

## **Geochemistry of plagioclase phenocrysts from andesite dykes of Wadi El-Mellaha area, Eastern Desert, Egypt**

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### **ABSTRACT**

Six plagioclase phenocryst samples have been separated from andesitic dyke rocks of Wadi El-Mellaha area. Selected major and trace elements of the plagioclase phenocrysts and their host rocks were chemically determined. The distribution and behaviour of these elements in the plagioclases and andesitic host rocks were analysed to determine the chemistry of plagioclase phenocrysts and the genesis of the host rocks. The plagioclase phenocrysts are characterized by low Ca, Sr and Fe contents toward the felsic end member. Opposite relations are observed in the case of Na, Ba and Ga. It is evident that the host rocks of plagioclase phenocrysts were formed from intermediate melt through a short-range fractional crystallization process.

### **INTRODUCTION**

The present study deals with the chemistry of plagioclase phenocrysts and their host andesitic dyke rocks of Wadi El-Mellaha area, Esh El-Mellaha range, in the Eastern Desert of Egypt (Fig. 1). The andesitic dykes of Wadi El-Mellaha cut all granitic basement rocks but were not seen to cut the Nubian sandstone or younger sediments, so that they must be of pre-Nubian and probably of Pre-Cambrian age. These andesite dykes dip strongly and are characterized by uniform thickness. Contacts with the host rocks are generally sharp; in some cases the contacts may be hematitised for a few centimetres into the dyke. The dykes are considered post-granitic and represent the final activity of magma in the area.

The andesite dyke rocks are generally hard, massive, fine-grained, and of greyish-green to brownish-green colour. They are normally equigranular, but sometimes abundant phenocrysts of plagioclase and mafic minerals are embedded in a fine ground-mass giving rise to andesite porphyry and porphyritic andesite. The general geology of dykes in Esh El-Mellaha range and Wadi El-Mellaha area was previously examined in detail by Kabesh & Shahin (1968) and Kabesh *et al.* (1970, 1977).

### **MINERALOGICAL INVESTIGATIONS**

Microscopic examination shows that the rocks are composed of plagioclase, pyroxene,

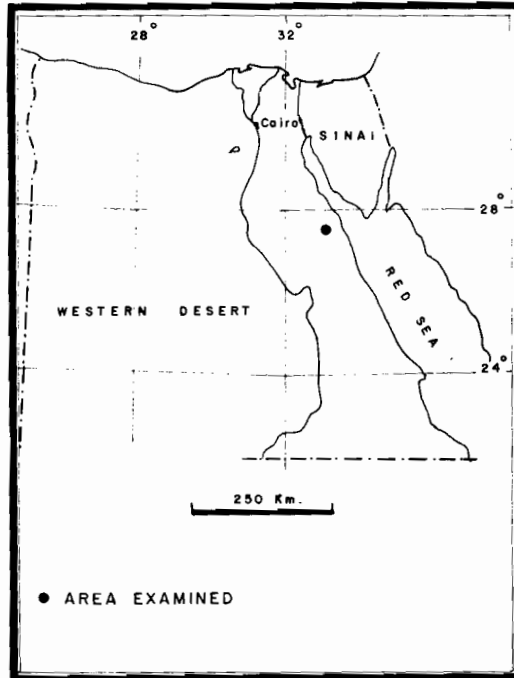


Fig. 1. Location map.

hornblende and biotite as essential minerals with magnetite, ilmenite and chlorite as accessories. The modal analyses of the andesites are shown in Table 1. The plagioclase phenocrysts are the most abundant mineral in andesites; this would indicate that the plagioclase is the initial liquidus phase in most of the andesitic dykes. The modal percentage of plagioclase phenocrysts varies from 21 to 31. The mafic mineral phenocrysts include augite (3%), hornblende (4–10%) and biotite (8%).

The groundmass consists of sodic-rich plagioclase ( $An_{20}$ – $An_{35}$ ), mafic minerals and small amounts of glass. The phenocryst to groundmass ratio ranges from 0.29 to 0.63, thus classifying the rock as andesite porphyry. The plagioclase phenocrysts usually form euhedral crystals varying from 3 to 13 mm in length and from 2 to 6 mm in breadth.

The composition of the plagioclase phenocrysts tends to vary from oligoclase ( $An_{25}$ ) to andesine ( $An_{45}$ ). Some phenocrysts are commonly zoned in which a chemical variation between the core ( $An_{38}$ ) and the rim ( $An_{27}$ ) reflects clear extinction contours. The presence of zoning in the plagioclase shows that compositional changes took place in the magma during decreasing temperature, i.e. the core of the plagioclase crystal received more calcium ions than the rim forming normal zoning (Homma 1932). Pringle *et al.* (1974) mentioned that the formation of normally zoned plagioclase crystals is controlled by relatively rapidly removed heat causing some degree of supercooling under anhydrous conditions. The plagioclase phenocrysts may show irregular fractures cutting across the twinning planes. Generally, the origin of these fractures is attributed to the crystal mesh of the cooling melt which has been subjected to a uniform internal stress which was resisted by the feldspars (Goodspeed 1959). Such fractures play a significant role in the final stage of the crystallization of the

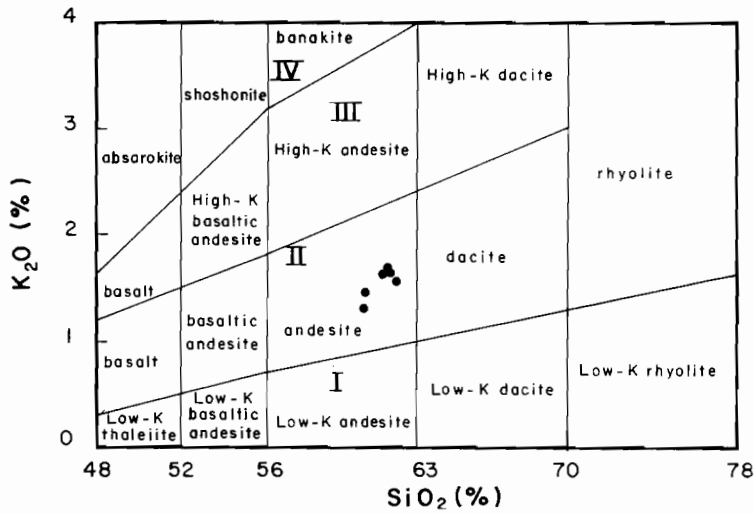


Fig. 2. Relationship between  $\text{SiO}_2$  and  $\text{K}_2\text{O}$  contents (after Taylor 1968).

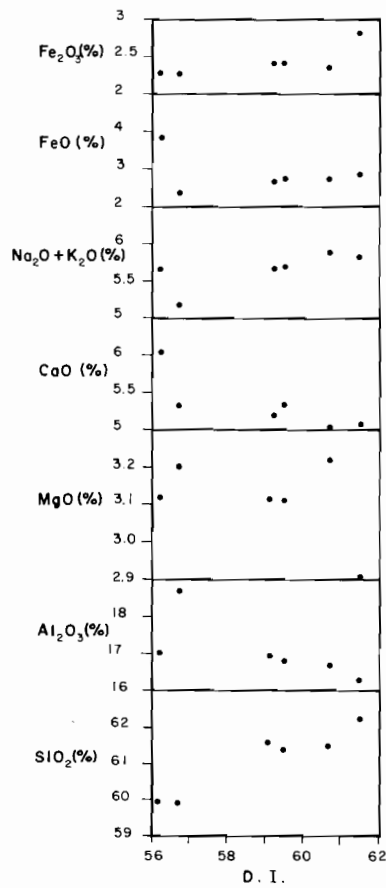


Fig. 3. Major oxide variations plotted against the differentiation index.

andesites, i.e. the fractures create minute paths for the late magmatic and deuteric alterations. In some cases, the plagioclase phenocrysts exhibit well-defined, irregular and embayed outlines which are attributed to magmatic corrosion. The corrosion may be caused by chemical reaction with the residual melt or by the increase of vapour tension during crystallization (Rittmann 1962).

### THE CHEMISTRY OF THE ANDESITES

The major elements of six andesite samples and their normative minerals are listed in Table 2. Selected trace elements were determined from the six samples of the andesite (Table 3). The major elements of the andesites were determined by using the volumetric and gravimetric methods of Bennett & Reed (1971) whereas the trace elements of the same samples were determined by using a Q 24 Carl Zeiss emission spectrograph.

### MAJOR AND TRACE ELEMENTS

The distribution and behaviour of major and trace elements in the andesites are discussed with the use of variation diagrams. According to Taylor *et al.* (1969), a classification scheme is based on the relation between  $\text{SiO}_2$  and  $\text{K}_2\text{O}$  (Fig. 2), in which the scheme is divided by three inclined lines into four main zones comprising tholeiite series (I), calc-alkaline series (II), high-K calc-alkaline series (III) and shoshonite series (IV). The andesite rocks examined fall in the field of normal andesite which is related to the calc-alkaline zone (II).

The various major elements are plotted against the differentiation index (Thornton & Tuttle 1960) in Fig. 3. The differentiation index (D.I.) of the andesite rocks varies

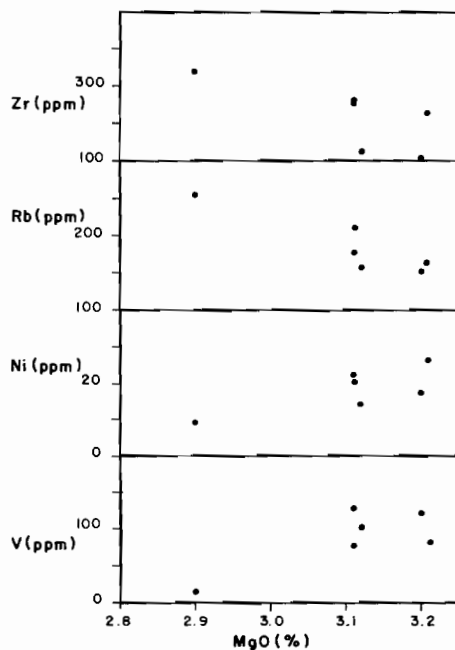


Fig. 4. A plot of V, Ni, Rb and Zr (ppm) versus  $\text{MgO}\%$  in the andesite rocks.

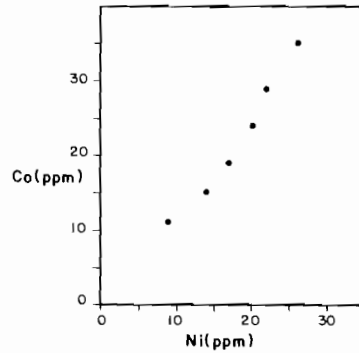


Fig. 5. Relationship between Ni and Co in the andesite rocks.

from 56.2 to 61.5 which is the sum of weight percentages of normative quartz + orthoclase + albite (Table 2). It is observed that  $\text{SiO}_2$  and  $\text{Na}_2\text{O} + \text{K}_2\text{O}$  increase with increasing D.I., whereas  $\text{Al}_2\text{O}_3$  is almost constant. The nature of major elements in Fig. 3 shows little chemical variation in the andesitic rocks, i.e. the elements concentration in the andesitic melt gradated, within a narrow range, through a magmatic crystallization process giving rise to similar types of andesitic rocks.

Selected whole-rock trace element contents (Table 3) are plotted against MgO content in Fig. 4. MgO content is considered a function reflecting the chemical magmatic variation of andesitic melt, i.e. the MgO of the melt decreases towards the felsic end member under decreasing temperature (Fig. 4). The diagram shows that V and Ni increase while the Rb and Zr content decreases with increasing MgO content. The relationship indicates that the V and Ni content increases in passing from late to early andesites whereas the Rb and Zr content decreases in the same direction.

Fig. 5 shows the relation between the Ni and Co content of the andesitic rocks.

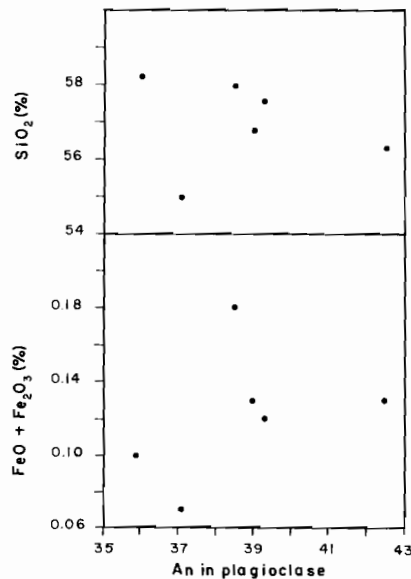


Fig. 6. Relationship between some major elements and normative An contents of plagioclases.

Both elements increase together forming a typical linear relationship in the andesites. The Ni values and Ni/Co ratios (Tables 3) vary from 9 to 22 ppm and from 0.74 to 0.93 respectively, showing that these andesites have low concentrations of Ni (< 22 ppm) and low Ni/Co ratios (< 1). The previously discussed data preclude derivation of these andesite dykes from basaltic magma by a fractional crystallization process (Taylor *et al.* 1969).

### CHEMISTRY OF THE PLAGIOCLASE PHENOCRYSTS

Six samples of plagioclase phenocrysts were separated from their host rocks by drilling with an electric nail bit. Initial separation was carried out utilising bromoform to separate plagioclase crystals from contaminated heavy materials. Final purification of plagioclase was carried out by applying the maximum current setting on the isodynamic separator. The major elements of the plagioclase phenocrysts and their structural formulae are shown in Table 4.

Fig. 6 shows the relationship between the normative An content of the plagioclases (Table 2) and the total iron (FeO + Fe<sub>2</sub>O<sub>3</sub>) and SiO<sub>2</sub> contents. The normative An content is calculated according to the following equation:

$$\text{An in plagioclase} = \frac{\text{Rock normative An} \times 100}{\text{Rock normative (An + Ab)}}$$

(after Caracas & Lexington, 1974).

It is concluded that the An content of the plagioclase increased with increase of the Fe content whereas an opposite relation is observed in the case of SiO<sub>2</sub>, i.e. Fe and Ca content decreased toward the felsic end member during the crystallization of the melt.

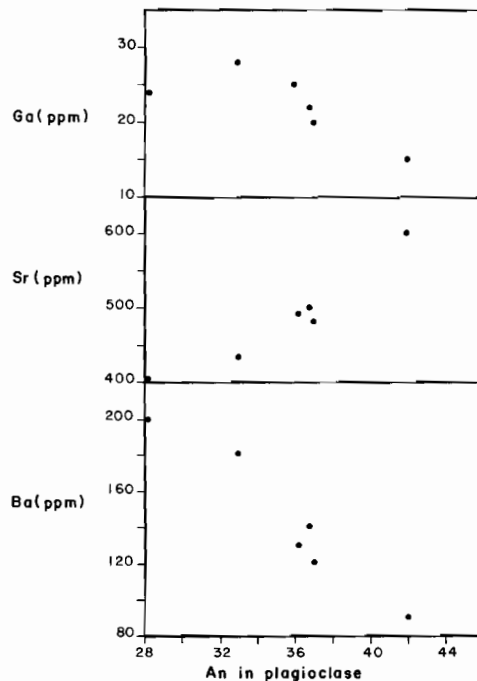


Fig. 7. Plot of An in plagioclases versus Ga, Sr and Ba contents in plagioclases.

### STRUCTURAL FORMULAE

The structural formulae of plagioclases was calculated from the chemical analyses on the basis of 32 oxygens (Table 4). The coordinated Z group (Si + Al) ranges from 15.140 to 16.554. The coordinated large cations of the X group ( $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ , Mg, Ca, Na and K) vary from 3.702 to 4.802. The Na atoms of the examined plagioclases form over 51.4% of the X ions. The plagioclases contain small amounts of the Fe and Mg. It is expected that Mg is replacing Ca in the X site of some of the plagioclases. The  $\text{K}^+$  content of the plagioclase phenocrysts ranges from 0.205 to 0.250 (Table 4), suggesting that these plagioclases were crystallised from a melt characterised by a homogeneous K content. The values of the An content of the plagioclases (Table 4) agree to some extent with the normative An (Table 2). Both An contents show that the majority of the plagioclase phenocrysts are of andesite composition.

The trace element contents in the plagioclase phenocrysts are given in Table 5. Fig. 7 shows the relationship between the An content of the plagioclases (Table 4) and their trace elements (Ga, Sr and Ba). Generally speaking, the plagioclase contains more abundant Ga than the alkali feldspars. Therefore, the less abundant disordered potassic phase in the andesitic melt allows the plagioclase to receive most of the Ga contents of the ordered sodic phase (Mackenzie & Smith 1961). The Ga contents of the examined plagioclases vary from 15 to 28 ppm. The data for Ga indicates that there is a decrease as the An content increases, i.e. plagioclases crystallised from Na-rich solutions tend to have high Ga content (Smith 1974). It is interesting to mention that the decrease of An content of the plagioclases is usually accompanied by enrichment in constituents of low melting temperature. These constituents receive Ga, which has high ionic radius ( $\text{Ga}^{3+}$  0.62 Å<sup>o</sup>), more than the low ionic radius Al ( $\text{Al}^{3+}$  0.51 Å<sup>o</sup>) during the magmatic crystallisation.

The distribution of Sr in the plagioclases of igneous rocks has received much attention from a number of workers. Wager & Mitchell (1951) and Butler & Skiba (1962) show that the Sr content of plagioclases increases as the An content decreases in basic rocks. On the other hand, Sen *et al.* (1959) mentioned that Sr content decreases as the An content decreases in the acidic rocks. The  $\text{SiO}_2$  content of the host rocks of the examined plagioclases ranges from 59.91% to 62.21% showing that the composition of the andesites varies from intermediate to sub-acidic types. Therefore, the Sr content of the plagioclase phenocrysts (Table 5) increases as the An content (Table 4) increases (Fig. 7). It is evident that the early crystallized plagioclases are richer in Ca and Sr but poorer in Ba than the plagioclases formed later on during the fractional crystallisation process of intermediate melt.

### CONCLUSION

The presence of irregular fractures in the examined plagioclases is attributed to a uniform internal stress which was resisted by the feldspars. The corrosion around the boundaries of the plagioclase phenocrysts is due to the chemical reactions between the residual melt and the earlier crystallised plagioclases. The plagioclase phenocrysts show progressive compositional zonation from calcic core to a sodic rim suggesting that a chemical magmatic change took place during decreasing temperature.

The petrographic classification of the andesite rocks is in harmony with the

classification based on the chemical data confirming that these host rocks fall in the field of andesites.

It can be concluded that little chemical variation in the major and trace elements took place during the magmatic crystallisation process. The andesitic melt was characterised by high contents of Al, Ca, Mg, V and Ni at the beginning of crystallization whereas the rocks which were formed later show some tendency towards Si, Na, K, Rb and Zr enrichment. The andesites have low concentrations of Ni in addition to low ratios of Ni/Co and this suggests that these andesites were not derived from basaltic magma by fractional crystallisation process (Taylor *et al.* 1969).

The plagioclases show initially an increase of CaO, but with further fractionation Na<sub>2</sub>O increases over CaO, whereas K<sub>2</sub>O remains almost constant with slight enrichment in some sericitised plagioclase phenocrysts. The plagioclase phenocrysts are characterised by high Na, Ba and Ga contents toward the felsic end member, i.e. the Na, Ba and Ga contents increase with an increase of Si in their host rocks or a decrease of An content of plagioclases; opposite relations are observed in the case of Ca, Sr and Fe.

It can be concluded that the compositional trends and distribution of the major and trace elements and their smooth curves in the variation diagrams show that the host rocks of the plagioclase phenocrysts were formed through a short-range fractional crystallisation process of a melt ranging in composition from intermediate to sub-acidic during decreasing temperature.

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**Table 1.** Modal analyses (%) of andesitic rocks

Field no.	1	2	3	4	5	6
Phenocrysts	24	23	29	38	39	30
Plagioclase	24	21	22	28	31	30
Augite	—	—	3	—	—	—
Hornblende	—	—	4	10	—	—
Biotite	—	—	—	—	8	—
Quartz	—	2	—	—	—	—
Groundmass	76	77	71	62	61	70
Plagioclase	41	52	47	40	34	42
Mafic minerals	35	11	24	22	27	21
Quartz	—	14	—	—	—	7
Colour index	37	11	31	32	35	21
Phenocrysts	0.31	0.29	0.42	0.61	0.63	0.42
Groundmass						

1, Andesite porphyry; 2, Quartz andesite porphyry; 3, Hornblende augite andesite porphyry; 4, Hornblende andesite porphyry; 5, Biotite andesite porphyry; 6, Quartz biotite andesite porphyry.

N.B.: Field numbers referring to various andesitic rocks are the same throughout the present paper.

**Table 2.** Chemical analyses (%) and norms of andesitic rocks

Field no.	1	2	3	4	5	6
SiO <sub>2</sub>	61.45	62.21	59.92	59.91	61.55	61.65
TiO <sub>2</sub>	0.33	0.21	0.65	0.31	0.50	0.55
Al <sub>2</sub> O <sub>3</sub>	16.81	16.32	18.71	17.01	16.72	16.93
Fe <sub>2</sub> O <sub>3</sub>	2.44	2.86	2.31	2.32	2.41	2.42
FeO	2.81	2.91	2.42	3.92	2.83	2.71
MgO	3.11	2.90	3.20	3.12	3.21	3.11
CaO	5.34	5.04	5.31	6.04	5.00	5.21
Na <sub>2</sub> O	4.12	4.32	4.01	4.32	4.31	4.21
K <sub>2</sub> O	1.61	1.55	1.21	1.42	1.62	1.52
H <sub>2</sub> O	1.43	1.61	1.31	1.21	1.43	1.29
P <sub>2</sub> O <sub>5</sub>	0.14	0.12	0.22	0.15	0.24	0.21
Total	99.59	100.05	99.27	99.71	99.82	99.81

Norm values (%)						
Field no.	1	2	3	4	5	6
Quartz	15.20	15.97	15.90	11.39	14.74	14.67
Orthoclase	9.45	9.16	7.12	8.40	9.56	9.01
Albite	34.84	36.36	33.85	36.47	36.42	35.50
Anorthite	22.57	20.42	25.00	22.80	21.46	22.71
Corundum	—	—	1.65	—	—	—
Diopside	2.60	3.10	—	5.16	1.61	1.30
Hypersthene	9.20	9.70	9.34	10.04	9.62	11.10
Magnetite	3.53	4.15	3.32	3.36	3.48	3.50
Ilmenite	0.62	0.39	1.23	0.59	0.95	1.03
Apatite	1.01	0.94	1.20	1.10	1.84	1.64
Colour index	15.95	17.34	13.89	19.15	15.66	16.93
$An = \frac{An \times 100}{An + Ab}$	39.31	35.96	42.48	38.46	37.07	39.00
Differentiation index	59.41	61.49	56.77	56.76	60.72	39.10

**Table 4.** Chemical analyses (%) and structural formulae of plagioclases from andesitic rocks

Field no.	1	2	3	4	5	6
SiO <sub>2</sub>	57.63	58.21	56.43	57.98	54.98	56.81
Al <sub>2</sub> O <sub>3</sub>	26.52	25.11	27.23	25.63	27.31	26.36
Fe <sub>2</sub> O <sub>3</sub>	0.03	0.02	0.03	0.05	—	0.04
FeO	0.09	0.08	0.10	0.13	0.07	0.09
MgO	0.01	0.01	—	0.07	—	0.02
CaO	7.98	8.32	7.66	6.58	9.13	6.45
Na <sub>2</sub> O	7.08	6.89	6.74	7.78	6.45	8.62
K <sub>2</sub> O	0.99	1.03	1.10	1.04	1.32	1.33
H <sub>2</sub> O	0.10	0.14	0.19	0.16	0.20	0.18
Total	100.43	99.81	99.48	99.42	99.46	99.90

	Cations for 32 oxygens					
Si } Z	10.268	10.557	10.097	9.990	10.795	10.224
Al } Z	5.461	5.234	5.938	5.149	5.759	5.438
Fe <sup>+3</sup>	0.004	0.002	0.003	0.006	—	0.005
Mg } X	0.267	0.272	—	0.175	—	0.543
Fe <sup>+2</sup>	0.001	0.011	0.014	0.185	0.099	0.013
Ca } X	1.497	1.526	1.468	1.132	1.772	1.196
Na } X	2.353	2.399	2.338	2.059	2.215	2.828
K } X	0.213	0.219	0.250	0.205	0.221	0.217
OH	0.016	0.152	0.226	0.164	0.221	0.217
Z	15.72	15.79	16.035	15.14	16.55	15.66
X	4.235	4.419	4.07	3.702	4.307	4.802
Ant(%)	36.8	37.00	36.19	33.2	42.1	28.2
Ab(%)	58	57.7	57.64	60.6	52.6	66.6
Or(%)	5.2	5.3	6.16	6.2	5.2	5.1

**Table 3.** Trace element concentrations (ppm) and some elemental ratios of the andesitic rocks

Field no.	1	2	3	4	5	6
Ba	169	117	216	197	236	159
Sr	618	851	377	411	514	620
V	76	19	120	99	81	127
Ni	20	9	17	14	26	22
Co	24	11	19	15	35	29
Rb	179	255	149	158	159	210
Zr	250	340	99	115	231	256
Ni/Co	0.83	0.87	0.90	0.93	0.74	0.76

**Table 5.** Trace element concentration (ppm) of plagioclases from andesitic rocks

Field no.	1	2	3	4	5	6
Ba	140	120	130	180	95	200
Sr	500	480	490	430	600	400
Ga	22	20	25	28	15	24

جيوكيميائية البلاجيوكليزات الظاهرة في قواطع الانديزيت  
لمنطقة وادى الملاحة بالصحراء الشرقية المصرية

زنب محمد عبدالله معهد التربية للمعلمات ، الشامية ، الكويت	عادل محمد رفعت معهد التربية للمعلمين ، العديلية ، الكويت	محمود لطفى كابش معمل علوم الارض بالمركز القومى للبحوث ، الدقى ، القاهرة
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خلاصة

تم فصل ست بلورات بلاجيوكليزية ظاهرة من القواطع الانديزيتية بمنطقة وادى الملاحة . وقد حددت بعض العناصر الاساسية والنادرة في هذه البلاجيوكليزات والصخور الحاوية لها ، وتمت مناقشة توزيع وسلوك هذه العناصر في البلاجيوكليزات وصخور الانديزيت من خلال مخططات مختلفة ، ومن خلال عديد من المدلولات الجيوكيميائية ، وذلك لاستنتاج الخواص الجيوكيميائية للبلاجيوكليزات الظاهرة بالاضافة الى معرفة اصل تكوين الصخور الحاوية لها .

