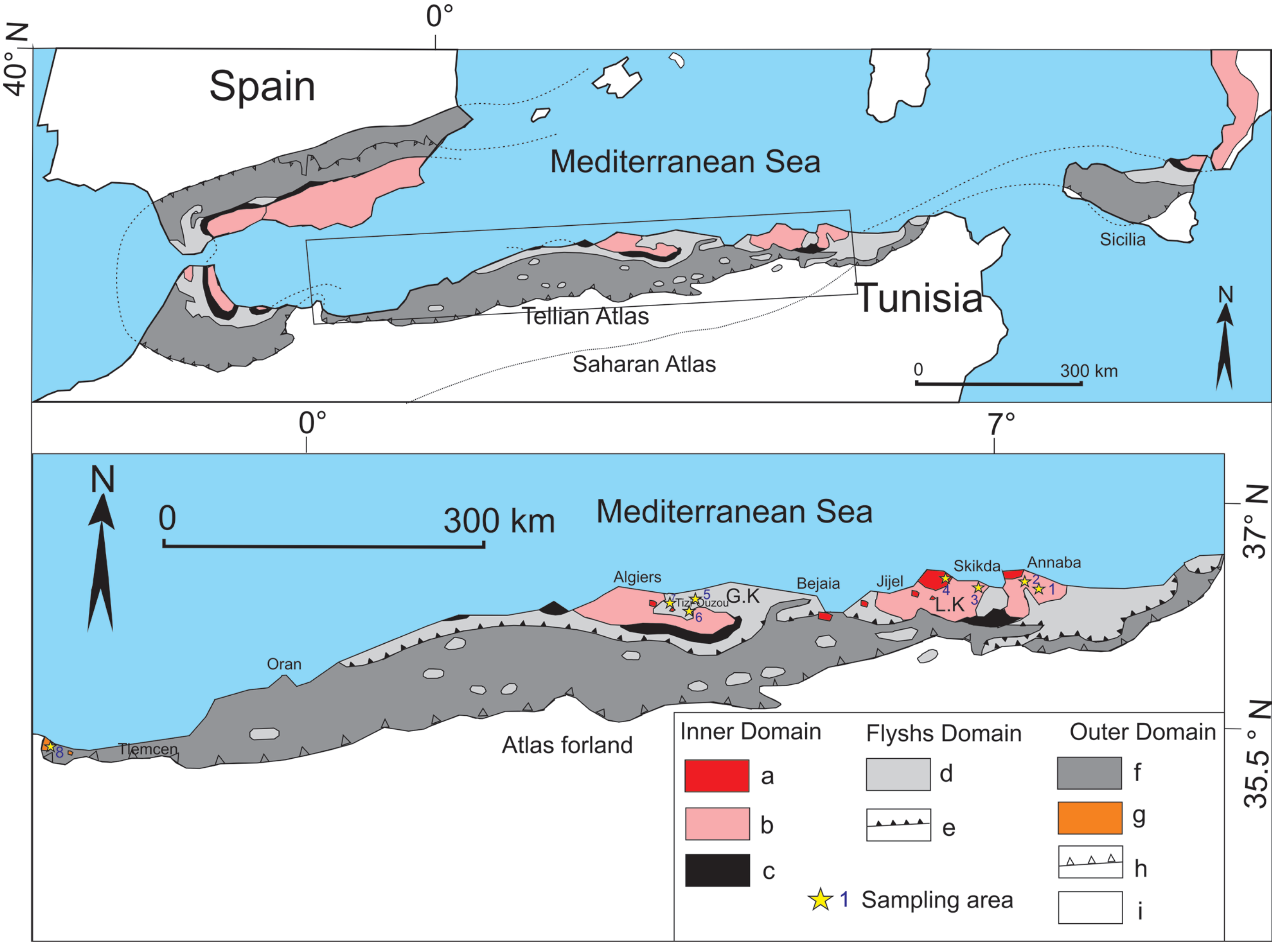

Figure 1. Geological map of the margins of the South-West Mediterranean showing the main study area and the palaeogeographical of southern Spain and North Africa. Inner domain: a: High-K calc-alkaline magmatism; b: Basement; c: Limestone cover; GK: Greater Kabylia; LK: Lesser Kabylia. Flyschs domain: d, Supra-Kabylian flyschs; Inner Alpine chain zones(b-c-d); e, Tortonian front line. Outer domain: f, Allochthonous (Infra-Kabylian flyschs and Tellian units); g, Alkaline volcanism; h, Langhian front line; i: Relative autochthonous; Outer Alpine chain zones (f-i). 1-8 Sampling area: 1-Wadi El-Anab (Annaba); 2-Ain Barbar (Annaba); 3-Filfila (Skikda); 4-Collo (Skikda); 5- Larba Nait Irathen (Tizi-Ouzou); 6- Draa El Mizane (Tizi-ouzou); 7-Naciria (Boumerdes); 8-Nadroma (Tlemcen) According (Durand-Delga and Fontboté, 1980; Mahdjoub et al., 1997; Vila, 1980).

by diorites and microdiorites from Iron Cap and Edough (Laouar et al., 2002; Laouar et al., 2005; Abbassene, 2016; Abbassene et al., 2019), granites, microgranites, rhyolites and gabbros from Collo-Cap Bougaroun region (Bouftouha and Bourefis, 2010), Filfila cordierite granites (Bouabsa et al., 2010) and granites, microgranites, andesite and rhyolites from Cavallo and Bejaia-Amizour (Laouar et al., 2018; Hamlaoui, 2019; Lekoui, 2019; Hamlaoui et al., 2020). The central part consists of tuffites associated with silexites from the Kabyle Oligo-Miocene formations recorded in the greater Kabylia (Rivière et al., 1977). Further west, between Dellys and Cherchell, there are basaltic, andesitic and rhyolitic lavas occur with granitic, granodioritic and monzonitic intrusions (Hernandez and Lepvrier, 1979; Belanteur, 1989; Belanteur et al., 1995). The western part of the Oranie sector is characterized by effusive basalt and rhyolite rocks (Megartsi, 1985; Louni-Hacini et al., 1995).

MATERIALS AND METHODS

Collection and selection of samples

Eight accessible leucogranitic Massifs were selected for this study. A field study led to; 24 intact samples being randomly collected. Three samples were taken for each Massif. The locations of samples were recorded using the Global Positioning System (GPS). The weight of each sample was between 5 and 10 kg. The samples were labelled and numbered and then sent to the laboratory of the Department of Geological Sciences at the University of Constantine for preparation.

Thin sections preparation

Thin sections were prepared for petrographic examination. A portion of each collected sample was cut into blocks of approximately 25 mm x approximately 45 mm x approximately 15 mm. Thin standard-size sections were prepared by successively lapping silicon carbide abrasives until a thickness of 30 μm was achieved.

X-ray diffraction sample preparation

To better verify the mineralogical composition of the samples, they were subjected to X-ray diffraction (XRD) analysis at the Geology of the Sahara laboratory at the University of Ouargla. The process begins with drying 100 g of each sample, which is then ground into a fine powder using a HUMBOLDT WEDAG milling machine. A 10 g portion of the powdered sample, less than 100 μm in size is compacted into pellets to promote proper random crystal orientation. These prepared pellets are then examined using an Olympus X-ray diffractometer, model BTX III, equipped with a copper target. An innovative feature of the BTX III is the use of a small vibrating sample holder that induces convective movement of the particles within the analysis chamber, thereby minimising the influence of orientation effects on the collected data. The obtained XRD spectra are analysed using X'pert Highscore software, which is integrated into the Powder Diffraction File 2 (PDF2) databases to allow a detailed interpretation of the mineralogical component.

Whole-rock chemical composition

For the geochemical investigation, height representative and fresh samples were selected for geochemical analysis. The samples were ground to approximately $1cm^3$ then cleaned and washed with distilled water and sent to the Global Leader in Testing (ALS) geochemistry laboratory in Sevilla. In the ALS geochemistry laboratory, these rocks were crushed to a size of less than 50 μm. The methodology used for the analysis of major elements involves an advanced ultra-trace technique using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). This special process is identified as "ME-MS61r." In practice, 0.25 grams of the sample prepared by a high-temperature melting at 1000 °C is dissolved in 0.90 grams proportions using a mixed flux of lithium metaborate and lithium tetraborate. The resulting melt is then carefully digested with a combination of acids: perchloric acid, 4% nitric acid, hydrofluoric acid, and 2% hydrochloric acid to ensure complete dissolution for subsequent analysis. The residue is prepared with dilute hydrochloric acid and analysed using ICP - AES. After this analysis, the results are checked for high concentrations of bismuth, mercury, molybdenum, silver and tungsten and diluted accordingly. Samples that meet these criteria are then analysed using ICP-MS. Data recording was carried out using the Geochemical Data Toolkit (GCDkit) software.

RESULTS

Petrographic description

The investigated Massifs are petrographically divided into three types according to their nature: microgranite, granite and pegmatite (Figure 2). All types consist mainly of potassium feldspar, plagioclase, and quartz with a small amount of micas (biotite and muscovite). All Massifs were artificially altered by hydrolytic alterations, which led to the formation of secondary minerals such as sericite, chlorite and calcite. In addition, a slight oxidation occurred in the Collo and Nadroma massifs, favouring the formation of iron oxide, especially hematite.

Microgranite

Microgranite covers the Wadi El-Anab, Ain Barber and Collo massifs. The Wadi Al-Anab massif has a porphyritic texture and consists mainly of ~30% potassium feldspar (orthoclase), ~22% plagioclase (albite and andesine), ~22% biotite and ~20% quartz. Chlorite, sericite and calcite occur as secondary minerals (~3%) (Figure 2a). Orthoclase is the most dominant and occurs as tabular or prismatic crystals ranging in size from 1 to 3 mm. Plagioclase has a tabular shape ranging from 1 to 4 mm. Biotite has a prismatic shape with a small size of 0.7 to 2 mm. Quartz is the least dominant and occurs as subhedral to anhedral crystals ranging in size from 1 to 3 mm. Sericite occurs as small flakes in crystals of plagioclase or potassium feldspar, while chlorite occurs as small flakes on the edges of biotite crystals. Calcite can be seen as fine crystals either on the edges or inside plagioclase. The Ain Barbar massif has a porphyritic texture with small crystals compared to the Wadi El-Anab massif. It is composed primarily of orthoclase (~32%), quartz (~25%) and albite (~25%) with a small amount of muscovite (~5%) and biotite (~3%). Chlorite and sericite occur as secondary minerals where they constitute about 4% of the whole rock (Figure 2b). The crystals have subhedral to anhedral shapes and range in size from 0.5 to 2 mm for feldspar (orthoclase and albite) and quartz and from 0.5 to 1 mm for micas. Chlorite and sericite are commonly found as fine-grained minerals. Chlorite tends to occur along the edges of biotite crystals, while sericite is typically occurring in plagioclase or orthoclase crystals. The Collo massif also has a porphyritic texture. It consists of ~30% orthoclase, ~25% plagioclase (Albite and andesine) ~22% quartz, ~10% biotite and ~5% muscovite as primary minerals, chlorite and sericite and iron oxide as secondary minerals

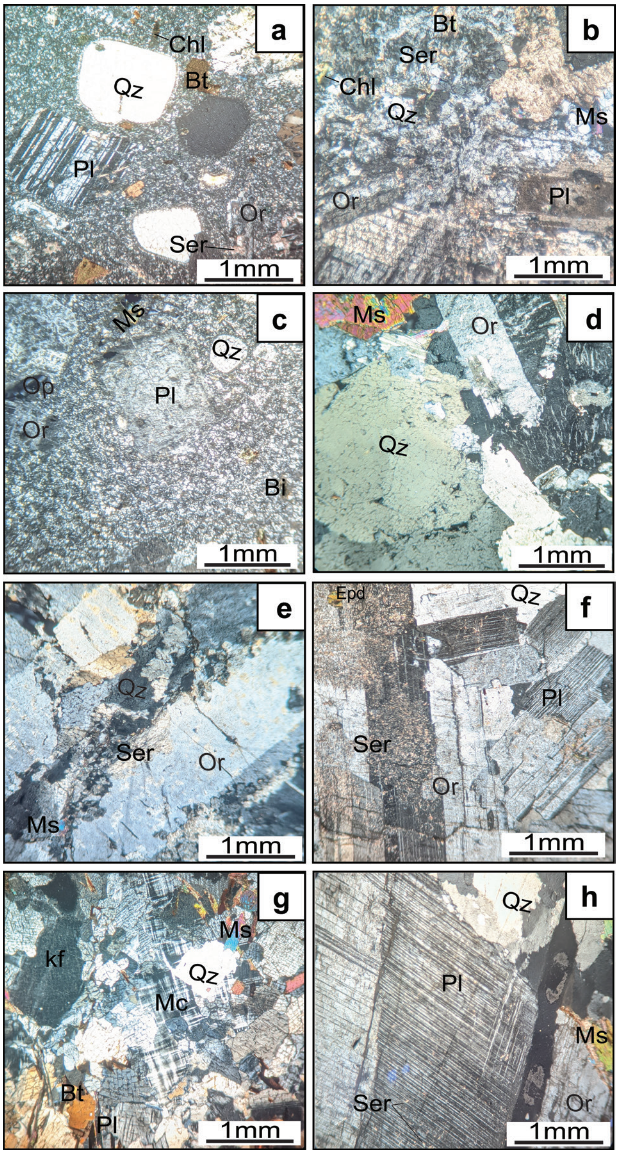

Figure 2. Crossed polarization microscopic view of the studied massifs. a-c: microgranite, a): Wadi El-Anab; b): Ain Barber; c): Collo. d-g: granite, d): Filfila; e): Draa El-Mizane; f): Nadroma; (g): Naciria. h) pegmatite of Larba Naith Irathen. (Bt: Biotite, Chl: chlorite, Epd: epidote, Mc: microcline, Ms: muscovite, Or: orthoclase, Op: opaque, Pl: plagioclases, Qz: quartz, ser: sericite).

(hematite) (~4%) (Figure 2c). The crystals vary from subhedral to anhedral with sizes ranging from 1 to 3 mm for orthoclase and plagioclase, and from 1 to 2 mm for quartz, where the size of biotite and muscovite is limited between 0.5 and 2mm. Chlorite is commonly found along the margins of biotite crystals, either in the form of small flacks or occasionally in a spherical shape. Sericite occurs predominantly in plagioclase crystals. In addition, iron oxides can be observed bordering the biotite crystals or filling the cracks in plagioclase and potassium feldspar.

Granite

The granite includes the Filfila massif, Draa El Mizane, Naciria and Nadroma. The Filfila massif has a grainy texture while the Draa El Mizane and Nadroma massifs are characterised by a grainy to porphyric texture. The Naciria massif is slightly metamorphosed, has some schist and is characterised by a grainy texture. The Filfila massif consists mainly of ~35% potassium feldspar (orthoclase and rarely microcline), ~25% quartz, ~25% plagioclase (albite and andesine) and ~10% micas (muscovite and rarely biotite) as primary minerals (Figure 2d), with sericite and chlorite being as secondary minerals (~3%). Orthoclase and plagioclase occur as tabular crystals, micas have a prismatic shape, and microcline and quartz occur as subhedral to anhedral crystals. Quartz, plagioclase and potassium feldspar have a similar size, ranging from 1 to 4 mm. Plagioclase and potassium feldspar are sometimes altered by sericite which occurs as fine grains in the margins of their crystals. Micas are less dominant and range in size from 0.5 to 3 mm. Chlorite is rare and occurs in the edge of biotite crystals. The Draa El Mizane massif consists mainly of ~40% potassium feldspar (orthoclase and microcline), ~30% plagioclase (albite and rarely andesine), ~20% quartz and rarely muscovite (~3%). Sericite occurs as a secondary mineral (~2%) (Figure 2e). Feldspar has a subhedral to anhedral shape and its size varies between 2 and 6 mm for potassium feldspar and between 2 and 4 mm for plagioclase. Plagioclase and feldspar are sometimes altered by sericite which is found inside their crystals as fine grains crystals. Quartz occurs as an anhedral crystal with a size between 1 and 5mm. Muscovite occurs as small elongated or irregular flakes or as spaces between plagioclase, quartz and potassium feldspar. The Nadroma massif consists mainly of ~30% plagioclase (albite and rarely andesine), ~25% potassium feldspar (orthoclase and microcline), ~25% quartz, ~5% muscovite and ~3% biotite with a small amount of epidote and zirconium as accessory minerals. Sericite, iron oxide (hematite) and rarely chlorite occur as secondary minerals (~4%) (Figure 2f). Plagioclase is the most dominant and found primarily in albite and occurs as tabular crystals of 1 to 5 mm. Potassium feldspars are presented by orthoclase and the microcline. Orthoclase occurs as prismatic crystals ranging in size from 2 to 6 mm. The microcline appears as subhedral crystals between 1 and 4 mm in size. Quartz occurs as anhedral crystal with a size between 1 and 5 mm. Micas (biotite and muscovite) are rare and occur as small anhedral crystals ranging in size from 0.5 to 1 mm. The biotite edges are altered by chlorite. Zircon is very rare and occurs as small prismatic and pyramidal crystals included in quartz or plagioclase. Epidote is found as small euhedral crystals included in orthoclase. Sericite occurs in feldspar crystals in the form of fine grains. Iron oxide is found along cracks of orthoclase and plagioclase. The Naciria massif consists essentially of ~30% plagioclase (albite and andesine), ~25% potassium feldspar (orthoclase and microcline), ~25% quartz, ~8% biotite and ~5% muscovite (Figure 2g). Chlorite and sericite are secondary minerals (~3%). iron oxide (hematite) is an accessory mineral. Feldspars (potassium feldspar and plagioclase) occur as subhedral tabular crystals, varying in size from 1 to 5 mm. Quartz occurs as anhedral crystals that are between 1 and 3 mm in size. Biotite occurs in prismatic or elongated crystals ranging in size from 0.5 to 3 mm. Muscovite shows small elongated lamellar or prismatic crystals ranging in size from 0.5 to 1mm. Sericite occurs along cracks and twin planes of microcline and plagioclase. Chlorite occurs as fine grains on the edges of biotite crystals. Iron oxide is rarely observed in the cracks or rimmed biotite crystals.

Pegmatite

The pegmatite is only presented in the Larba Nait Irathen massif; it has a coarse-grained texture. The pegmatite of the Larba Nait Irathen massif consists mainly of ~30% potassium feldspar (orthoclase and microcline), ~25% plagioclase (albite and rarely andesine ~25% quartz and ~10% muscovite (Figure 2h), garnet is an accessory mineral, sericite as a secondary mineral (~2%). All crystals are anhedral to subhedral with an average grain size ranging from 2 mm to 6 mm. In some cases, the size of the crystals reaches 8 cm for muscovite, 6 cm for feldspar and 5 cm for quartz. Garnet is an accessory mineral in the Larba Naith Irathen pegmatites massif included in potassium feldspar or plagioclase crystals in the form of small globular crystals. Sericite occurs as fine grains inside plagioclase or potassium feldspar.

X-ray diffraction

The XRD spectra show that the samples consist mainly of potassium feldspar (orthoclase and microcline), plagioclase (mainly albite, anorthoclase and anorthite) and quartz and micas (biotite and muscovite). Secondary minerals are calcite, sericite, clay minerals (kaolinite, smectite and chlorite) and hematite (Table 1; Figure 3). The Wadi El-Anab Microgranite consists of quartz, orthoclase, biotite, albite and small amounts of anorthoclase. Chlorite and sericite occur as secondary minerals (Figure 3a). Ain Barbar microgranite is composed of quartz, orthoclase and albite with a small amount of muscovite and biotite as essential minerals; it also contains kaolinite and chlorite as secondary minerals (Figure 3b). Filfila granite is composed primarily of quartz, orthoclase and albite with microcline, muscovite, biotite, and anorthoclase in small amounts (Figure 3c). The Collo microgranite consists of potassium feldspar (orthoclase and rarely microcline), plagioclase (mainly albite), quartz and a small amount of mica (biotite and muscovite) as primary minerals. It also contains a small amount of chlorite, kaolinite and hematite as secondary minerals (Figure 3d). The Draa El-Mizane granite is mainly composed of quartz, potassium feldspar (orthoclase+microcline) and albite. Smectite and kaolinite occur as secondary minerals in small amounts (Figure 3e). The Naciria granite is composed of microcline, orthoclase, albite and quartz and also contains small amounts of biotite and muscovite (Figure 3f). The Larba Nait Irathen pegmatite is mainly composed of quartz, potassium feldspar (orthoclase+microcline), albite and muscovite as primary minerals and sericite and smectite as secondary minerals (Figure 3g). The Nadroma granite consists mainly of quartz, orthoclase and albite with a small amount of muscovite and biotite. It also contains sericite and hematite as secondary minerals (Figure 3h). The results show a perfect agreement with the petrographical description.

Geochemical analyses

The content of major oxides was determined in all samples and is shown in Table 2. The results show a varying range of chemical composition. All samples are completely sufficient for the requirements of the industry. Two massifs have +4 Na_2O content, Naciria (4.91 wt%) and Nadroma (4.27 wt%). Three massifs with +3 content, Filfila (3.26 wt%), Collo (3.63 wt%) and Draa El Mizane (3.38 wt%) as well as three massifs with +2 content, Wadi Al Anab (2.61 wt%), Ain Barbar (2,92 wt%) and Larba Naith Irathen (2.64 wt%). All Massifs have a high K_2O content, while Draa El Mizane has the highest content (5.11 wt%). Exception for Nadroma massif that has 3.40 wt%, all other massifs have +4 of K_2O, Wadi Al Anab (4.24 wt%), Ain Barbar (4.22 wt%), Filfila (4.94 wt%), Collo (4.33 wt%), Larba Naith Irathen (4.45 wt%) and Naciria (4.33 wt%). The F_2O_3 content is low to moderate and is <1 in Draa El Mizane (0.34 wt%) and Larba Nait Irathen (0.93 wt%). It is <2 in Ain Barbar (1.32 wt%), Filfila (1.72 wt%) and Naciria (1.24 wt%). For Collo and Nadroma it is 2.67 wt% and 2.19 wt% sequentially and 3.08 wt% in Wadi El Al Anab. TiO_2 content is generally low in all massifs and is 0.37 wt% in Wadi Al Anab, 0.05 wt% in Ain Barbar, 0.09 wt% in Filfila and Draa El Mizane, 0.3 wt% in Collo, 0.11 wt% in Naciria, 0.02 wt% in Larba Nait Irathen and 0.33 wt% in Nadroma.

DISCUSSIONS

Nomenclature and Classification of granitic rocks

For more precise names, the samples are plotted on the total alkali-silica diagram (TAS) from (Middlemost,

Table 1. The characteristic peaks of studied massifs present with their models recorded in the PDF2 database.

Minerals	characteristic peaks (2θ)							
	Wadi El Anab	Ain Barbar	Filfila	Collo	Draa El Mizane	Naciria	Larba Nait Irathen	Nadroma
Orthoclase	13.63 20.73 23.55 25.59	13.88 23.41 25.61 32.16 34.71 49.69	13.89 21.91 23.57 25.38 34.75	13.81 25.61 29.02 32.06 34.77	13.88 23.20 25.45 49.65	13.89 23.35 25.38	13.79 25.46 30.03	13.84 25.35 50.00
Albite	16.20 22.00 24.42	16.03 21.81 24.12 36.35	16.19 21.91 36.41	16.26 21.89 36.42	16.03 21.96 36.44	16.19 21.91 36.41	15.96 21.96 36.53	16.08 21.90 27.75 29.40 30.65
Orthoclase-Albite	27.50 32.20 49.77	27.67 29.58 42.36	30.15 32.25 39.30 42.31	27.69 31.02 39.29 49.78	27.86 30.25 42.25	27.82 30.15 34.65 42.30 49.85	34.99 49.74	24.14 34.91 42.33
Quartz	26.52 39.27	20.81 26.34 39.09	20.74 26.44	20.75 26.51	20.76 26.55 39.14 50.05	20.74 26.44 39.15	20.82 26.51 39.30	20.81 23.61 39.21
Biotite	8.75 36.43 45.59	8.77	/	8.82	/	8.77	/	8.79
Muscovite	/	/	27.80	/	/	/	27.82 45.58	45.55
Microcline	/	/	/	24.10	24.04 29.35	24.10	23.32 24.13 29.20	/
Orthoclase-Microcline	/	/	/	/	32.15	/	42.32	/
Biotite-Muscovite	/	45.61	46.21	46.23	46.19	46.18	/	/
Anorthoclase	42.35	/	/	52.02	/	/	/	12.25
Chlorite	12.41	6.10		6.13	/	/	/	/
Sericite	20.15 25.20	20.21	/	/		/	19.82	20.05
Kaolinite	/	12.37		12.39	12.37	/	/	/
Smectite	/	/	/	/	40.05	40.00	40.03	/
Hematite	/	/	/	24.25	/	/	/	41.05

1994). Due to the high K_2O content, all samples are plotted in the granite field (Figure 4a). The total alkali-silica from De La Roche et al., (1980) shows that the Wadi Al Anab, Ain Barbar and Collo massifs are plotted in the granite field while the remaining massifs are plotted in the alkali-granite field, indicating high contents of K_2O and Na_2O (Figure 4b).

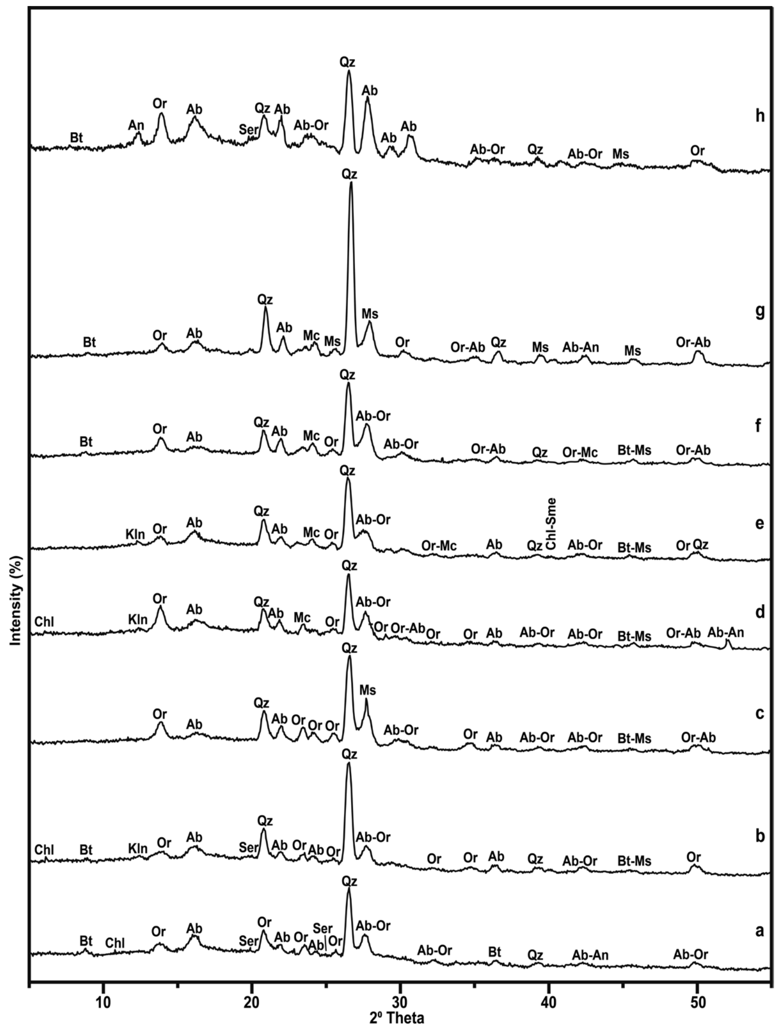

Figure 3. The Massifs' characteristic peaks present with their models recorded in the PDF2 database. a – Wadi El Anab, b- Ain Barbar, c- Filfila, d- Collo, e- Draa El Mizane, f- Naciria, g- Larba Nait Irathen, h- Nadroma. Ab: albite, An: anorthoclase, Bt: Biotite, Chl: chlorite, Hem: hematite, Kln: Kaolinite, Mc: microcline, Ms: muscovite, Or: orthoclase, Qz: quartz, Sem: smectite, Ser: serecite.

Magma type of granitic rocks

Plotting the major oxides data in the K_2O-SiO_2 classification diagram (Peccerillo and Taylor, 1976) (Figure 5a) shows that all samples are presented in high-K calc-alkaline series, indicating alkali richness (Na_2O+K_2O). Calc-alkaline magmatic is due to the contamination of the lower and upper continental crust caused by the melting of a metasomatic lithospheric mantle by fluids of an oceanic plate (Maury et al., 2000; Fourcade et al., 2001; Coulon et al., 2002; Laouar et al., 2005). According to the A/CNK versus the A/NK diagram (Shand, 1943), these granitic rocks are peraluminous (Figure 5b). These results are confirmed in graph B-A (Debon and Le Fort, 1983) (Figure 5c). Debon and Le Fort (1983) divided granitic rocks into six types: I to III are peraluminous where I with two micas (muscovite> biotite), II - with biotite muscovite and III with biotite. IV to VI are metaluminous, with IV containing biotite ± amphibole ± orthopyroxene ± clinopyroxene; V - exceptional rocks such as carbonates and VI - leucogranites. Except for the Wadi El Anab sample, which was only detected with biotite in the peraluminous field, all samples are peraluminous with two micas. In the study by Villaseca et al. (1998) modified plot A-B. The results show that the Wadi El Anab sample is plotted in a weak peraluminous field, while the other samples are plotted in the felsic peraluminous field (Figure 5d). According to Chappell (1999), the source of peraluminous granitic rocks is metasedimentary suggesting a metasedimentary source for these Massifs. Figure 5 shows that the studied massifs are peraluminous and have a high calc-alkaline affinity.

Table 2. Major element oxide (wt.%) compositions of granitic rocks of the studied massifs from the Algerian coast. * LOI: Loss of ignition; A: Al_2O_3; C: CaO; N: Na_2O; K: K_2O; S: SiO_2.

Rocks	Microgranite			Granite				Pegmatite
Oxides (wt%)	Wadi El Anab	Ain Barbar	Collo	Filfila	Draa ElMizane	Naciria	Nadroma	Larba Nait Irathen
SiO_2	67.10	76.70	74.90	75.10	78	73.60	73.30	79.60
Al_2O_3	14.90	12.55	14.55	14.9	12.9	14.95	13.90	12.25
Fe_2O_3	3.08	1.32	2.67	1.72	0.34	1.24	2.19	0.93
CaO	2.71	1.02	0.97	0.43	0.21	0.65	0.32	0.26
MgO	1.68	0.16	0.79	0.16	0.03	0.25	0.84	0.08
Na_2O	2.61	2.92	3.63	3.26	3.38	4.91	4.27	2.64
K_2O	4.34	4.22	4.33	4.94	5.11	4.33	3.40	4.45
Cr_2O_3	0.027	0.002	0.022	<0.002	0.032	0.037	0.036	0.003
TiO_2	0.37	0.05	0.3	0.09	0.09	0.11	0.33	0.02
MnO	0.03	0.02	0.02	0.02	<0.01	0.01	0.03	0.01
P_2O_5	0.2	0.24	0.1	0.31	0.01	0.02	0.12	0.24
SrO	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BaO	0.03	0.027	0.05	0.01	0.02	0.01	0.03	<0.01
LOI	3.15	1.42	1.27	0.88	0.60	0.41	1.32	0.67
Total	97.07	99.23	102.33	100.94	100.12	100.11	98.76	100.48
Na_2O+K_2O	6.95	7.14	7.96	8.20	8.49	9.24	7.67	7.09
A/NK	2.14	1.75	1.82	1.81	1.51	1.61	1.81	1.72
A/CNK	1.54	1.53	1.62	1.72	1.48	1.51	1.73	1.66
CNK	9.66	8.16	8.93	8.63	8.7	9.89	7.99	7.35
S/A	4.50	6.11	5.14	5.04	6.04	4.92	5.27	6.49
Na_2O/K_2O	0.60	0.69	0.83	0.65	0.86	1.13	1.25	0.59
K_2O/Na_2O	1.66	1.44	1.19	1.51	1.51	0.88	0.79	1.68

Assessment of feldspar mineral deposits in studied granitic rocks

Table 3 shows the chemical composition of some alkali and calc-alkali granitic rocks around the world where these granitic rocks are mined or evaluated as a source of feldspar (Scheepers and Schoch, 1988; Lan et al., 2005; Katzir et al., 2007; Geng et al., 2009; Aliani et al., 2011; Gougazeh et al., 2018; Deniz and Kadioğlu, 2019; Breiter et al., 2023). Comparison of the studied granitic rocks with the granitic rocks of Japan, Klipberg-Africa, Junggar-Mongolia, Changyi-China, Katharina-Egypt, Alvand-Iran, Madinah-KSA, Czech Republic, Deliler-Turkey shows that most of the studied massifs have a lower Fe_2O_3 content, while the TiO_2 content is almost the same. Except for the Wadi El-Annab massif, the studied massifs have a moderate to high total alkali content compared to those massifs, where the Naciria massif (9.24 wt%) ranks third after Madinah (9.87 wt%) and Klipberg (9.72 wt%). The Draa El Mizane massif has the lowest percentage of iron oxide content compared to all other massifs listed in Table 3.

A comparison of the chemical composition of our rocks with the standard granitic rock containing the average composition of primary commercial sources of feldspar for industry (Table 4) (Dondi, 2018) shows that the required percentages of K_2O, Na_2O, Fe_2O_3 and TiO_2 are successively 5.21%, 4.17%, 0.3% and 0.06%. According to the results of Table 2, the Draa El Mizane massif has a potassium content (+5%) closest to the required percentage, while all other massifs except the Nadroma massif contain +4% potassium. For sodium, Naciria and Nadroma have sodium percentages higher than the required percentage. For the magnetic phase, the Draa El Mizane and Larba Naith Irathen massifs have a close required percentage (<1%), while the other massifs have

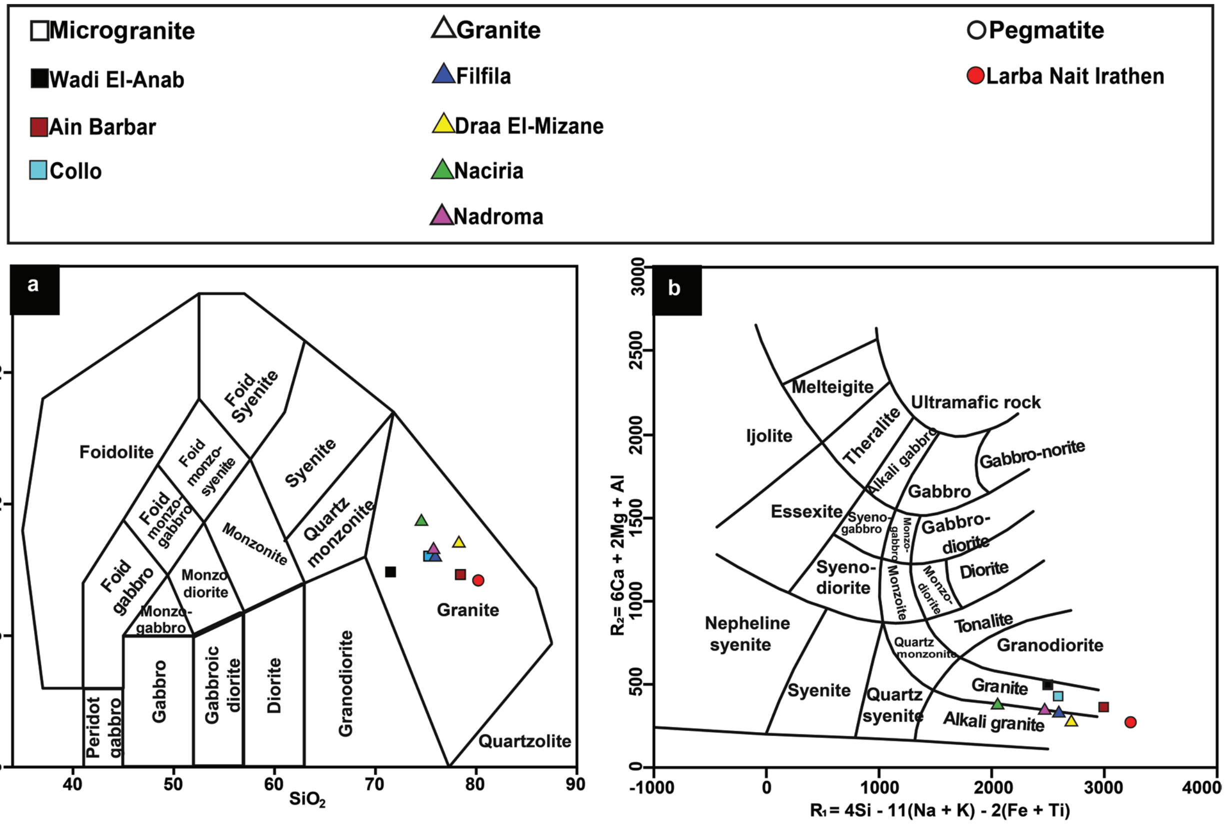

Figure 4. Chemical classification and nomenclature diagrams for the granitic rocks of the studied massifs based on TAS. a):(SiO_2 vs Na_2O+K_2O) diagram of Middlemost (1994) shows that all Massifs are plotted in the granite field; b): total alkali-silica of De la Roche et al. (1980) shows that the microgranitic massifs are plotted in the granite field where the granites and the pegmatite are plotted in the alkali granite field.

a slightly higher percentage.

Based on the mineralogical and chemical results and the comparison between the studied massifs with several similar massifs in the world and the standard granitic rock, all the studied massifs can be evaluated as a source of feldspar for industry (with some reservations for the massif of Wadi El-Anab) for the following reasons: moderate to high content of total alkali (K_2O+Na_2O), low content of accessory and the Massifs are accessible with a large area, which offers a high reserve.

Areas of application of rock feldspar studied

The main elements affecting ceramics and glass processing and product superiority are K_2O, CaO, Na_2O, Al_2O_3, SiO_2, Fe_2O_3 and TiO_2. A comparison of the concentration of these elements with the concentration required for the ceramics and glass industries (Amaireh et Aljaradin, 2014) (Table 5) shows that all the Massifs presidents have suitable chemical compositions as raw materials for the ceramics industry, while in the glass industry, only the massifs of Naciria and Nadroma are suitable as raw material after treatment.

- The Draa El Mizane massif is the only massif that has a higher alkali content than required for ceramics and also has a very low iron content.
- The Filfila, Naciria and Nadroma massifs have a Na_2O content higher than that required for ceramics.
- Except Filfila and Nadroma, all massifs have a K_2O content higher than that required for glass.

From the above, it shows that these Massifs are better adapted to ceramics than to glass so we will compare the chemical properties of these Massifs with those required for the different classes of ceramics according to Deniz and Kadioğlu (2019) (Table 6). The Naciria massif is the only massif suitable for Class II. Filfila and Draa El Mizane are suitable for Class III ceramics. The other Massifs require a treatment (flotation) to be at least suitable for Class III. It is also observed that after treatment, all Massifs may be suitable for Class I or at least for Class II or III.

Advantages of ceramic fluxes

The raw resources mentioned above can be subjected

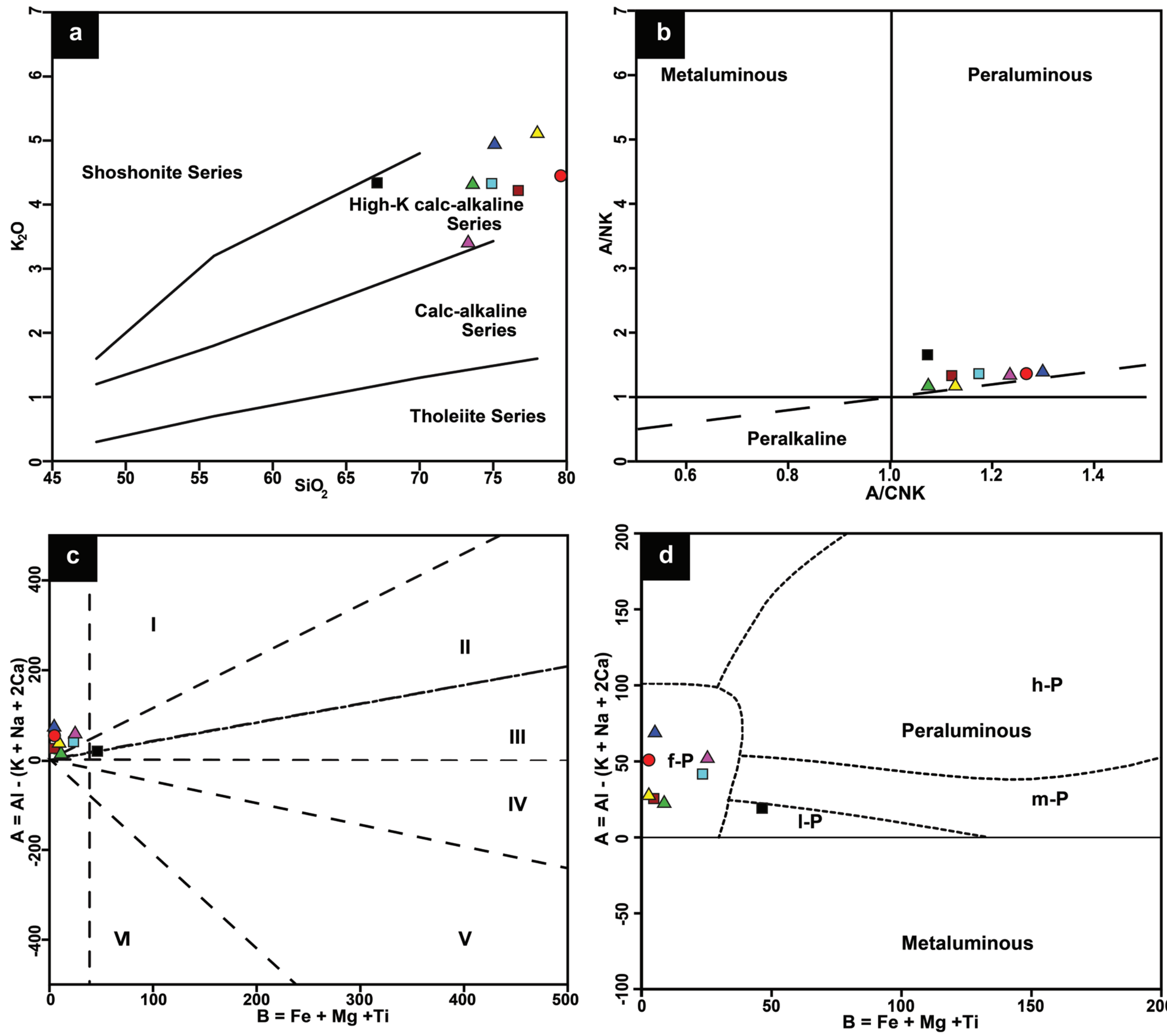

Figure 5. Magma type of the studied granitic rocks: a) SiO_2-K_2O diagram (after Peccerillo and Taylor, 1976); b) shows A/CNK versus the A/NK plot of the studied granitic rocks (after Shand 1943); c) A-B diagram shows the plotted samples of the studied granitic rocks. I, II and III are peraluminous sectors, while IV, V and VI are metaluminous sectors (after Debon and Le Fort, 1983); d) B-A plot modified by studied granitic (after Villaseca et al., 1998) (symbols are shown in Figure 4).

to a more or less extensive processing process to produce products that meet the technical and compositional criteria of commercial fluxes. This process often includes crushing, washing and grinding (Potter, 2006; Saklar et al., 2004). However, additional processes such as attrition, magnetic separation, electrostatic separation, flotation, acid leaching and micronisation may be necessary (Štyriaková et al., 2006; Gougazeh, 2006; Cho et al., 2009; Abouzeid and Negm, 2014). A complete description of these mineralogical treatments cannot be given as it is beyond the scope of this study. The main objective of these mineralogical treatments is to eliminate the minerals that provide iron and titanium oxides, thus preserving or even increasing the number of fluxing minerals in the final product.

The chemistry of the feldspar minerals in the rock or the concentrated feldspar mineral obtained is crucial for their use in industry. The studied massifs are rich in orthoclase and albite (Figures 2 and 3). Due to their chemical composition, feldspar minerals are used for a wide range of applications in glass and ceramic production. The melting temperature of orthoclase in the composition $KAlSi_3O_8$ is 1170 °C, but it can be widely used in the ceramics industry because it can reach 1280 °C. Due

Table 3. Average chemical composition of some world granitic rocks (Scheepers and Schoch, 1988; Lan et al., 2005; Katzir et al., 2007; Geng et al., 2009; Aliani et al., 2011; Gougazeh et al., 2018; Deniz; Kadioğlu, 2019; Breiter et al., 2023).

Oxides (wt%)	Japan	Klipberg (Africa)	Junggar (Mongolia)	Changyi (China)	Katharina (Egypt)	Alvand (Iran)	Madinah (KSA)	Czech	Deliler (Turkey)
SiO_2	72.51	73.08	74.8	76.9	76.8	75.60	70.15	73.05	76.97
Al_2O_3	14.11	13.44	12.9	11.85	12.40	12.90	14.25	14.90	13.02
Fe_2O_3	2.79	1.49	1.96	2.99	1.42	1.50	2.04	0.66	0.72
CaO	2.20	0.18	1.01	0.71	0.35	0.42	1.30	0.39	0.68
MgO	0.37	0.11	0.32	0.35	0.02	0.08	0.39	0.10	0.65
Na_2O	3.20	4.92	4.21	3.82	3.90	2.41	5.03	4.17	2.82
K_2O	4.38	4.80	4.49	4.10	4.32	6.12	4.84	4.65	4.24
TiO_2	0.00	0.08	0.20	0.26	0.08	0.03	0.36	0.03	0.18
Na_2O+K_2O	7.58	9.72	8.7	7.92	8.22	8.53	9.87	8.82	7.06
K_2O/Na_2O	1.37	0.97	1.06	1.07	1.10	2.53	0.96	1.11	1.50
Na_2O/K_2O	0.73	1.025	0.93	0.93	0.9	0.39	1.03	0.89	0.66

Table 4. Average composition of commercial fluxes from granitic rocks (Dondi, 2018).

Elements (wt%)	Granitic rocks
SiO_2	73.10
Al_2O_3	15.14
Fe_2O_3	0.32
CaO	0.74
MgO	0.11
Na_2O	4.17
K_2O	5.21
TiO_2	0.06

Table 5. Elements required concentrations for the ceramic and glass industry (Amaireh et Aljaradin, 2014).

Elements (wt%)	Ceramic industry	Glass industry
SiO_2	75.0	68.90
Al_2O_3	15.0	18.75
Fe_2O_3	0.3	0.30
Na_2O	3.3	7.15
K_2O	4.5	3.85
CaO	-	1.85

to its melting temperature of 1120 °C in the $NaAlSi_3O_8$ composition, albite has strong melting properties. Therefore, it is used in the vitrification phase (Gürsoy, 1999; Deniz and Kadioğlu, 2019). Na-rich feldspar ($K_2O/Na_2O \leq 1$) is preferred in modern flash firing processes due to its high melting point and solvent properties (Lewicka, 2010). In these studied granitic rocks, except Naciria and Nadroma, the K_2O/Na_2O of all Massifs is >1 (Table 2). In this case, the Naciria and Nadroma granites are suitable for rapid firing, while the other Massifs are suitable for traditional firing.

CONCLUSIONS

Produce feldspar from our studied massifs with the desired quality, taking into account that the colour elements in the rocks are below the desired values since the availability of high-quality feldspar depends entirely on the removal of unfavourable minerals by modern technologies. Reducing the magnetic separation phases leads to a reduction in the amount of colour-forming oxides such as Fe_2O_3, in the mineral and/or rock, saving time and labour.

The granitic rocks of the Algerian coast provide a source of feldspar extraction for industry. Sharing these Massifs gives them greater value:

(i) The massifs Naciria (Boumerdes), Draa El Mizane (Tizi Ouzou) and Larba Nait Irathen (Tizi Ouzou) can be exploited together. These three Massifs take first place with a total alkali content (Na_2O+K_2O) of 7.64 wt% to 9.24 wt% (average 8.45 wt%) and low iron oxides (0.34 wt% - 2.19 wt%, average 1.25 wt%). They have a large

Table 6. Required chemical compositions of Feldspar Class in the ceramic sector (Deniz and Kadioğlu, 2019).

Composition de feldspath (wt%)	Classe I	Classe II	Classe III
Na_2O+K_2O	10.00	9.0	8.0
Fe_2O_3	0.10	0.2	0.5
TiO_2	0.15	0.3	0.4
CaO+MgO	1.00	1.2	1.6
TiO_2+CaO+MgO	1.15	1.5	2.0

reserve that gives them priority in exploitation.

(ii) Wadi El-Anab (Annaba), Ain Barber (Annaba), Filfila (Skikda) and Collo (Skikda) took second place. They can be extracted together considering the distance between them, having a high quantity with an average total alkali range of 6.95 wt% to 8.2% wt% (average 7.56 wt%) and the average iron oxides are between 1.32 wt% and 3.08 wt% (average 2.19 wt%).

(iii) As a good reserve, the Nadroma massif (Tlemcen) has an average total amount of alkali (7.67 wt%) and iron oxides (2.19 wt%).

The availability of high-quality feldspar from these Massifs depends entirely on the removal of the magnetic phase through advanced technology; therefore, it seems possible to produce feldspar of the required quality, considering that the colour components of the rocks are below the desired values. As a result, it was decided that the studied massifs in the region represent high feldspar potential, particularly for ceramics.

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