Acta Mineralogica-Petrographica, Szeged, XXVI/2, 187—205, 1984

PETROGRAPHY AND PETROCHEMISTRY OF WADI KAREIM IRON-BEARING FORMATION EASTERN DESERT, EGYPT

E. A. NIAZY, A. EL BAKRY and O. A. KAMEL

ABSTRACT

The petrography of the Precambrian iron-bearing formation at Wadi Kareim proved that the formation consists of the following regionally metamorphosed rock types of the greenschist facies;

1. Graywackes (mainly volcanic grading to volcanic breccias, normal greywackes are less common).
2. Schists (chlorite, chlorite-calcite, and actinolite-epidote)
3. Volcanics (keratophyres, quartz-keratophyres, spilites, spilitic diabase and diabase).
4. Pyroclastics (lithoclastic and crystal tuffs, lapilli tuffs — mainly spilitic in composition).

The petrographic study is corporated with the results of eight new chemical analyses, representing the different rock types. The analysis of the basic metavolcanic is similar to the average world spilite, and that of the acid metavolcanic is comparable to the aphanitic keratophyre (Schirmeck-type) of the preorogenic Hercynian volcanics of Western Europe.

The recently suggested Al/3—K versus Al/3—Na and Si/3—(Na+K+2Ca/3) *versus* K—(Na++Ca) diagrams, the FMA and Na—K—Ca diagrams are adopted for the petrochemical presentation of the chemical data. It is suggested that most rock types either have a composition comparable to basalts or spilitic mineral assemblages. This mostly reflects the primary link of the spilitic rock with other volcanic and pyroclastic rocks, particularly keratophyres. The only exception, is the chlorite schist which has a composition similar to shales.

INTRODUCTION

The iron ore deposit of Wadi Kareim lies on the northern side of Wadi Kareim, some 38 km southwest of Quseir on the Red Sea coast *(Fig. 1)*.

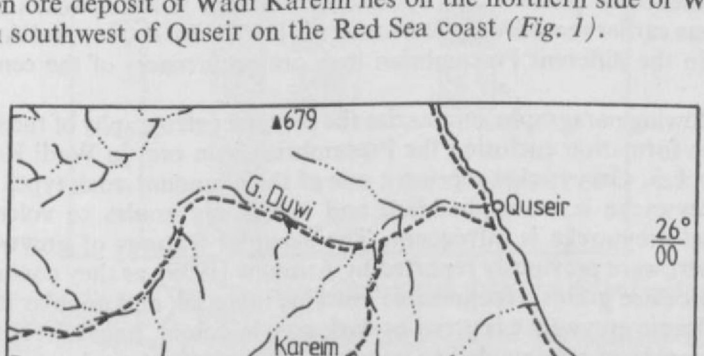

Fig. 1. Location map.

The geology, petrography and mineralogy of the Precambrian iron ores and their country rocks have been studied by many authors. Among whom may be mentioned; ABDEL NASSER and AFIA [1949]; NAKHLA, [1954]: EL-SHAZLY, [1957]; GINDY, [1957]; SIGAEV, [1959]; FRIED KRUPP, [1959]; AKAAD, [1959]; ABDEL AZIZ, [1968]; NIAZY, [1969]; HILMY *et al.,* [1972]; and KAMEL *et al.,* [1977].

The area of Wadi Kareim is covered by different basement rock units, which can be arranged chronologically as follows [HILMY *et al.,* 1972];

Top 5) Minor intrusions (mainly bostonite dykes)
4) Granodiorites
3) Igla Formation
2) Metavolcanics (keratophyres, quartz-keratophyres, spilites and diabases)
Base 1) Metasediments (mainly greywackes, schists and tuffs).

The iron-bearing formation in Wadi Kareim has been considered to consist of regionally metamorphosed: 1) geosynclinal sediments, 2) banded-siliceous iron ores, and 3) volcanic rocks [KAMEL *et al.,* 1977]. The Precambrian metasediments, metavolcanics and banded iron ores are paragenetically related to each other. The iron-bearing formation represents a large monoclinal fold, which is intersected by a major thrust fault, along which a highly sheared structural unit is displaced over the formation from the east [SIGAEV, 1959; HILMY *et al.,* 1972].

PETROGRAPHY

The iron-bearing formation in Wadi Kareim, comprises different metasedimentary and metavolcanic rocks of the green schist facies. The geosynclinal metasediments and the associated volcanics are represented by the following rock types *(Fig. 2);* 1) graywackes, 2) schists, 3) metavolcanics, and 4) pyroclastics.

The formation represents the oldest rock unit in the studied area [NIAZY, 1969; KAMEL *et al.,* 1977]. Generally, the metamorphosed volcanogenic-sedimentary rocks of the formation have a pale brown colour, grading into pale green and greyish green colours. In some parts, the rocks are tough, however, they are commonly shattered and even friable. Most of the rock types are intersected by calcite veinlets.

The presence of pebbles and cobbles of different volcanic rocks in the metasediments was earlier recorded by SHUKRI *et al.,* [1959], EL-RAMLY and AKAAD [1960], and others in the different Precambrian iron ore occurrences of the central Eastern Desert.

The following paragraphs summarize the detailed petrography of the sedimentary-volcanogenic formation enclosing the Precambrian iron ores in Wadi Kareim.

Greywackes. Greywackes represent one of the abundant rock types in the area. Volcanic greywacke is more abundant and commonly grades to volcanic breccia, while normal greywacke is infrequent. The essential features of greywackes in the Eastern Desert were previously reported by ANDREW [1939], as they contain abundant detrital plagioclase grains, recognizable volcanic material, and angular clastic grains.

The volcanic greywacke is green or dark grey in colour, hard and coarse-grained. The rock consists of subrounded to angular, relatively fresh and polymictic mineral grains and rock fragments, with a common diameter ranging from 0.5 to 3 mm. They comprise different volcanic rock fragments *(Figs. 3* and *4),* such as trachyte, andesite, spilite, diabase, and glassy material. The rock also contains other mineral grains, mainly of quartz. The rock fragments and mineral grains display sub-parallel arrangement and are usually embedded in a clayey matrix, with chlorite and sericite, that may show flow-banding.

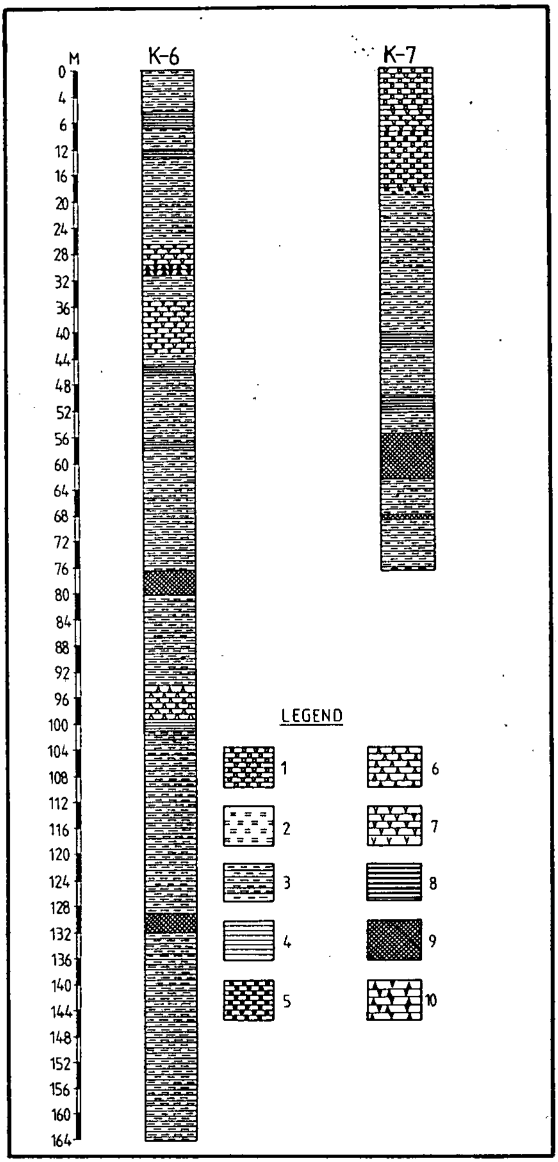

Fig. 2. Geologic succession of the iron-bearing formation as shown by the inclined wells K—6 and K—7, according to E. A. Niazy.
1: volcanic greywacke; 2: tuff; 3: chlorite, calcite-chlorite and actinolite schists; 4: graphite-calcite —actinolite schist; 5: garnet — actinolite schist; 6: meta-alkali-trachyte-(keratophyre); 7: diabase; 8: banded iron ore; 9: massive iron ore; 10: brecciation zone.

The normal greywacke has a greyish-green colour and is moderately compact. The rock consists of mineral grains and infrequent rock fragments. The essential clastic minerals are ill-sorted and consist of subangular quartz and fine orthoclase

Fig. 3. Photomicrograph of volcanic greywacke, composed of different subrounded rock fragments showing subparallel arrangement in a clayey-chloritic matrix. Plane light, 20×.

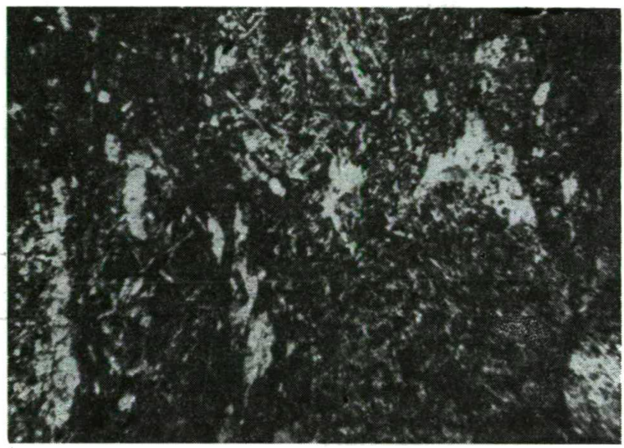

Fig. 4. Photomicrograph of volcanic greywacke, composed of spilite and other volcanic fragments in a similar groundmass. Crossed nicols, 20×.

grains *(Fig. 5)*. Flakes of muscovite are not uncommon. Grains of epidote, plagioclase, apatite, magnetite and tourmaline are rarely encountered. Coarse fragments of chert and greenstones are present, which diameter is about 0.5—1 mm. The mineral grains and rock fragments are embedded in a pasty matrix of chlorite, sericite and clayey material. The flaky minerals usually exhibit parallel arrangement to the rock cleavage.

Schists. Schists are represented by chlorite, chlorite-calcite and actinolite-epidote varieties which grade into each other imperceptibly. The schists are distinctly foliated with parallel allignment of flaky and prismatic minerals. Most of these schists belong to the same mineral assemblage.

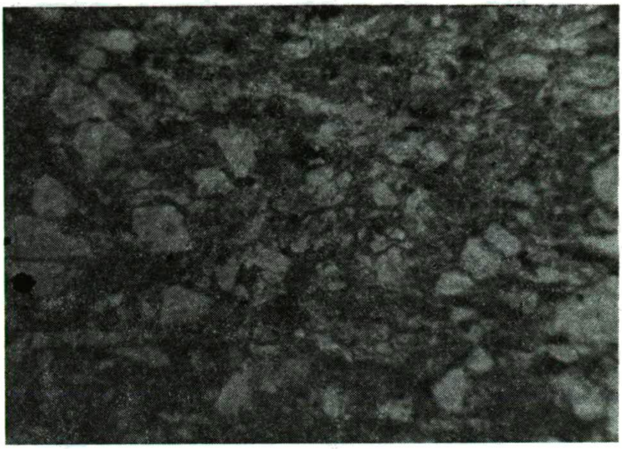

Fig. 5. Photomicrograph of normal greywacke, showing ill-sorted subangular quartz and feldspar grains in a matrix of chlorite and clayey material. Plane light, 20×.

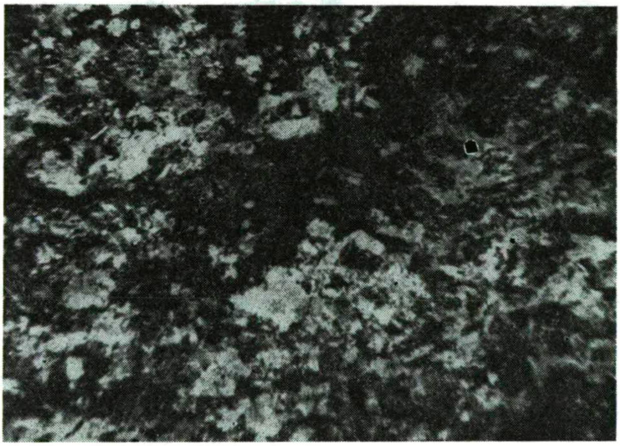

Fig. 6. Photomicrograph of chlorite schist, composed of chlorite (grey), quartz (colourless) and magnetite (black). Plane light, 20×.

The chlorite schist is greyish-green in colour, and fine to medium-grained. The rock is essentially composed of chlorite, quartz and calcite *(Fig. 6)*. Albite, magnetite, muscovite, epidote, actinolite and carbonaceous matter are less common. Chlorite is mainly represented by pennine, that forms fine twin aggregates of small andehral crystals. The mineral displays noticeable pleochroism (Z=green, Y=green, and X=yellowish green), with $n_\gamma=1.575$, $n_\alpha=1.572$, and anomalous interference. Clinochlore is less common and forms thin tabular crystals. Occasionally, brown stilpnomelane occurs as fine to coarse plates in subparallel bands of sheaflike aggregates *(Fig. 7)*, indicating high percentages of K_2O in the rock. Quartz is subrounded, and occurs as fine aggregates between chlorite and calcite. The latter mineral forms fine-grained anhedral crystals, that may be aggregated in small patches and irregular

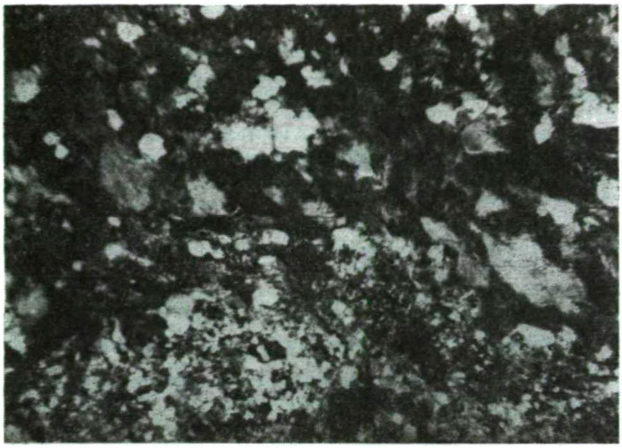

Fig. 7. Photomicrograph showing sheaflike aggregate of brown stilpnomelane in the chlorite schist. Plane light, 20×.

clots. Albite (Ab_{95} An_5) is irregular, and displays albite twinning with $X' \wedge (010) = -16°$. Magnetite is disseminated in the rock. Chlorite schist is most probably the result of regional metamorphism of some pelitic and psammopelitic sediments. They belong to rocks of greenschist facies [TURNER and VERHOOGEN, 1960: TURNER, 1958].

The chlorite-calcite schists may be broadly referred to either original basic volcanic rocks or else calc-pelitic sediments. Schists derived from basic volcanics are dominant. They are essentially composed of chlorite, calcite, quartz and albite. Epidote, leucoxene, actinolite, magnetite and pyrite are uncommonly present. Remnants of the primary mafic minerals are still preserved. Magnetite forms clustered aggregates or scattered crystals. In some parts, the rock is traversed by quartz, chalcedony and calcite veinlets. Vein quartz is commonly associated with coarse pyrite cubes, which may be surrounded by microcrystalline quartz at the tapering parts of the veinlets. Later deformation of pyrite is sometimes observed accompanied by its partial replacement of quartz.

Chlorite-calcite schists derived from the calc-pelitic sediments are less abundant. They consist of carbonate laminae, bands, and lenses alternating with others of chlorite, quartz, magnetite and muscovite. The chlorite minerals are very similar to those of the chlorite schist. The carbonates are mainly calcite, dolomite associated with quartz, talc and tremolite. Coarse grains of detrital quartz are frequent at the boundaries of the carbonate and chlorite laminae. This quartz exhibits undulatory extinction and is optically biaxial. The rock is commonly traversed by calcite veinlets.

The actinolite-epidote schist has a light green colour, and consists essentially of actinolite, epidote and chlorite. Calcite, quartz, and albite are subordinate in abundance, while pyrite, magnetite, augite, apatite, sphene, muscovite and leucoxene are rarely observed. Actinolite forms fibrous aggregates of thin crystals. It is weakly pleochroic (X=light green, X=greenish yellow, and Z=green) with $c \wedge Z' = 15°$. The mineral is occasionally associated by anthophyllite. Pistacite is found accompanied by actinolite and chlorite. It is yellowish-green in colour and moderately pleochroic. The mineral usually forms small euhedral crystals and granular aggregates that display parallel extinction, with $n_\gamma = 1.737$ and $n_\alpha = 1.722$. Pennine forms patches of fine anhedral crystals commonly associated by calcite. Feathery quartz is sometimes observed around the pyrite and magnetite porphyroblasts. The quartz crystals may show twisting indicating post-or syncrystallization rotation.

The described actinolite-epidote schists belong to the albite epidote hornfelses of the contact metamorphic facies [TURNER, 1958], They were, however, previously classified as actinolite-epidote hornfels subfacies [TURNER and VERHOOGEN, 1960]. It is reasonable to suggest that such schists were principally formed in sheared parts of the volcanic rocks and tuffs of the iron-bearing formation.

At the close contacts with granodiorite, the described schists are facially changed to a highly foliated reddish brown rock with papery appearance, where biotite replaces chlorite in the chlorite-biotite schist. Such a rock consists of biotite, quartz, chlorite, muscovite, actinolite and calcite. It may also contain disseminations of garnet, magnetite and pyrite, and the rock grades to chlorite-biotite-garnet schist. In some peripheral parts, however, the metasediments consist mainly of coarse crystalline calcite bands. Here, graphite is sometimes observed, where the mineral forms laminae, patches and streaks, and is associated with chlorite, epidote, phlogopite, anthophyllite, sodic plagioclase, and talc.

Metavolcanics. Metavolcanics include keratophyre, quartz-keratophyre, spilites, spilitic diabase and diabase. The metavolcanic rocks commonly form sheeted dyke and sill-like bodies which are often concordant with the schists, greywackes and tuffs. In many parts, keratophyres are in direct contact with the "banded-siliceous" iron ores.

It should be mentioned that along the upper reaches of the central wadi of the investigated area, a massive greyish-green, fine grained effusive rock grading to a coarser variety with abundant magnetite phenocrysts, which has a pillow-like structure *(Fig. 8)*, is exposed intruding the greywackes, schists and tuffs. The rock is identified as possible keratophyre. The formation of such a rock is considered to be of probable submarine-effusive origin. Metamorphosed alkaline effusive rocks with spherulitic and trachytic textures are commonly encountered in many parts of Wadi Kareim, particularly, along adit No. 4 and borehole K—6 [NIAZY, 1969].

Keratophyre is hard, porphryitic *(Fig. 9)* with splintery fracture. The rock

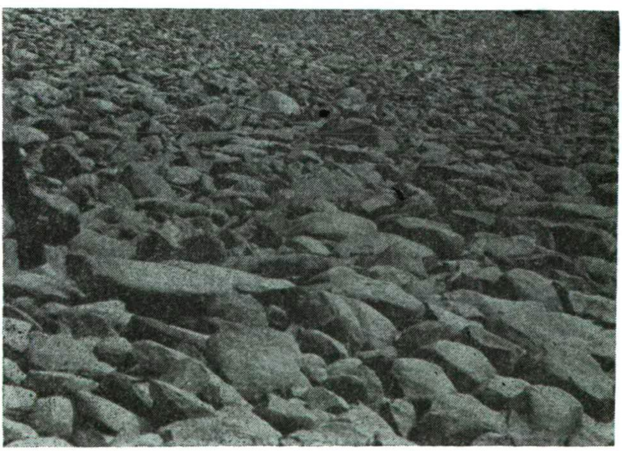

Fig. 8. Photograph of the central wadi in Kareim area, showing pillow-like bodies of a metavolcanic field.

displays sub-parallel arrangement of the mineral constituents. The phenocrysts consist of albite, oligoclase, and augite. The albite laths display both albite and Carlsbad twinning, and are often radially disposed and highly altered. The mineral microlites commonly show fluxional flow and trachytic fabric. Coarse augite ($c \wedge Z' = 38°$) is almost completely altered, however, their outlines and cleavage traces are occasionally preserved. The pyroxene mineral is usually altered to chlorite, actinolite and epidote. Potash feldspar commonly forms perthitic intergrowths with quartz, while sanidine is rare.

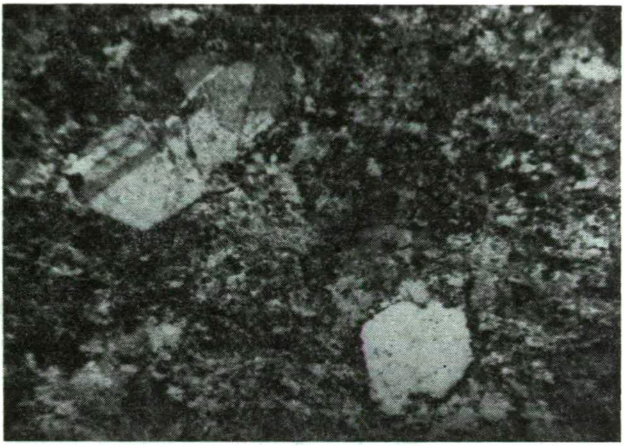

Fig. 9. Photomicrograph of porphyritic keratophyre. Phenocrysts are represented by quartz and sodic plagioclase in a trachytic groundmass. Plane light, 20×.

The quartz-keratophyre is marked by abundant quartz phenocrysts. Quartz is sometimes intergrown with sodic plagioclase in the groundmass. The rock is characterized by the presence of variolitic spherulites *(Fig. 10)* composed of radially arranged albite laths associated with fine-grained quartz. The spherulites are embedded

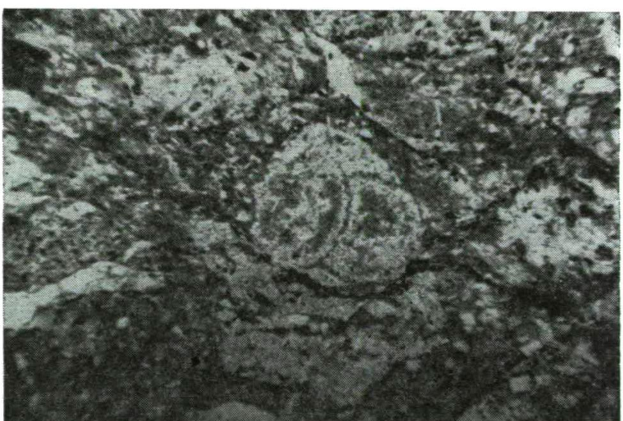

Fig. 10. Photomicrograph of keratophyre showing variolitic spherulites of radially arranged albite laths. Crossed nicols, 50×.

in a cryptocrystalline groundmass of minute albite microlites, quartz, chlorite, zoisite and microcrystalline silica. Apatite, sphene and talc are rare, while opaque minerals (magnetite, pyrite, ilmenite and leucoxene) are uncommon. Amygdales of quartz, chalcedony or calcite are also encountered.

In some parts, the keratophyres are associated with other effusive rocks, spilite [Niazy, 1969], and spilitic diabase. The identification of spilite was earlier ascertained both by X-ray diffraction and chemical analysis [Abdel Aziz, 1968]. Spilite is hard, spotted and dark green. It consists of short thin albite laths ($\sim$70 by volume) in a chlorite matrix *(Fig. 11)*. Relicts of unaltered augite are sometimes observed. The rock is marked by the radial arrangement of the albite laths and is characterized by the triangular disposal of the mineral in the mesostasis of altered pyroxene, chlorite, clinozoisite and epidote. Magnetite, ilmenite, actinolite, apatite and calcite are rarely present. Small pools of jasper and amygdales filled by chert, microcrystalline quartz or calcite are occasionally observed *(Fig. 12)*. Occasionally, the rock merges to a rather coarse-grained variety, i. e. spilitic diabase.

Fig. 11. Photomicrograph of spilite, composed of albite laths displaying intersertal texture in a chloritic groundmass. Crossed nicols, 20×.

The diabase is dark green, medium-grained and porphyritic. It is mainly composed of zone labradorite (Ab_{44} An_{56}), augite and titaniferous augite showing ophitic and sub-ophitic textures. Calcite and chlorite are present in fair amounts, in the groundmass. Apatite, quartz, ilmenite and magnetite are rarely encountered. Generally, diabase is less affected by the regional metamorphism, and may show some contact effects with different rocks of the studied formation.

Pyroclastics. The pyroclastic rocks are represented by tuffs and lapilli tuff. The tuffs are fine-grained rocks, with light green, grey or even brown colours, and show banded texture *(Fig. 13)*. The tuff bands have regular, sharp and uniform contacts and their thickness varies between 0.5 and 2 mm. Sometimes, the bands are rather irregular and displaying gradation in grain size. In the studied area, both crystal and lithoclastic tuffs are encountered.

Crystal tuff is composed of angular to subangular crystals and ill-sorted glass particles embedded in a glassy, clayey or chloritic groundmass. The crystals may be cracked, corroded, and consist of sodic plagioclase, sanidine, potash feldspars,

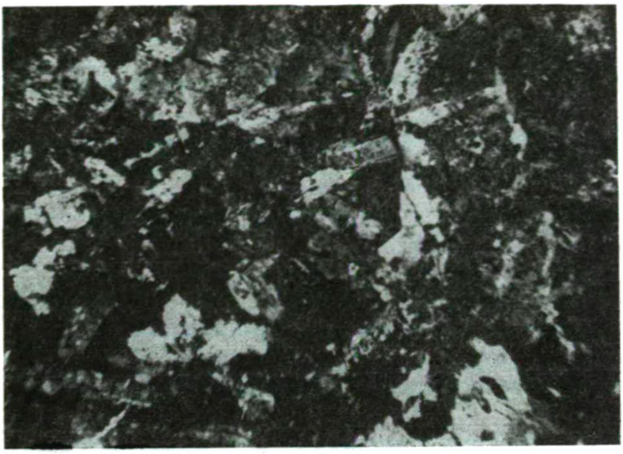

Fig. 12. Photomicrograph of spilitic diabase with small pools of jasper and chert. Crossed nicols, 20×.

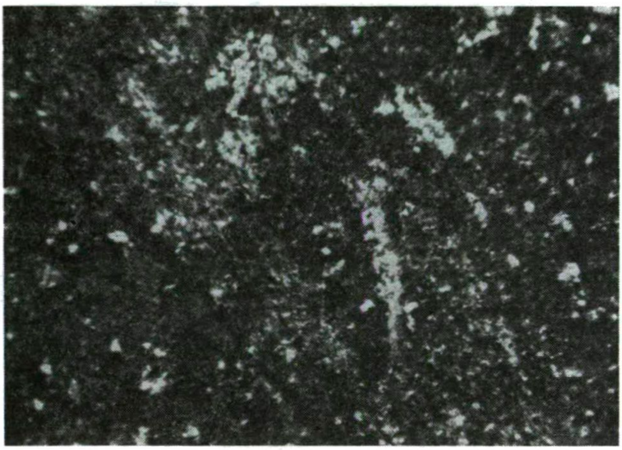

Fig. 13. Photomicrograph of fine-grained tuff with angular quartz grains and displaying banded texture. Plane light, 20×.

quartz, magnetite and leucoxene, some of the tuff bands are carbonate-rich or composed of pelitic material. Glassy material is normally altered to clay minerals, and the rock may be mistaken for "mudstone".

Lithoclastic tuff is also fine-grained, with common rock fragments of spilite, spilitic diabase, keratophyre and siliceous material. Frequently, the rock grades to lithoclastic lapilli tuff, with coarser rock fragments and lapilli. The most common variety is spilitic lithic tuff, where the lapilli are subangular to subrounded and composed mainly of spilitic rock fragments, about 0.2—1.5 cm in diameter, embedded in a groundmass of microcrystalline and cryptocrystalline spilite *(Fig. 14)*. Trachytic lithic tuff is also encountered, but in lesser amounts. The lithoclastic lapilli tuffs normally display flow-banding of the matrix and merge to the volcanic greywacke and volcanic breccia.

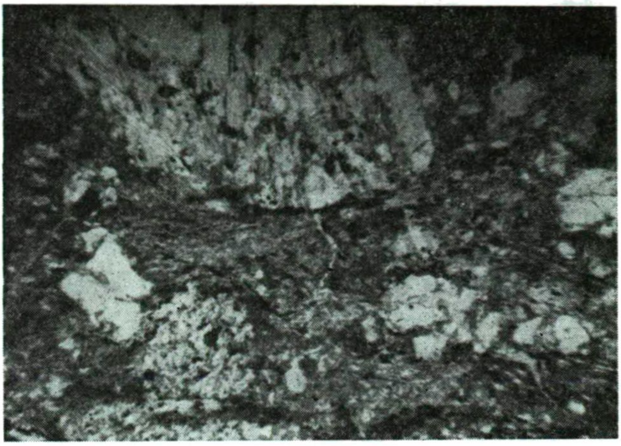

Fig. 14. Photomicrograph of spilitic lithic tuff, with lapilli of spilite in a groundmass of microcrystalline spilite. Plane light, 20×.

PETROCHEMISTRY

The results of chemical analysis of newly analyzed eight samples from the iron-bearing formation of Wadi Kareim are given in Table 1. The average chemical analysis of spilite [VALLANCE, 1960], chemical analysis of aphanitic keratophyre [JUTEAU and ROCCI, 1974] are also cited for comparison.

TABLE 1

Chemical analysis data of W. Kareim iron-bearing formation

Analysis No.	1	2	3	4	5	6	7	8	9	10
SiO_2	48,97	49,65	62,41	61,30	49,65	56,93	63,91	59,26	46,92	59,07
Al_2O_3	16,86	16,00	14,11	18,20	16,78	10,73	13 94	12,70	13,63	17,10
Fe_2O_3	1,96	3,85	2,06	6,76	1,94	7,97	2,99	2,12	2,16	4,22
FeO	9,07	6,08	5,29	3,34	5,87	9,47	8,37	4,22	3,95	2,86
MnO	0,23	0,15	0,19	0,20	0,18	0,21	0,13	0,23	0,27	0,16
MgO	3,41	5,10	2,75	2,46	6,81	4,80	2,31	1,98	3,30	3,73
CaO	6,56	6,62	3,36	Tr.	6,72	3,05	1,83	7,63	12,97	2,44
Na_2O	3,54	4,29	3.13	5,12	2,93	0,23	0,47	2,83	2,86	5,80
K_2O	1,17	1,28	1,39	1,78	0,66	0,24	0,92	1,54	1,81	0,42
TiO_2	2,28	1,57	0,93	0,57	0,72	0,85	0,56	0,61	0,58	0,95
P_2O_5	0,32	0,26	0,07	—	0,05	0,21	0,71	0,13	0,09	0,09
L. O. I	5,19	5,12	4,27	—	7,72	5,00	2,41	6,95	11,76	3,62
	99,56	99,97	99,96	99,73	100,03	99,69	100,55	100,20	100,30	100,46

1. Spilite, W. Kareim.
2. Average spilite (WALLANCE, 1960].
3. Keratophyre of intermediate composition, W. Kareim.
4. Aphanitic keratophyre (Schirmeck type) [JUTEAU and ROCCI, 1974].
5. Volcanic greywacke (spilitic lithic tuff), W. Kareim.
6. Normal greywacke, W. Kareim.

7. Chlorite schist derived from shale, W. Kareim.
8. Chlorite-calcite schist derived from calc-alk. dacite, W. Kareim.
9. Calcite-chlorite schist derived from calc-alk. dacite, W. Kareim.
10. Tuff, W. Kareim.

The associated albite-oligoclase and chlorite in the spilitic rocks is accompanied by increased proportions of Na_2O. FIALA [1967], suggested that 4% Na_2O can be accepted as a dividing line for similar occurrences in Bohemia. This dividing line is not sharp, and gradational types with 3.5—4% Na_2O and oligoclase as the main feldspar, sometimes with fresh augite are common. The value of the ratio $CaO/Na_2O + K_2O < 2$ is accepted, as a rule, in analogy. The K_2O content is generally very low in spilites [TURNER and VERHOOGEN, 1960).

Types enriched in K_2O also exist, e. g. the weakly metamorphosed chlorite schists characterized by presence of stilpnomelane. These schists seem to be derived from some pelitic sediments. Ca-enriched varieties, e. g. calcite-chlorite schist do occur in some parts of the area, and a value of 12.97% CaO is also reached. In such varieties, the ratio CaO/Na_2O+K_2O is deviated from the mentioned rule. Similar Ca enriched varieties with a CaO up to 16.42% were earlier reported by VALLANCE [1965].

Al/3 — K versus Al/3 — Na diagrams

The Al, Na, K diagram *(Fig. 15)* was first suggested by DE LA ROCHE [1966], and then adopted by DE LA ROCHE *et al.*, [1974] for the chemical presentation of spilitic rocks. The diagram is constructed by calculating the numbers of milliatoms-grams of each component in 100 grams. The diagram allows a clear distinction between the characteristic transition anorthite-albite during spilitization. It shows the disposal of the volcanic associations and their distribution fields against those of the sedimentary associations. Also, it is useful in the separation of sedimentary degradation *versus* the magmatic differentiation.

From the diagram, it is clear that analysis No. 1 (spilite) is plotted within the field of spilitic volcanics, which is also reflected in the chemical analysis of the sample and is very similar to the average spilite composition given by VALLANCE [1960], analysis No. 2. Analysis No. 3 (keratophyre) is plotted in the field of intermediate volcanics. The chemical composition of the rock is quite comparable to the aphanitic keratophyre [JUTEAU and ROCCI, 1974], analysis No. 4 (Schirmeck type). Analysis No. 5 (volcanic greywacke) has a plot very near to the field of spilitic volcanics and the domain of basalts. On the contrary, analysis No. 6 (normal greywacke) is plotted very near to the boundary line of greywackes and shales, within the sedimentary sector. Again, analysis No. 7 (chlorite schist) is plotted in the field of shales. Analyses No. 8 (chlorite-calcite schist), and No. 9 (calcite-chlorite schist), however, are plotted in the field of calc-alkaline Pacific tholeiitic volcanics and within the area specific for dacites. Lastly, analysis No. 10 (tuff) is plotted outside the fields of volcanic and sedimentary rocks, but rather near to the field of spilitic volcanics.

The Al, Na, K diagram *(Fig. 16)* was also suggested by DE LA ROCHE *et al.*, [1974]. The diagram shows the domain of basalts and the field of the spilitic mineral assemblage. It delineates a limited zone for basalts, within the sector of calcic plagioclase (labradorite-bytownite) and the point of origin of the axes near to the area of common pyroxenes and amphiboles.

However, the minerals characteristic for the spilitic assemblage (albite, chlorite, calcite, K-feldspar, augite, quartz, iron oxides) occupy a vast area covering the domain of basalts.

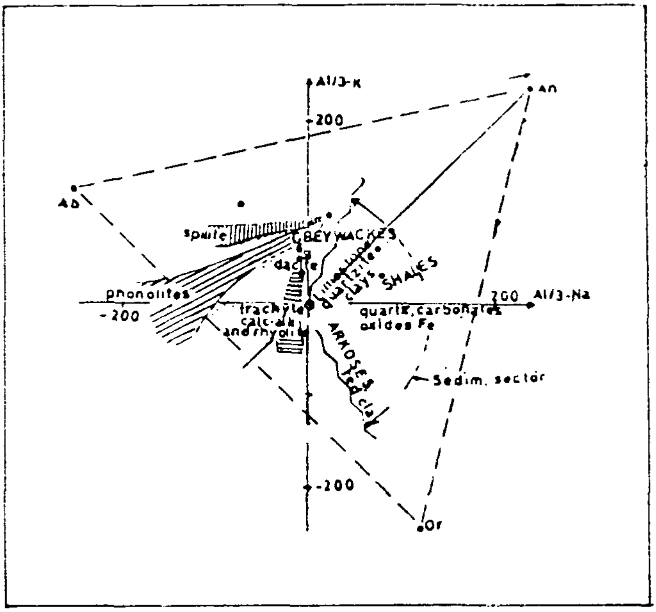

Fig. 15. Al—Na—K variation diagram showing general disposal of volcanic and sedimentary rock association in Wadi Kareim.

From the diagram, it is noticed that the analyzed samples of spilite, volcanic greywacke and chlorite-calcite schist have mineral composition comparable to basalts as their analyses are plotted in the domain of basalts. Also, the samples of keratophyre as their analyses are plotted in the domain of basalts. Also, the samples of keratophyre, calcite-chlorite schist, tuff and normal greywacke have mineral composition of spilitic mineral assemblage. The only exception is the analysis of chlorite schist as

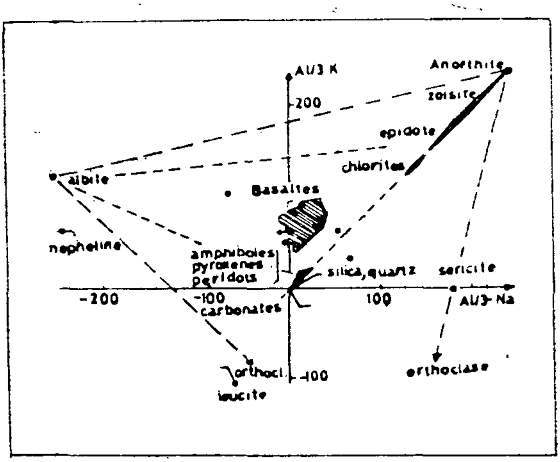

Fig. 16. Al—Na—K variation diagram showing domain of basalts and field of spilitic rock association.

its plot is located outside the area of spilitic assemblage. The disposal of plots of the different volcanics on the Al. Na, K, diagrams points to the primary link of the spilitic rocks with the other volcanic and pyroclastic rocks, particularly keratophyres.

Si/3 — (Na+K+2Ca/3) versus K — (Na+Ca) diagram

The Si, K, Na, Ca diagram *(Fig. 17)* was also adopted by DE LA ROCHE *et al.* [op. cit., 1974] for differentiation of the lithological types of the preorogenic Hercynian volcanics in Northern Europe. Distinction has been made into two evolution trends (Schirmeck-type and Lahn-Dill type) in relation with the paleogeography. A magmatism of folds (Schirmeck-type) to a magmatism of "grabens" (Lahn-Dill type) has been outlined by JUTEAU and ROCCI [1974] in their petrographic and chemical investigation of the Hercynian orogeny in Western Europe.

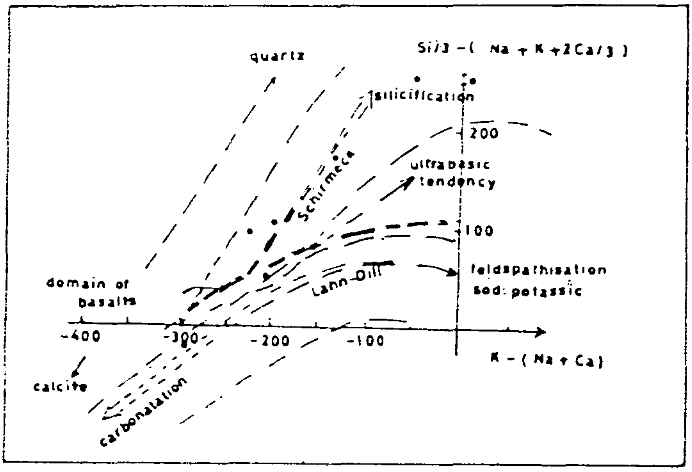

Fig. 17. Si—K—Na—Ca variation diagram showing evolution trend of volcanogenic-sedimentary iron-bearing formation in Wadi Kareim.

The diagram indicates that the investigated association of rocks of the iron-bearing formation in Wadi Kareim had an evolution trend similar to the Schirmeck type of preorogenic Hercynian volcanics and is more inclined towards a tholeiitic tendency, i. e. spilites relatively poor in calcium, and rather siliceous keratophyres.

The FMA variation diagram

In the FMA ternary diagram illustrating the tholeiitic and calc-alkali series proposed by NOCKOLDS [1954], the metavolcanic and pyroclastic rocks of the studied area show a trend similar to the tholeiitic series *(Fig. 18)*.

The Na—K—Ca ternary diagram

The Na—K—Ca ternary diagram for the metavolcanic and pyroclastic rocks of Wadi Kareim is very comparable to such diagrams published by JUTEAU and ROCCI [op. cit., 1974] for some spilite-keratophyre association of the Lahn-Dill rock series rather than the Schirmeck rock series of the Hercynian orogeny. The same similarity

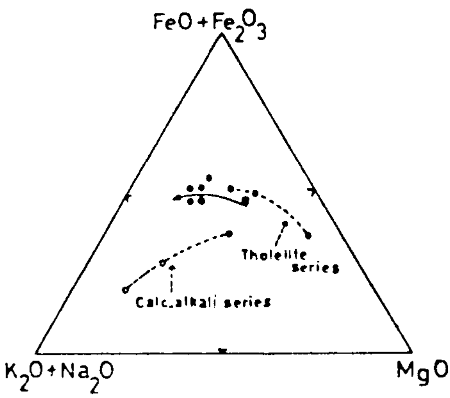

Fig. 18. FMA ternary diagram.

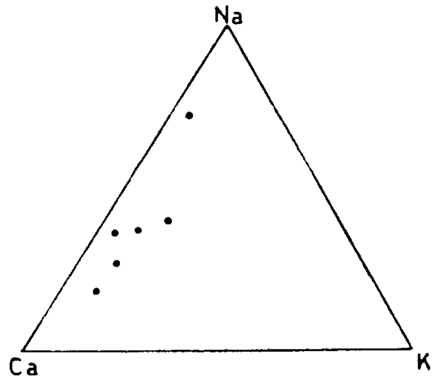

Fig. 19. Na—K—Ca ternary diagram.

is again noted from the Na—K—Ca ternary diagram of the amalyzed rocks *(Fig. 19)*, based on the number of calculated atoms.

This discrepancy in the presentation of chemical data of the studied rock association on the Si/3 — (Na+K+2 Ca/3) *versus* K — (Na+Ca) diagram, and the Na—K—Ca ternary diagram is most probably due to he presence of abundant calcite veinlets intersecting most of the studied metavolcanic rocks in Wadi Kareim area.

Niggli-values

The Niggli-values for the metavolcanic and pyroclastic rocks of the iron-bearing formation in Wadi Kareim, are calculated according to the method suggested by NIGGLI [1954], and the modifications adopted by BARTH [1959].

From the Niggli values given in Table 2, it is evident that most of the rocks are saturated with respect to silica. The quartz value (qz) is more than −12, with the exception of analysis No. 9, which indicates that olivine is absent. The k-value also is less than 0.36, which points that the studied rocks do not contain potash feldspars,

TABLE 2

Niggli-values of W. Kareim metavolcanics and pyroclastics

Analysis No	1	3	5	8	9	10
si	138	239	134	215	130	198
al	28	32	27	27	22	34
fm	40	39	45	30	28	38
c	20	14	19	30	39	9
alk	12	15	9	13	11	19
k	0,18	0,23	0,13	0,26	0,29	0,04
mg	0,35	0,4	0,61	0,36	0,48	0,49
ti	4,9	2,5	1,5	1,7	1,3	2,4
p	0,34	0,23	0,16	0,22	0,16	0,20
qz	−10	79	−2	63	−14	22

Analyses numbers as those indicated in Table 1.

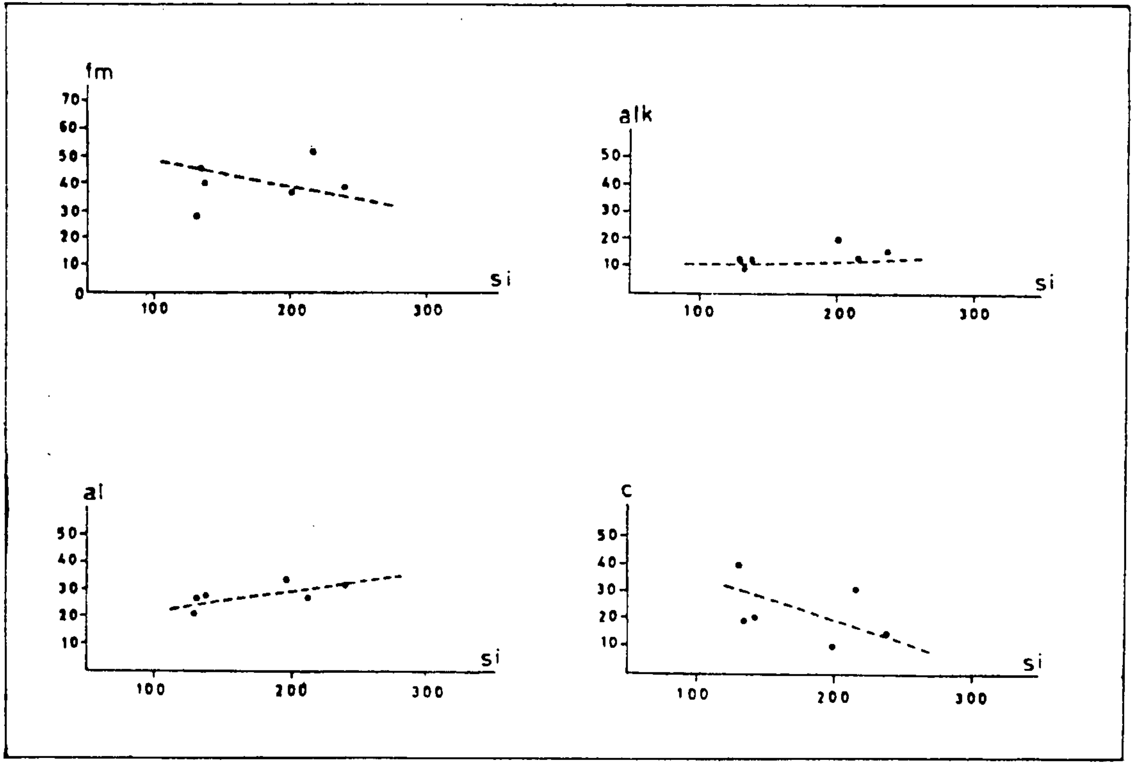

Fig. 20. The relation between si and al, fm, c, alk values of Niggli.

and that the sum of potassium should be incorporated in the plagioclase structure [CHETVERIKOV, 1956]. However, uncommon sanidine and perthitic intergrowths are occasionally observed in some rock varieties. The calculated k-values, are also similar to the data reported by FIALA [1967] for spilitic rocks from Bohemia, which k-values vary from 0.1 to 0.31, with the higher values are specific for keratophyres and quartz-keratophyres. Also, silicates with isomorphous replacement of magnesium by iron are more high-temperature, the more they contain magnesium. Therefore, the calculated mg-values for the studied metavolcanic and pyroclastic rocks (more than 0.35) possibly indicate they are high-temperature [CHETVERIKOV, 1956].

Fig. 20 illustrates the correlation diagrams; si—al, si—fm, si—c, and si—alk for the analysed rock samples. It is obvious that by increasing the values of si those of al and alk increase, while those of fm and c decrease consequently. Such relationships are quite normal for igneous rocks. The relations between si and al and alk are rather linear, which indicate positive correlations between si—al, and si—alk values, i. e. most of Al_2O_3, Na_2O and K_2O are combined with SiO_2 in the silicate minerals. The relations between si and fm and c, however, deviate from the linear arrangement, that point to presence of iron oxide minerals, and calcite in the investigated rocks beside their sharing in the structure of silicates.

CONCLUSIONS

From the foregoing discussion it sould be concluded that the Precambrian iron-bearing formation at Wadi Kareim consists of low-grade regionally metamorphosed greywackes, schists, volcanics and tuffs, of the green schists facies.

The greywackes are mainly represented by volcanic greywackes grading to volcanic breccias and infrequent normal greywackes. The described metasediments contain abundant polymictic and mesomictic ill-sorted fragments and grains indicating rapid transportation as was mentioned by KAMEL *et al.* [1977]. The mechanically carried pebbles and particles are relatively fresh fragments and represent many of the associated volcanic rocks. Such polymictic rock fragments and grains point to deposition during the period of intense subsidence of the geosyncline.

The schists are represented by chlorite, chlorite-calcite and actinolite-epidote varieties. Chlorite schist is most probably the regionally metamorphosed product of the geosynclinal pelitic and psammopelitic sediments, whereas the chlorite-calcite schists are either the products of some basic volcanic rocks or calc-pelitic sediments. The actinolite-epidote schists, however, belong to the albite-epidote hornfelses of the contact metamorphic facies. It is suggested that such schists were most probably developed along the sheared parts of the metavolcanic and associated pyroclastic rocks. Near the contact surfaces of granodiorite, the described schists may be facially changed to chlorite-biotite and chlorite-biotite-garnet varieties.

The metavolcanic rocks comprise keratophyre, quartz-keratophyre, spilite, spilitic diabase and diabase, that commonly occur as sheeted dykes and sill-like bodies, concordant with the schists, greywackes, lapilli tuffs (mainly spilitic), and banded lithic and crystal tuffs.

Application of the Al/3—K *versus* Al/3—Na diagrams aids in the petrochemical classification of the investigated rocks, and the designation of their magmatic differentiation or sedimentary degradation. The spilite of Wadi Kareim is similar to the average world spilite reported by VALLANCE [1960]. The keratophyre has an intermediate composition and is comparable to the aphanitic keratophyre of Schirmeck-type [JUTEAU and ROCCI, 1974]. The volcanic graywacke has a composition comparable to the spilitic. volcanics. Normal graywacke, however, has an intermediate composition between graywackes and shales. The chlorite schist also has a composition similar to shales. Again, the chlorite-calcite schists have a composition similar to tholeiitic dacites of the calc-alkaline series. Meanwhile, tuff has a different composition from normal volcanic and sedimentary rocks, but rather near to that of spilitic volcanics.

The Si/3—(Na + K + 2 Ca/3) *versus* K—(Na + Ca) diagram of the investigated group of rocks shows an evolution trend similar to the Schirmeck-type of preorogenic Hercynian volcanics denoting a magmatism of "folds" for the preorogenic Precambrian volcanics of Wadi Kareim, Central Eastern Desert, Egypt. Also, the FMA diagram of the studied rocks indicates a variation trend similar to the tholeiitic rock series. However, the Na—K—Ca diagram is rather comparable to the diagrams of the spilite-keratophyre rock association of the Lahn-Dill series, characteristic for a magmatism of "grabens". This discrepancy, may be partly due to the presence of abundant calcite veinlets in the studied group of rocks. However, the present authors feel that more petrochemical data concerning the Precambrian iron-bearing formation in the Eastern Desert are required to confirm the above suggested ideas concerning the paleographic and paleostructural conditions affecting the early geosynclinal volcanism.

REFERENCES

ABDEL AZIZ, M. GH. [1968]: Geology of Wadi Kareim area, Eastern Desert. Ph. D. Thesis, Cairo Univ.

ABDEL NASSER, S., and AFIA, M. S. [1949]: Report on Wadi Kareim deposit. Unpublished report, Mineral Research Division, Mines Dept., Cairo.

AKAAD, M. K. [1959]: Geology of Wadi Kareim iron ore deposit, Eastern Desert. Bull. Sci and Tech., Assiut Univ.

ANDREW, G. [1939]: The greywackes of the Eastern Desert of Egypt. Bull. Inst. Egypt **71**.

BARTH, T. W. [1959]: Theoretical Petrology. Wiley and Sons, New York.

CHETVERIKOV, S. D. [1956]: Guide to Petrochemical Calculations for Chemical Analyses of Rocks and Determination of their Chemical Types (in Russian). Gosgeoltekhizdat, Moscow.

EL-SHAZLY, E. M. [1957]: Classification of the Egyptian mineral deposits. Egypt. Jour. Geol., **1**, No. 1.

EL-RAMLY, M. F. and AKAAD, M. K. [1960]: The basement complex in the central Eastern Desert of Egypt. Geol. Surv. Egypt. Paper No. **8**.

FIALA, F. [1967]: The chemism of the Algonkian and Eocambrian volcanites in the Železné Hory Mountains. In: "Geochemistry in Czechoslovakia", Transactions of the first Conference on Geochemistry, Ostrava, 1965 p. 15—29.

FRIED KRUPP ROHSTOFFE [1959]: Report on the iron occurrences of Quseir Region.

Gindy, A. R. [1957]: The succession and correlation of the pre-Nubian sandstone rocks around the phosphate mining district of Quseir, Red Sea Province, Egypt. Arab Sci. Congress, p. 529—610.

JUTEAU, TH. and ROCCI, G. [1974]: Vers une meilleure connaissance du probléme des spilites a partir, de données nouvelles sur la cortége spilite-keratophyrique hercynotype. In: AMSTUTZ, G. C; (Ed.): Spilites and Spilitic Rocks. Inter. Union of Geol. Sci. Series A, No. **4**, Springer-Verlag Berlin, 253—329.

HILMY, M. E., KAMEL, O. A., and NIAZY, E. A. [1972]: Mineralogy of iron ore deposits of Wadi Kareim, Eastern Desert, A. R. Egypt. Proc. 6th. Arab Sci. Cong., Damascus, ***4B***, 685—716.

KAMEL, O. A., HILMY, M. E., and NIAZY, E. A. [1977]: Origin of Precambrian iron ore deposits from Wadi Kareim, Eastern Desert, Egypt. Bull. NRC, Egypt **2**, 401—413.

LA ROCHE H. DE [1966]: Sur l'usage du concept d'association minérale dan l'étude chimique des roches. C. R. Acad. Sci. (Paris), **262**, series D., 1665—1668.

LA ROCHE, H. DE, ROCCI, G. and JUTEAU, TH. [1974]: Essai de caracterisation chimique des associations spilitique. In: AMSTUTZ, G. G. (Ed.): Spilites and Spilitic Rocks. Inter. Union of Geol. Sci., Series A, No **4**, Springer Verlag, Berlin, p. 39—58.

NAKHLA, F. M. [1954]: Notes on the mineralography of some Egyptian ore minerals. Trans. Min. Petrol. Assoc. Egypt **9**, No. 3.
NIAZY, E. A. [1969]: Mineralogy of the iron ore deposits of Wadi Kareim and some other occurrences in the Eastern Desert, Egypt, U. A. R., M. Sc. Thesis, Ain Shams Univ.
NIGGLI, P. [1954]: Rocks and Mineral Deposits. Freeman, San Francisco.
NOCKOLDS, S. R. [1954]: Average chemical composition of some igneous rocks. Bull. Geol. Soc. America **65**, 1007—1032.
SHUKRI, N. M., EL SHAZLY, E. M., and SABET, A. H. [1959]: The iron ore deposit of Umm Ghamis El-Zarqa, Eastern Desert. Egypt. Jour. Geol., **III**, No. 2, 123—146.
SIGAEV, N. A. [1959]: Report on Wadi Kareim iron deposit. Unpublished report, Geol. Survey, Egypt.
TURNER, F. J. [1958]: Mineral assemblages of individual metamorphic facies, Mem. Geol. Soc. Amer.
TURNER, F. J. and VERHOOGEN, J. [1960]: Igneous and Metamorphic Petrology. Mc. Graw-Hill Book Company, New York.
VALLANCE, T. G. [1960]: Concerning spilites. Proc. Linnean Soc. N. S. Wales **IXXXV**, Part I. 8—52.
VALLANCE, T. G. [1965]: On the chemistry of pillow lavas and the origin of spilites. Mineralogical Magazine **34**, No. 268, 471—481.

Manuscript received, 1 October. 1983

E. A. NIAZY
National Research Centre, Cairo, Egypt

A. EL BAKRY and KAMEL, O. A.
El-Minia University, El-Minia, Egypt