Ahmad M. MORSY*, Mohamed S. ATIA**

EFFECTS OF WEATHERING ON THE MINERALOGY AND CHEMICAL COMPOSITION OF SOME EGYPTIAN BASALTS

Abstract. X-ray diffraction and chemical analyses were carried out on fresh and weathered basalt samples from seven localities in Egypt, viz. Abu Rawash, Abu Zaabal, Qatrani, Bahariya, Bahnasa, the Cairo-Suez road and the Red Sea coast. Progressive weathering induces variations in the intensities of X-ray reflections of different minerals, accompanied by variation in the contents of different elements as resulting from chemical analysis. The degree of weathering was related to two parameters, viz. the degree of oxidation of iron and the weathering index of Parker (1970). A fair correlation was found between these parameters, both indicating that the Bahariya samples are the most whilst the Qatrani samples the least weathered. The identified clay minerals resulted from weathering processes were chlorite, montmorillonite, illite and mixed-layer montmorillonite//vermiculite and illite/montmorillonite. These clay minerals were formed through neoformation from silicates and degradational transformation of these neoformed minerals.

INTRODUCTION

The mid-Tertiary sedimentation in Egyptian territory was interrupted by extensive volcanic activity accompanied by crustal movements which were responsible for the formation of the Red Sea Graben. Magma penetrated Oligocene and older rocks in many localities hundreds of kilometers apart. This resulted in the formation of isolated basaltic dykes, sheets and volcanic cones. A detailed presentation of these occurrences was given by Andrew (1937) and later by Said (1962). It is almost certain that the active magma of all the Tertiary volcanoes of Lower Egypt was basaltic. Nevertheless, the types of eruptions varied from pure effusive and mixed to highly explosive and even cryptovolcanic (Said 1962). Although these basalts may not be exactly contemporaneous, they constitute a mappable rock unit that is frequently taken as the upper limit of the Oligocene succession in Egypt.

The present paper aims to study the exposed basaltic rocks and their weathering clays in seven localities, viz. Abu Rawash, Abu Zaabal, Qatrani, Bahariya, Bahnasa, the Cairo-Suez road and the Red Sea coast (Fig. 1), in order to identify the effects of weathering on the mineralogy and chemical composition of these basalts.

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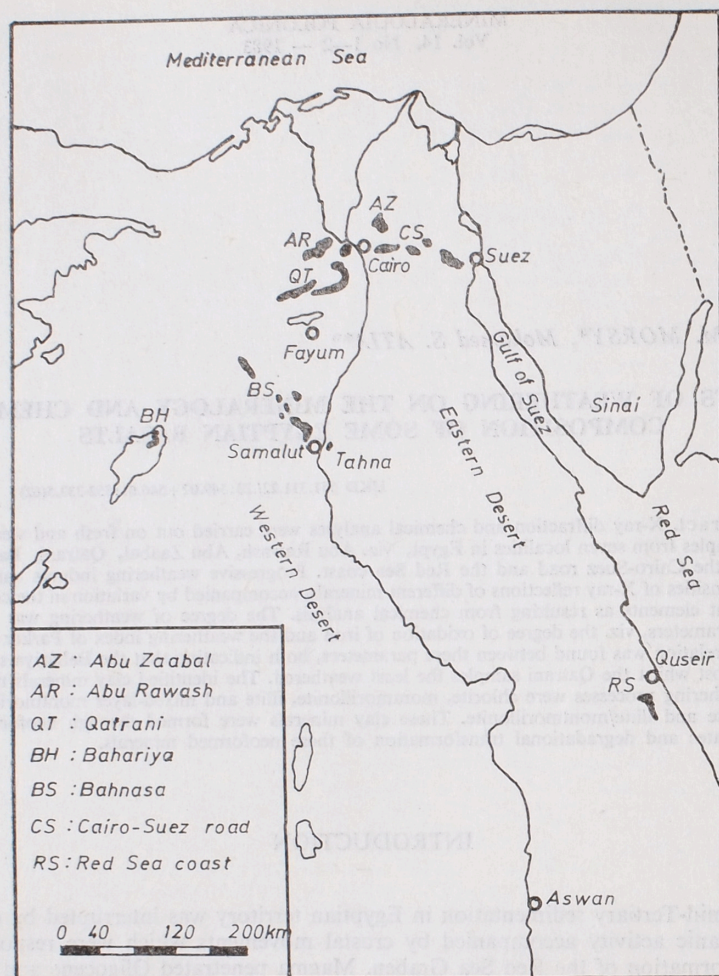* Geology Dept., Faculty of Science, El-Menofiya University, Shebin El-Kom, Egypt.

Fig. 1. Location map of investigated Egyptian basalts

AZ : Abu Zaabal
AR : Abu Rawash
QT : Qatrani
BH : Bahariya
BS : Bahnasa
CS : Cairo-Suez road
RS : Red Sea coast

0 40   120   200 km

In Abu Rawash, the main basaltic sheet averages 40 m in thickness and is defined by Gindy and Ghozlan (1968) as olivine dolerites with in-situ weathering products.

In Abu Zaabal, the basalt was defined as coarse-grained rather than doleritic (Faris, Kamel 1953), and was classified as calc-alkaline, intermediate between average tholeiitic and average alkali basalt (Abd El-Aal 1975).

In Gebel Qatrani, a 25 m thick sheet of basalt was described as early as in 1905 by Beadnell as post-Oligocene and pre-Lower Miocene amygdaloidal rock associated with pyroclastic rocks.

In Bahariya Oasis, a 20 m thick sheet of olivine basalt occurs (Akkad, Issawi 1963). Tosson (1964) described it as a dolerite with holocrystalline medium-grained groundmass. Both types were detected by El-Kaluobi (1974), who stated that Ba-

hariya volcanic rocks belong to the alkali group derived from one parent magma of olivine-basaltic composition intruded during two consecutive cycles of volcanic activity (based upon age determination).

In Bahnasa, extrusive basalt flows forming isolated outcrops extend to the southwest as far as Bahariya Oasis. These were described as hard dark andesitic basalts (Ball, Beadnell 1903) and considered by Abd El-Maksoud (1969) to be erupted beneath shallow waters, as indicated by pillow lavas observed in some parts of the area.

Along the Cairo-Suez road, a 15 m thick sheet of basalt is frequently seen near the top of the Oligocene and underlying the marine Miocene deposits, always connected with faulting and fissures. Shukri and Akmal (1953) stated that basalts of Gebel El-Nasuri and Gebel El-Anqabiya are similar to other Egyptian Tertiary basalts, especially those of Abu Zaabal. Shukri and El-Ayouty (1956) stated that some of the basalts of Gebel Gafra and Gebel Iweibid are amygdaloidal olivine basalt, the amygdales being filled with quartz, chlorite and calcite, and that very thin later-stage veins of quartz and calcite are present.

On the Red Sea coast, Sabet (1958, 1961) defined five dolerite flows south of Quseir, all being porphyritic olivine dolerites with an average thickness of about 25 m, jointed, fractured and extremely weathered.

EXPERIMENTAL

The present studies were carried out on 42 basalt samples from the above mentioned localities, six from each locality. Samples were taken after the arbitrary field classification of the basalt exposures into three categories, namely, fresh, slightly weathered and weathered (denoted as *f*, *sw*, and *w*, respectively), and then two samples were collected from each category. The sampling sites of weathered basalts were chosen so as to guarantee the leak of any material derived from other units of the country rock.

Chemical analyses were carried out following mainly the method presented by Shapiro and Brannock (1962) with slight modifications. SiO_2, total iron oxides, TiO_2, MnO and P_2O_5 were determined spectrophotometrically, Na_2O and K_2O — by flame photometry. CaO and MgO were estimated by complexometric titration, and FeO — volumetrically.

X-ray diffraction analysis of basalt samples was carried out using a Philips PW 1010 X-ray generator fitted with a PW 1050 vertical goniometer and a PM 8000 flat-bed recorder. Iron-filtered cobalt radiation was used, applying the most appropriate instrument settings and working conditions.

The clay fraction ($< 2\ \mu m$) was separated from the slightly weathered and weathered samples after washing them several times with hot (70—80°C) dilute (1.2%) HCl, and then with 30% H_2O_2. This fraction was separated according to Stoke's law, deposited on glass slides and left to settle and dry. Three slides were prepared from each sample and X-rayed as untreated (U), glycolated (G) and heated (H) at 550°C for 2 hours. Identification of clay minerals was performed by comparing with the data given by Brindley (1951), Grim (1953), Brindley and Gillery (1956), Weaver (1956), Brown (1961) and Millot (1970).

RESULTS AND DISCUSSION

During the present study, the plagioclase X-ray diffraction lines were found to be closer to those of reference labradorite than any of the plagioclase members. Consequently, labradorite was taken as a plagioclase representative in the rocks studied. The same applies to pyroxenes for which augite was taken as the major mafic mineral.

For samples from the same locality only slight differences were observed in the intensities of X-ray reflections so that the patterns of samples of the same category (fresh, slightly weathered or weathered) from the same locality could be considered identical. The minerals detected by X-ray diffraction in representative samples were labradorite, augite, olivine, magnetite, ilmenite, haematite, antigorite, nepheline and calcite (Tab. 1).

The results of chemical analyses of samples representative of the slightly weathered and weathered categories from different localities, as compared with those of fresh samples, are presented in Table 2.

Table 1

Mineral composition of Egyptian basalts determined by X-ray study

Locality	Degree of weathering	Minerals identified								
		Lab	Aug	Mag	Ilm	Hem	Olv	Ant	Cal	Nph
Abu Rawash	f	+	+	+	+	+	+			
	sw	+	+	+	+	+				
	w	+	+	+	+	+				
Abu Zaabal	f	+	+	+	+					
	sw	+	+	+	+					
	w	+	+	+	+					
Qatrani	f	+	+				+			
	sw	+	+							
	w	+	+	+						
Bahariya	f	+	+	+						+
	sw	+	+	+						+
	w	+	+	+						+
Bahnasa	f	+	+	+				+	+	
	sw	+	+	+					+	
	w	+	+	+					+	
Cairo-Suez	f	+	+	+			+		+	
	sw	+	+	+					+	
	w	+	+	+	+				+	
Red Sea	f	+	+	+	+		+			
	sw	+	+	+	+					
	w	+	+	+	+					

Symbols: f — fresh, sw — slightly weathered, w — weathered.
Minerals: Lab — labradorite, Aug — augite, Mag — magnetite, Ilm — ilmenite, Hem — haematite, Olv — olivine, Ant — antigorite, Cal — calcite, Nph — nepheline.

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Table 2

Results of chemical analysis of weathered Egyptian basalts

Sample No	Locality	Status	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O	Loss on ignition	Total
1	AR	f	47.70	2.52	15.97	4.51	7.76	0.18	5.88	9.58	2.86	0.77	0.38	0.91	0.82	99.84
2	AR	sw	47.62	2.56	16.40	5.23	6.95	0.18	5.66	9.52	2.92	0.77	0.39	0.95	0.90	100.04
4	AR	w	47.37	2.54	16.92	6.85	4.87	0.12	5.45	9.12	2.75	0.75	0.39	1.92	0.95	100.00
6	AZ	f	48.04	2.44	15.94	5.12	7.69	0.16	5.84	9.52	2.69	0.79	0.37	0.89	0.80	100.29
7	AZ	sw	47.64	2.44	16.52	6.54	5.33	0.14	5.86	9.44	2.75	0.80	0.36	1.56	0.85	100.23
9	AZ	w	47.28	2.48	16.54	7.08	4.40	0.14	5.40	9.57	2.66	0.74	0.38	2.30	1.41	100.38
10	QT	f	47.60	2.52	16.12	4.44	8.22	0.14	5.97	9.72	2.45	0.76	0.36	0.69	0.90	99.88
11	QT	sw	47.52	2.54	16.38	5.56	7.08	0.13	5.82	9.66	2.49	0.76	0.39	0.80	0.91	100.02
13	QT	w	47.17	2.57	16.96	6.34	5.10	0.12	5.92	9.72	2.43	0.72	0.50	1.80	1.46	100.81
14	BH	f	47.72	1.97	16.53	3.13	7.39	0.16	7.48	8.78	3.15	1.56	0.32	0.77	0.64	99.54
15	BH	sw	48.02	1.77	16.92	3.85	6.36	0.14	7.54	8.56	3.10	1.50	0.35	0.86	1.02	99.99
17	BH	w	47.94	2.18	18.32	5.58	1.95	0.08	6.27	8.02	3.11	1.55	0.64	2.21	2.18	101.03
18	BS	f	45.46	2.99	17.02	4.09	9.34	0.16	6.02	10.00	2.69	0.55	0.48	0.52	0.04	99.36
19	BS	sw	45.40	3.10	17.07	5.59	7.71	0.19	6.05	9.99	2.60	0.53	0.47	0.60	0.12	99.35
21	BS	w	44.57	3.02	17.17	7.46	4.88	0.17	5.89	10.10	2.60	0.53	0.48	2.14	0.61	99.62
26	RS	f	48.40	2.39	16.22	4.29	6.95	0.16	5.97	9.71	2.66	0.89	0.40	0.82	0.62	99.48
27	RS	sw	48.38	2.42	16.10	5.76	5.06	0.16	6.00	9.72	2.73	0.89	0.39	1.57	0.75	99.93
28	RS	w	48.38	2.45	16.18	6.50	4.24	0.16	6.05	9.85	2.65	0.90	0.42	1.72	1.82	101.32
31	CS	f	47.78	2.85	15.96	4.45	8.97	0.19	5.50	9.96	2.62	0.92	0.46	0.52	0.39	100.52
32	CS	sw	47.60	2.84	16.00	5.30	7.80	0.18	5.44	9.90	2.60	0.90	0.46	0.65	0.45	100.12
35	CS	w	47.00	2.90	15.85	7.77	4.84	0.17	5.40	10.02	2.50	0.80	0.50	1.85	0.98	100.58

Locality: AR — Abu Rawash, QT — Qatrani, BS — Bahnasa, CS — Cairo-Suez road, AZ — Abu Zaabal, BH — Bahariya, RS — Red Sea coast.
Symbols: f — fresh, sw — slightly weathered, w — weathered.

Effect of weathering. Progressive weathering is accompanied by changes in X-ray intensities of minerals occurred. For examples, olivine lines dissappeared completely in the slightly weathered and weathered samples. Antigorite, the lines of which appear in the X-ray pattern of fresh and slightly weathered samples of Bahnasa, may be formed after olivine, but these lines also dissapeared in the case of weathered samples. Table 2 shows a slight decrease in MgO content with progressive weathering, what cannot be related directly to the diminution in olivine content since olivine weathers normally into Mg-bearing minerals. This slight decrease in MgO reflects, in a more realistic sense, the conditions of poor drainage and limited rainfall.

The intensity of X-ray reflections of ilmenite and magnetite decreased with progressive weathering while those of haematite — increased. In Table 2 a marked decrease in FeO and a marked increase in Fe_2O_3 contents can be observed. Obviously, this is due to the progressive oxidation of FeO into Fe_2O_3. The values of the degree of oxidation of iron calculated as

$$\frac{Fe_2O_3 \cdot 100}{Fe_2O_3 + FeO}$$

are listed in Table 3 and show a progressive increase with progressive degree of weathering.

Calculated values of the degree of oxidation of iron

Sample	Locality	Status	Degree	Sample	Locality	Status	Degree
1	AR	f	36.75	18	BS	f	30.45
2	AR	sw	42.94	19	BS	sw	42.03
3	AR	w	53.91	20	BS	w	58.26
4	AR	w	58.44	21	BS	w	60.45
5	AR	w	63.08				
				22	RS	f	31.12
6	AZ	f	39.96	23	RS	sw	32.70
7	AZ	sw	55.09	24	RS	w	52.30
8	AZ	w	60.39	25	RS	w	55.97
9	AZ	w	61.67	26	RS	f	38.16
10	Qt	f	36.07	27	RS	sw	53.23
11	Qt	sw	43.98	28	RS	w	60.52
12	Qt	w	48.21	29	RS	w	71.97
13	Qt	w	55.42	30	RS	w	73.09
14	BH	f	29.75	31	CS	f	33.16
15	BH	sw	37.71	32	CS	sw	40.46
16	BH	w	63.37	33	CS	w	50.15
17	BH	w	78.71	34	CS	w	61.25
				35	CS	w	61.62

Locality: AR — Abu Rawash, AZ — Abu Zaabal, QT — Qatrani, BH — Bahariya, BS — Bahnasa, RS — Red Sea, CS — Cairo-Suez.
Symbols: f — fresh, sw — slightly weathered, w — weathered rock.

The data for major oxides show a slight increase of CaO in some weathered samples, which may be attributed to the formation of secondary carbonates (mainly calcite) in the course of weathering. Calcite was detected by X-ray diffraction only in Bahnasa and Cairo-Sues samples. These rocks contain the highest amounts of CaO (up to 10%, Table 2).

Nepheline was identified by X-ray diffraction only in Bahariya samples (Table 1). These samples showed the highest content of Na_2O and K_2O, they have a three times higher content of K_2O than Bahnasa samples (Table 2).

The diffraction lines of labradorite and augite also showed a decrease in intensity with progressive weathering. Chemical analyses display slight decrease in SiO_2 and MnO, and a slight increase in TiO_2, Al_2O_3 and P_2O_5 contents.

Degree of weathering. Quantitative estimation of the degree of chemical weathering of rocks has been a subject of much discussion. Ruxton (1968) discussed several proposals and suggested that the mole ratio of silica to alumina is the most useful, though subject to some qualification as to its use. Kramer (1968) stated that the ultimate weathering equation may be considered as the exchange of Na, Ca, Mg and K for H in the mineral structure with or without the loss of Si. This is the case which may be acceptable for the weathering processes affecting the Egyptian basaltic rocks studied herein. Silica tends to be mobile during weathering but the total amount lost during weathering is usually small.

Values of weathering index

Locality	Weathering index			
	fresh	slightly weathered	weathered	weathered
Abu Rawash	73.52	73.29	72.10	69.97
Abu Zaabal	71.86	72.34	71.00	70.07
Qatrani	70.18	70.05	69.94	69.59
Bahariya	85.11	83.91	79.94	79.55
Bahnasa	71.54	70.60	72.98	70.44
Red Sea	72.77	72.54	72.50	69.70
Red Sea	73.28	74.03	73.84	
Red Sea	73.67		71.37	
Cairo-Suez	72.50	71.83	71.53	70.76

Parker (1970) proposed an index of weathering for silicate rocks, which is widely applicable for acid, intermediate and basic rocks. It takes into account the individual mobilities of the most mobile major alkalis and alkaline earthes (Na, K, Ca, Mg) based on the bond strength. The equation given is as follows: Weathering

$$\text{index} = \frac{(Na)a}{0.35} + \frac{(Mg)a}{0.9} + \frac{(K)a}{0.25} + \frac{(Ca)a}{0.7} \cdot 100$$

where $(X)a$ indicates the atomic proportion of element X defined as atomic percentage divided by atomic weight, and the denominators in the function are in each case the bond strength between the element and oxygen. Thus, the calculated weathering index will decrease with increasing degree of weathering.

To evaluate quantitatively the degree of weathering of examined samples, the index of weathering was calculated according to the presented equation. Table 4 exhibits a steady decrease in the index value with increasing weathering, except where

temporary enrichment in one of the elements has occurred (e.g. Abu Zaabal slightly weathered, Bahnasa weathered and Red Sea slightly weathered samples).

In order to relate the degree of oxidation of iron to the weathering index, the arithmetic difference between the maximum and minimum values was calculated in each case and plotted for the different localities as shown in Fig. 2. Fairly good positive correlation was found between the two plots, both indicating that Bahariya samples are the most while Qatrani samples the least weathered. This correlation may also extend the use of the degree of oxidation of iron as a measure of the degree of weathering.
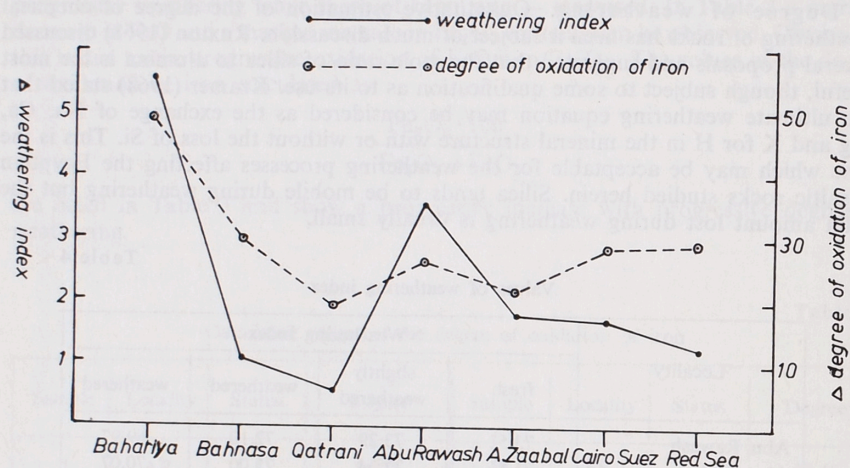

Fig. 2. Comparison of the relative (Δ) degree of oxidation of iron and weathering index values of Egyptian basalts from different localities (see Tables 3 and 4)

Weathering clays. The identified minerals formed during weathering of the present rocks are chlorite, illite, montmorillonite/vermiculite. In Table 5 there is a list of minerals identified in 10 representative samples from Abu Rawash, Abu Zaabal, Qatrani, Bahnasa and the Red Sea coast. No Bahariya or Cairo-Suez samples were analyzed in view of the difficulty in obtaining the clay fraction from them.

Genetically, the identified clay minerals may be classified according to the view of Millot (1970) as follows: a) illite and chlorite are neoformed from the silicates of the parent rocks, and b) vermiculite, mixed layers and possibly montmorillonite are clays formed by weathering or transformed from the previous ones. The third category given by Millot (clays neoformed from hydrolysis products under special conditions, including montmorillonite or kaolinite) was not expected herein due to the climatic aridity of the basaltic occurrences studied. This is in accord with the view of Godard et al. (1961) that the presence of kaolinite indicates excellent drainage. Thus, clay minerals formed during weathering of Egyptian basaltic rocks resulted from silicates through neoformation followed by transformation which was degradational according to the classification of Lucas (1962), and proceeded according to the sequences given by Millot (1970) as follows:

Table 5

Clay minerals identified by X-ray method in representative samples

Locality	Sample	Identified minerals
Abu Rawash	C5	chlor, mont-verm
Abu Zaabal	C11	mont-verm, chlor, ill
	C12	chlor, mont-verm, ill (very weak)
Qatrani	C17	mont-verm, chlor, ill
	C18	mont-verm, chlor, ill
Bahnasa	C29	chlor, mont, ill
	C30	chlor, mont-verm, ill-mont
Red Sea	C40	mont-verm, chlor, ill
	C41	mont, chlor
	C42	chlor, mont-verm

Minerals: chlor — chlorite, mont — montmorillonite, verm — vermiculite, ill — illite, hyphen denotes mixed layer clays.

chlor. → chlor/verm. → verm. → mont.

illite/verm. → verm. → verm/mont. → mont.*

The mechanism of weathering proposed by Loughnan (1969), in which clay minerals result from the weathering of olivine, pyroxene and feldspar, are applicable in the present case.

CONCLUSIONS

The main mineral constituents of Egyptian basalts are represented by labradorite, augite, olivine, antigorite, magnetite, ilmenite, haematite, nepheline and calcite. Progressive weathering reflects in a decrease of olivine, ilmenite, magnetite, augite and labradorite, and in an increase in haematite and clay minerals contents. This is accompanied by a slight decrease in MgO, SiO_2, MnO and slight increase in CaO, TiO_2, Al_2O_3 and P_2O_5, a marked decrease in FeO and a marked increase in Fe_2O_3.

To evaluate quantitatively the degree of weathering, a fair correlation was found between the degree of oxidation of iron and the weathering index of Parker (1970). This may indicate the validity of the degree of oxidation of iron as a measure of the degree of weathering. However, these two indices of weathering give optimal results if calculated for samples exhibiting different extent of weathering of the same rock mass. Relatively speaking, the Bahariya basalts were found to be the most while those of Qatrani the least weathered.

The identified clay minerals, being the products of weathering, are: chlorite, montmorillonite/vermiculite, illite and mixed-layer montmorillonite/vermiculite, illite and mixed-layer montmorillonite/vermiculite and illite/montmorillonite. These clays were formed both through neoformation from the silicates

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* Chlor. = chlorite, verm. = vermiculite, mont. = montmorillonite.

and by degradational transformation of these neoformed minerals. The limited existence of montmorillonite and the absence of kaolinite indicate poor drainage and limited rainfall, which have always prohibited the formation of clay minerals through neoformation from hydrolysis products.

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WPŁYW WIETRZENIA NA SKŁAD MINERALNY I CHEMICZNY NIEKTÓRYCH BAZALTÓW EGIPTU

Streszczenie

Wykonano badania rentgenowskie i analizy chemiczne próbek świeżych i zwietrzałych bazaltów, pobranych z 7 miejsc ich występowania w Egipcie (Abu Rawash, Abu Zaabal, Qatrani, Baharija, Bahnasa, szosa Kairo-Suez, wybrzeże Morza Czerwonego). W miarę postępującego wietrzenia obserwuje się zmiany intensywności refleksów rentgenowskich pochodzących od różnych minerałów oraz zmianę zawartości różnych składników chemicznych. Stopień zwietrzenia charakteryzowano dwoma parametrami: stopniem utlenienia żelaza oraz wskaźnikiem zwietrzenia zaproponowanym przez Parkera (1970). Stwierdzono dobrą korelację między tymi parametrami. Obydwa z nich wskazują, że skały z Baharija są najsilniej zwietrzałe, a z Qatrani — najmniej. Wśród wietrzeniowych minerałów ilastych zidentyfikowano chloryt, montmorillonit, illit oraz minerały mieszanopakietowe montmorillonit/wermikulit i illit/montmorillonit. Minerały te powstały w wyniku wietrzenia innych minerałów krzemianowych oraz dalszej degradacyjnej transformacji ilastych produktów wietrzenia.

OBJAŚNIENIA FIGUR

Fig. 1. Mapka lokalizacyjna bazaltów egipskich.
Fig. 2. Porównanie zmian Δ stopnia utlenienia żelaza i współczynnika wietrzenia bazaltów z różnych miejscowości (por. tabele 3 i 4)

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ВЛИЯНИЕ ВЫВЕТРИВАНИЯ НА МИНЕРАЛЬНЫЙ И ХИМИЧЕСКИЙ СОСТАВ НЕКОТОРЫХ БАЗАЛЬТОВ ЕГИПТА

Резюме

Проведены рентгеновские и химические анализы образцов невыветрелых и выветрелых базальтов, отобранных из семи мест их местонахождений в Египте (Абу Раваш, Абу Заабал, Катрани, Бахария, Бахнаса, шоссе Каир-Суэц, побережье Красного моря). По мере поступающего выветривания наблюдается изменение интенсивности рентгеновских линий, происходящих от разных минералов, а также изменение содержания различных химических компонентов. Степень выветривания характеризуется двумя параметрами — степенью окисления железа, а также показателем выветривания, предложенным Паркером (1970). Обнаружена хорошая корреляция между этими параметрами. Оба они показывают, что породы из Бахарии наиболее выветрелы, а с Катрани наименее изменены. Среди глинистых минералов коры выветривания обнаружен хлорит, монтмориллонит, иллит, а также смешанно-пакетные минералы

монтмориллонит/вермикулит и иллит/монтмориллонит. Эти минералы образовались в итоге выветривания других силикатных минералов, а также деградационного видоизменения глинистых продуктов выветривания.

ОБЪЯСНЕНИЯ К ФИГУРАМ

Фиг. 1. Схематическая карта местоположения египетских базальтов
Фиг. 2. Сопоставление Δ изменений степени окисления железа и коэффициента выветривания базальтов из разных мест (срав. таблицы 3 и 4)