

The mineralogy of Egyptian serpentinites and talc-carbonates

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SUMMARY. Optical, d.t.a., X-ray, and chemical analysis investigations were carried out on serpentinites from various Egyptian localities and on their associated talc-carbonates. The serpentinites were proved to consist of pure antigorite, lizardite, or clinochrysotile, or of mixtures of any pair of these serpentine minerals. Lizardite, which is reported for the first time in Egypt, is found to be of common occurrence. Talc, tremolite, carbonates, chlorite, olivine, biotite, chromite, magnetite, goethite, and stevensite are the main admixtures. The talc-carbonates consist mainly of talc and magnesite, or magnesite, dolomite, and talc together with minor amounts of antigorite, magnetite, goethite, and occasionally a little chlorite or calcite. Spectrographic analyses of some of the magnetically separated serpentinites have been carried out and the origin of the Egyptian serpentinites and talc-carbonates is briefly discussed.

SERPENTINITES are of wide distribution in the Eastern Desert of Egypt and are typically of Alpine type, occurring either as large steeply inclined sheets attaining several tens of square kilometres in extent or as minor dyke-like bodies and lenses. They were generally considered to consist of either antigorite only (Amin, 1948; Moustafa and Abdalla, 1954; Basta and Zaki, 1961; Gad, 1952) or of a mixture of antigorite and chrysotile (Hume, 1934; Shukri and Lotfi, 1955; Shukri and Basta, 1962). Associated with the serpentinites, talc-carbonate rocks (the so-called Barramyia rocks of Hume) are frequently encountered. These rocks are reported to consist of talc and calcite (Amin, 1948), of talc and breunnerite (Gad, 1952), or of talc, ankeritic siderite, chlorite, and sericite (Basta and Zaki, 1961). All previous studies on Egyptian serpentinites and talc-carbonates with the exception of that by Gad were based on microscopic examination only.

The present paper gives the results of a detailed mineralogical investigation of these rocks using optical, X-ray, differential thermal analysis, chemical, and spectrographic methods. It was hoped that such a study would help to clarify the origin of the serpentinites and talc-carbonate rocks of Egypt.

About 135 thin sections and the same number of polished sections were examined. The samples were collected from various localities in the central and south Eastern Desert of Egypt including: the serpentine ranges of Barramyia, Umm el-Salatit, Fatiri el Aswad, Abu Dahr, and Ras Shait, and several other minor occurrences. Forty-one samples were examined by X-ray methods: partly by powder photographs (using a 5-cm diameter camera and Cu- $K\alpha$ radiation) and partly by X-ray diffractometer (General Electric apparatus, Co- $K\alpha$ radiation). Thirty-four of these samples were also investigated by d.t.a., using a furnace with two vertical fused alumina tubes and Pt/Pt-rhodium thermocouple and a constant heating range of 10° per minute.

Finally, complete chemical analysis (giving the major elements) was carried out for thirteen representative samples, and trace elements (Cu, Cr, Co, and Ni) were also determined spectrographically for another ten.

Optical examination revealed the presence of *lizardite* as the main constituent of many of the serpentinite samples studied. Lizardite generally forms large rectangular plates ranging from 0.8 to 1.4 mm diameter, which are sometimes traversed by veinlets of clinochrysotile (fig. 1a) and which may be aggregated in bundles (fig. 1b). It is usually colourless with weak birefringence (about 0.01), plumose structure, and straight or shadowy extinction, average $2V_{\alpha}$ about 2° , average γ 1.558 ± 0.002 . Some of the serpentinites exhibiting mesh texture and previously considered to consist of antigorite and chrysotile were found to be either entirely lizardite (fig. 1c), as shown by X-ray powder photographs, or mixtures of lizardite and clinochrysotile; in the latter case the lizardite occupies the cores of the mesh while the walls are of clinochrysotile. In other cases, the two minerals form a fine-grained massive aggregate of clinochrysotile and platelets of lizardite that are nearly isotropic; the latter probably corresponds to the so-called 'serpophite' frequently reported by Hume (1934).

Antigorite is a common constituent of Egyptian serpentinites; some samples consist entirely or almost entirely of antigorite while others are mixtures of antigorite and clinochrysotile or of antigorite and lizardite (fig. 1d). Average $2V_{\alpha}$ about 50° , average α 1.559 ± 0.002 , average γ 1.566 ± 0.002 , birefringence about 0.007. Several forms of antigorite were observed. The most common type consists of fine scaly or lamellar aggregates, which exhibit plumose structure with radiating flame-like habit (fig. 1e); occasional specimens show schistose arrangement. Another variety of antigorite forms aggregates of small well-developed (001) plates 0.2–0.5 mm diameter oriented at random (fig. 1f). Very big plates of the so-called 'bastite' variety reaching up to 5 mm diameter and showing distinct cleavage traces were observed in some samples (fig. 2b), and are pseudomorphous after pyroxene. A fourth type exhibits both plumose and mesh structure. In a few cases, a fibrous type of antigorite (picrolite) was observed; the fibres are colourless or pale yellow, with positive sign of elongation, and frequently show preferred orientation (fig. 2a). Some specimens from Wadi Barramiya consist of a mixture of the fibrous and platy antigorite, the fibrous type constituting about 90% of the rock.

Serpentinites consisting almost entirely of *clinochrysotile* are the least common among the samples examined. The fine closely packed fibres are frequently interrupted by parallel bands of different orientation (fig. 2c); birefringence slightly higher than that of lizardite and antigorite (about 0.018), average γ 1.547 ± 0.002 , average α 1.528 ± 0.002 . More frequently clinochrysotile forms large veins that traverse antigorite or lizardite or fill cracks in partly replaced olivine; the fibres are always oriented perpendicular to the length of the vein. Very fine-grained massive clinochrysotile showing pseudo-spherulitic arrangements is occasionally observed.

Besides the serpentine-group minerals, other minerals are frequently observed in Egyptian serpentinites. These include talc, carbonates, tremolite, olivine, biotite, chlorite, chromite, and magnetite. Talc and carbonates are the most common and generally represent alteration products of serpentines. The talc occurs in flaky or

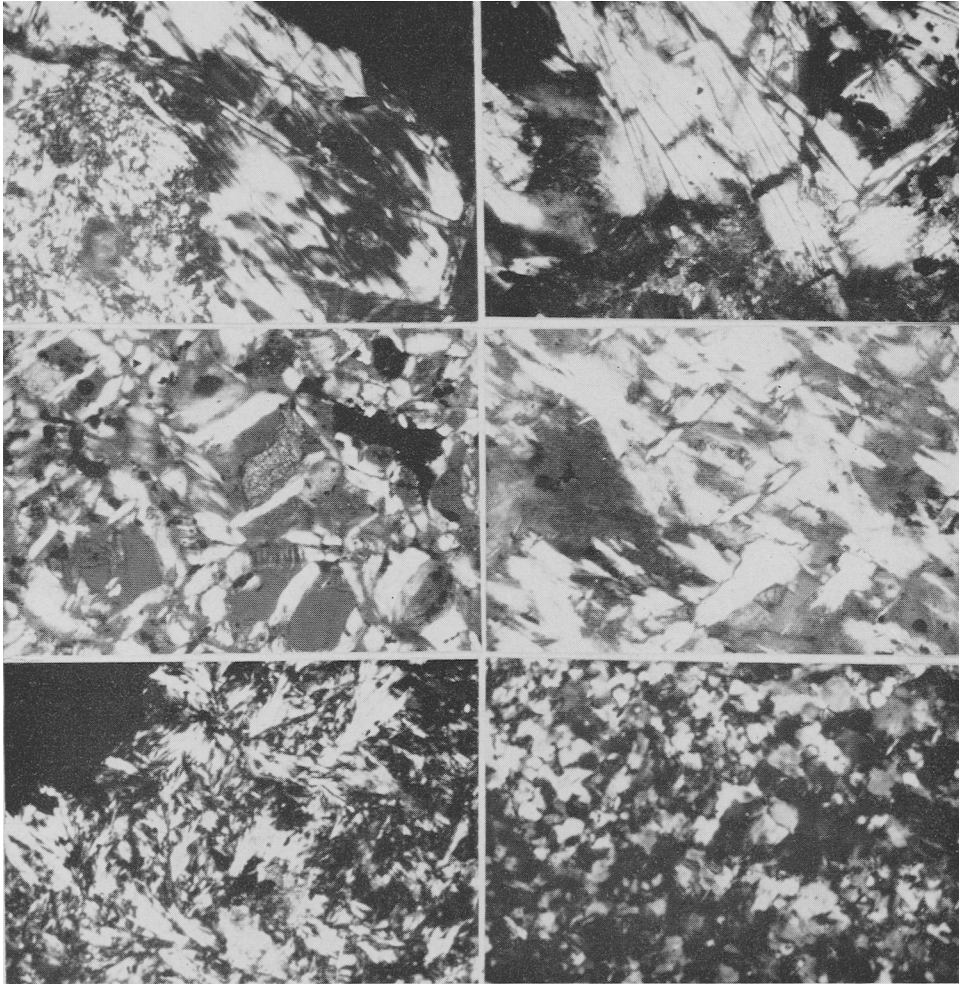


FIG. 1. *a*, top left, large plates of lizardite traversed by a vein of chrysotile in a fine-grained matrix of lizardite and chrysotile. The lizardite plates show flamboyant extinction. S-69, Black Marble quarry. Crossed polars, $\times 140$. *b*, top right, bundles of lizardite with small grains of carbonates and chromite. S-36, Wadi el-Barramyia. Crossed polars, $\times 96$. *c*, middle left, mesh texture formed almost entirely of lizardite; relics of olivine (high relief) are seen in the cores of the meshes. S-82, Wadi Beitan. Crossed polars, $\times 56$. *d*, middle right, lizardite and smaller lamellae of plumose antigorite. S-20, Wadi el-Barramyia. Crossed polars, $\times 56$. *e*, bottom left, radiating bundles of flame antigorite. S-104, Wadi Atalla. Crossed polars, $\times 56$. *f*, bottom right, basal plates of antigorite. S-98, Wadi Bezah. Crossed polars, $\times 56$.

fibrous forms and is frequently associated with lizardite or with lizardite-clinocrysotile mixtures; a serpentinite specimen from Wadi Badia (S-108) consists of lizardite and flaky talc in almost equal proportions. In some antigorite serpentinites exhibiting mesh texture, talc occupies the walls of the mesh and seems to have been formed by

the direct alteration of original olivine. Magnesite and dolomite are the most abundant carbonates. Veins of later calcite are also not uncommon.

The serpentines are usually pseudomorphous after olivine or clinopyroxene, or less frequently after tremolite or magnesian biotite. Relics of these minerals are occasionally observed; the serpentinization is frequently accompanied by the deposition

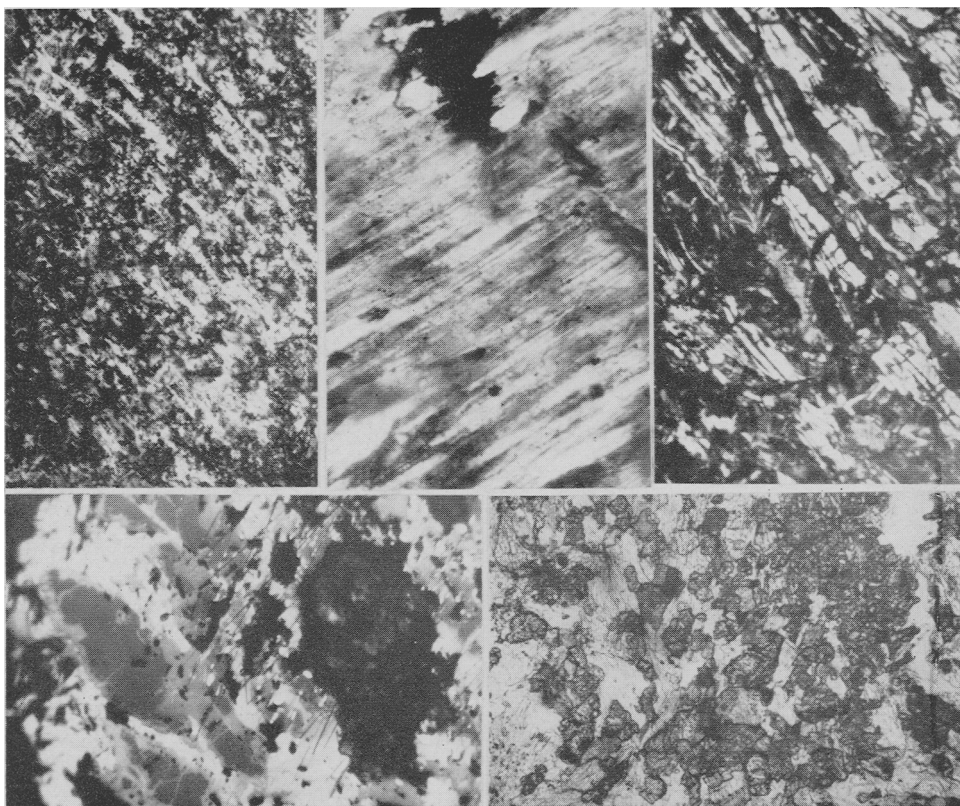


FIG. 2. *a*, top left, fibrous splintery antigorite; the fibres show preferred orientation. S-98, Wadi Bezah. Crossed polars, $\times 56$. *b*, top middle, large plate of antigorite showing distinct cleavage traces and shadowy extinction. S-106, north of Sukkari. Crossed polars, $\times 140$. *c*, top right, loosely mingled fibres of chrysotile interrupted by parallel bands. S-103, Wadi Umm Khariga. Crossed polars, $\times 140$. *d*, bottom left, chromite (dark grey) surrounded by a zone of oxidation (pale grey) and magnetite (white). S-55, Wadi el-Barramyia. Reflected light, $\times 56$. *e*, bottom right, aggregates of crystals of magnesite in a matrix of talc. Talc carbonate (Barramyia rock). T-3, Wadi el-Barramyia. $\times 56$.

of magnetite along the borders and cleavage planes. Chlorite and stevensite were detected in very few samples and probably belong to the same paragenetic sequence as the serpentines.

Chromite is relatively common in Egyptian serpentinites and is as a rule of early crystallization, occurring in euhedral or skeletal crystals that are corroded by the serpentines; veinlets of serpentine sometimes cut the chromite crystals. In polished

sections the chromite exhibits various degrees of replacement by magnetite; the replacement starts from cracks or from the margins of the crystals. In samples S-15 and S-55, relatively big crystals of chromite show zoning; the outer zone has a reflectivity higher than chromite but much lower than magnetite; the zoned crystals are surrounded by magnetite (fig. 2*d*). This type of zoning was observed by a number of authors and was attributed to partial oxidation of FeO to Fe₂O₃ (Mukherjee, 1962), or to the

TABLE I. *Chemical analyses of serpentinites. Anal. Chemical Laboratories, Cairo*

	S-30	S-33	S-15	S-57	S-21	S-81	S-84	S-80	S-20
SiO ₂	40.23	40.88	36.40	39.79	39.44	45.90	36.36	35.04	40.26
Al ₂ O ₃	0.20	1.04	0.50	1.00	0.74	0.19	0.24	0.42	0.97
Cr ₂ O ₃	1.04	0.27	0.45	0.51	0.50	0.76	0.57	0.34	0.25
Fe ₂ O ₃	5.28	5.30	10.23	6.34	7.86	3.12	7.73	8.22	6.11
FeO	1.91	1.42	3.76	0.90	0.92	1.60	0.97	1.09	1.30
MnO	0.61	0.14	0.11	0.31	0.26	0.39	0.05	0.11	0.12
MgO	40.02	40.54	36.85	39.36	38.01	37.73	39.77	39.26	40.44
CaO	traces	traces	traces	traces	traces	traces	traces	traces	traces
Na ₂ O	0.07	0.33	0.37	—	—	0.17	0.03	0.37	0.30
K ₂ O	0.01	0.08	0.11	—	—	0.02	—	0.11	0.08
H ₂ O ⁺	10.40	11.10	10.40	12.20	12.70	10.10	13.60	11.90	11.00
CO ₂	0.46	0.30	1.35	0.40	0.64	0.23	1.59	2.53	0.19
Total	100.29	101.40	100.53	100.81	101.07	100.21	100.91	99.39	101.02
<i>Number of ions on the basis of 10 oxygen</i>									
Si	3.93	3.9	3.96	3.82	4.01	4.19	3.65	3.72	3.82
Al ^{iv}	0.02	0.1	0.04	0.10	—	—	0.03	0.05	0.10
Fe ³⁺	0.05	—	—	0.08	—	—	0.32	—	0.08
Al ^{vi}	—	0.01	0.02	—	0.08	0.01	—	—	—
Fe ²⁺	0.02	0.15	—	0.23	—	0.21	0.01	—	0.15
Cr	0.06	0.01	—	0.03	0.04	—	0.04	0.02	0.01
Fe ²⁺	—	—	—	—	—	0.09	—	—	—
Mn	0.05	0.01	—	0.03	0.01	0.01	—	—	—
Mg	5.83	5.76	5.97	5.64	5.76	5.15	5.95	6.31	5.80
Σ ^{iv}	4.00	4.00	4.00	4.00	4.01	4.19	4.00	3.72	4.00
Σ ^{vi}	5.96	5.94	5.99	5.93	5.89	5.47	6.09	6.33	5.96

S-84, S-80 and S-20 are mainly lizardite. S-30, S-33, S-15, S-57, S-21 and S-81 are mainly antigorite. For the localities and description of these samples, see table V.

alteration of chromite accompanied by rapid leaching of Al and Mg (Wijkerslooth, 1943; Panagos and Ottemann, 1966) or of Mg only (Golding and Bayliss, 1968).

Separate idiomorphic octahedra of magnetite are also common and are frequently oxidized to martite, and both minerals may be hydrated to goethite. Sulphide minerals are rare and are mainly pyrrhotine together with minor amounts of chalcopyrite, bravoite, pyrite, and sphalerite.

The talc-carbonate rocks consist mainly of densely packed aggregates of magnesite embedded in a fine-grained matrix of talc (fig. 2*e*). One sample from Gebel Atud (T-4) contains, in addition, an appreciable amount of dolomite. Minor amounts of antigorite, magnetite, and goethite are also generally present, and in few cases some shreds of chlorite and veinlets of calcite.

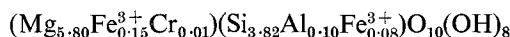
The results of chemical *analysis* of Egyptian serpentinites are given in table I. The silica, magnesia, and water contents compare well with those of typical lizardite and antigorite from other localities (see Deer, Howie, and Zussman, 1963, p. 176). The Egyptian serpentinites, however, are characterized by distinctly high percentages of Fe_2O_3 and Cr_2O_3 , which are generally due to admixtures of magnetite and chromite. The analyses of samples S-80 and S-84 from Wadi Beitan show a relatively high percentage of CO_2 as a result of the presence of some magnesite impurity. The slightly higher content of SiO_2 in sample S-81 is due to some admixed talc.

TABLE II. *Chemical analyses of talc-carbonates. Anal. M. Kamel*

	SiO_2	Al_2O_3	Fe_2O_3^*	MgO	CaO	Ign.	Total	
T-2	35.88	4.35	5.68	23.50	0.95	22.09	102.45	Wadi el-Barramyia
T-3	48.11	6.73	4.18	28.47	0.55	14.70	102.74	
T-4	31.37	9.73	9.44	26.53	5.93	19.32	99.82	Gebel Atud

* Total iron as Fe_2O_3 .

The distribution of the ions in octahedral and tetrahedral coordination as calculated from the chemical analyses on the basis of 10 oxygens and after the subtraction of the magnetite and chromite impurities is also given in table I. For examples S-20 and S-33, which are the purest samples analysed of lizardite and antigorite respectively, recalculation gave the formulae:



and



Table II gives the results of new chemical analyses of talc-carbonates, which may be compared with those quoted by Hume *et al.* (1935), Amin (1948), and Gad (1952). All the analyses with the exception of that of T-4 from Gebel Atud show a very low percentage of CaO indicating that, in general, calcite and dolomite are not the principal carbonate present in these rocks; a conclusion confirmed by optical, d.t.a., and X-ray examination. The FeO and Fe_2O_3 contents are due to the presence of small amounts of magnetite and goethite. The relatively high percentage of Al_2O_3 observed in the analyses is ascribed to chlorite. Specimen T-3 reveals an exceptionally high content of SiO_2 as a result of talc being in preponderance over carbonates.

The *X-ray data* of some examples of the serpentinite samples examined are given in table III; the results of the X-ray examination of the rest of the samples are shown in table V. The criteria used for the identification of the serpentine-group minerals were those given by Whittaker and Zussman (1956).

Fifteen samples (S-7, S-12, S-20, S-36, S-48, S-50, S-78, S-80, S-82, S-84, S-100, S-101, S-102, S-108, and S-111) gave the pattern of almost pure lizardite, characterized by the very strong line at about 2.495 Å and the pair of lines at about 1.535 Å (m.s.) and 1.502 Å (w.). On the other hand, the intense line at about 2.525 Å and the pair of lines at about 1.564 Å and 1.536 Å, which are characteristic for antigorite, have been observed in the patterns of thirteen other samples (S-9, S-15, S-21, S-30, S-33, S-57,

TABLE III X-ray data of serpentinites

S-84	S-20	S-7	S-39	S-33	S-17	S-110	S-123	S-104
$d, \text{\AA}$	$d, \text{\AA}$	$d, \text{\AA}$	$d, \text{\AA}$	$d, \text{\AA}$	$d, \text{\AA}$	$d, \text{\AA}$	$d, \text{\AA}$	$d, \text{\AA}$
I	I	I	I	I	I	I	I	I
7.31	7.31	7.31	7.2	7.28	7.41	7.25	7.25	7.31
50	4.60	4.48	100	4.62	4.63	4.53	4.46	4.6
3.63	3.65	3.65	80	3.62	3.66	3.63	3.66	3.6
2.89 ^d	10	3.15 ^t	10	3.01 ^c	80	100	2.92 ^d	3.07 ^d
2.69	5	2.71 ^m	10	3.01 ^c	10		2.578	100
2.49	100	2.50	100	2.521	100	2.529	2.458	40
2.298	5	2.286	10	2.442	10	2.456	2.458	60
2.176	50	2.186	60	2.205	10	2.205	2.292	20
2.099	10	2.113	10	2.09	60	2.171	2.132	40
				1.817	10	1.829	2.018	10
1.796	20	1.804	30	1.756	10		1.80	40
1.71	20	1.753	10				1.728	10
		1.686	5					
1.603	60	1.629	5					
				1.629	10		1.629	10
1.54	60	1.537	60	1.57	40	1.568	1.57	10
1.502	10	1.508	10	1.53	10	1.542	1.53	10
1.413	10	1.416	5	1.53	10	1.542	1.54	20
1.313	20	1.315	30	1.504	20	1.504	1.482	10
1.320	10			1.323	30	1.324		
				1.315	50	1.321		
				1.315	50			

* S-84, S-20, and S-7 are mainly lizardite; S-39 and S-123 are mainly clinochrysoite; S-33 and S-104 are mainly antigorite; S-17 is a mixture of antigorite and lizardite; S-110 a mixture of antigorite and clinochrysoite. Foreign lines: d = dolomite, c = calcite, t = talc, m = magnesite. For the location and description of these samples, see table V.

S-61, S-63, S-88, S-94, S-98, S-104, S-106). Six samples (S-37, S-39, S-45, S-65, S-103, S-123) gave the pattern of almost pure clinochrysotile. All these patterns are of ordinary clinochrysotile characterized by a strong line at about 2.458 Å and a medium weak band extending from it to about 2.59 Å, also a single strong line at about 1.54 Å. No pattern of the clinochrysotile 'Globe type' as described by Faust and Fahey (1962) was observed. The medium line at 2.604 Å (the 201 reflection when $\beta = 90^\circ$) was never detected, indicating the absence of any orthochrysotile in all the samples examined.

Two samples (S-17 and S-110) gave mixed patterns of antigorite and lizardite and of antigorite and clinochrysotile respectively (see table III). Besides the pattern of the serpentine group-minerals, a few faint foreign lines appeared for some of the samples as a result of impurities (talc, dolomite, calcite, and magnesite).

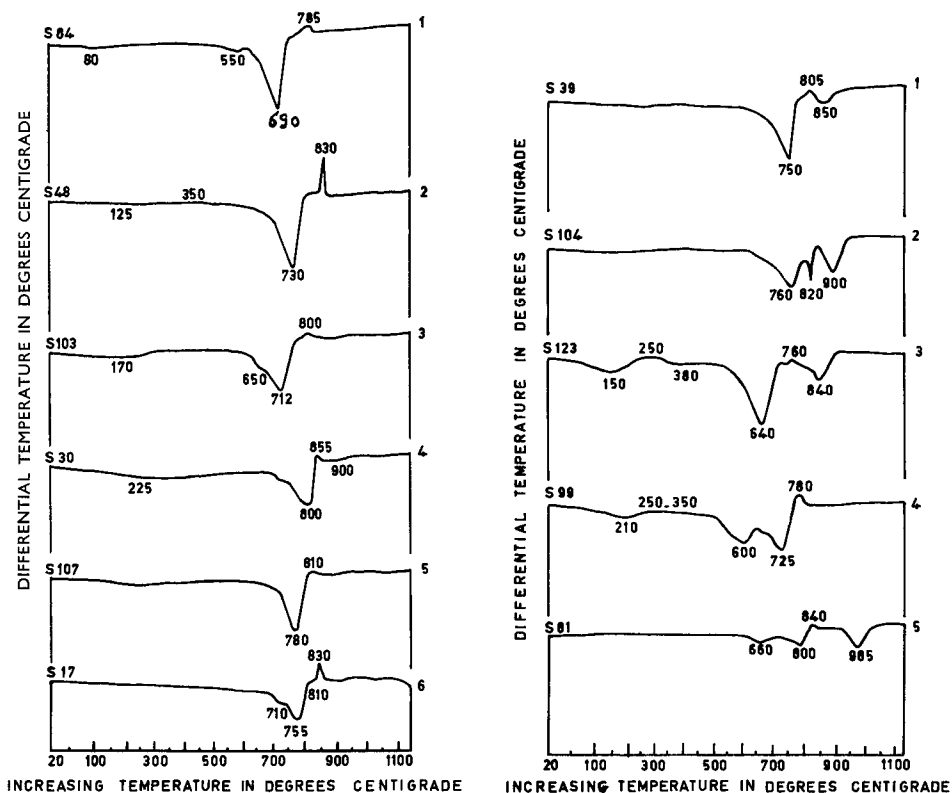
As regards the talc-carbonate rocks, four samples were examined by X-ray methods. Samples T-1, T-2, and T-3 from Wadi el-Barramyia (the Barramyia rocks) gave similar patterns, showing mixtures of talc and magnesite. The pattern of the Gebel Atud sample (T-4), on the other hand, revealed the presence of a considerable amount of dolomite while the amounts of talc and magnesite were much reduced.

Differential thermal analysis was carried out on most of the samples examined by X-ray methods. Fig. 3 gives representative examples of the d.t.a. curves of serpentinites composed almost entirely of serpentine-group minerals. From the d.t.a. curves, it was readily possible to distinguish antigorite from both lizardite and clinochrysotile. The d.t.a. curves of lizardite and clinochrysotile, on the other hand, are so similar (see Faust and Fahey, 1962) that the distinction between the two has to be based chiefly on X-ray methods. All the curves of pure or practically pure lizardite and clinochrysotile (fig. 3, curves 1, 2, 3) showed a major endothermic trough with the temperature of the minimum ranging from 690 to 730 °C with an average for nine curves of 708 °C. This endothermic trough occurs at a slightly higher temperature (740–750 °C) in samples containing a minor amount of admixed antigorite (e.g. S-78, S-100, S-50, S-12, S-37, and S-39). Sample S-17, which consists of lizardite and antigorite in almost equal proportions, shows resolution of this endothermic trough into two separate troughs (fig. 3, curve 6). A similar curve was described by Faust and Fahey (1962, fig. 40, C-116) for a specimen from Baltimore County, Md. containing 50 % chrysotile and 50 % antigorite.

The endothermic reaction is followed after a short distance by a pronounced exothermic peak with a maximum temperature ranging from 770 to 835 °C with an average of 802 °C. This exothermic peak represents the recrystallization of some of the dehydrated lizardite or clinochrysotile, and the difference between its temperature and that of the endothermic peak ($\Delta EX-EN$) for pure samples ranges from 73 to 100 °C with an average of about 90 °C.

In addition to these two major thermal effects, most of the curves show a gentle downward bow between 80 and 200 °C indicating continuous loss of adsorbed water, and this is immediately followed by a slight upward bow in the temperature range of 250–500 °C; for this last phenomenon, no satisfactory explanation is at present possible. The curves of the clinochrysotile specimens S-103 and S-87 show a small

inflection at 650 and 685 °C, respectively, on the low-temperature side of the major trough (see fig. 3, curve 3); an even smaller inflection was observed at 650 °C in the curve of a lizardite specimen (S-101). In view of this, the statement made by Faust and Fahey (1962, p. 67) that such an inflection may be diagnostic for lizardite cannot be corroborated.



FIGS. 3 and 4: FIG. 3 (left). D.t.a. curves of pure serpentinites: S-84, lizardite, Wadi Beitan; S-48, lizardite, Wadi el-Barramyia; S-103, clinochrysotile, Wadi Umm Khariga; S-30, antigorite, Wadi el-Barramyia; S-107, antigorite, El Gindi district; S-17, antigorite and lizardite, Wadi Zeidun. FIG. 4 (right). D.t.a. curves of serpentinites composed of serpentine minerals admixed with genetically related minerals: S-39, clinochrysotile with minor antigorite and a little dolomite, Sikeit; S-104, antigorite with much dolomite, Wadi Atalla; S-123, clinochrysotile with stevensite, dolomite, and goethite, Wadi Badia; S-99, lizardite and magnesite, Gebel Ghadir; S-81, antigorite with biotite and talc, Wadi Beitan.

The d.t.a. curves of serpentinites consisting of pure or practically pure antigorite (curves 4 and 5, fig. 3) are simpler than those of lizardite and clinochrysotile. They are characterized by the absence of the 250–500 °C upward bow and the fact that the major endothermic trough has a minimum temperature ranging between 780 and 820 °C with an average for six curves of 797 °C. Immediately following the endotherm, a very minor exothermic peak appears at a temperature ranging from 810 to 855 °C

($\Delta EX-EN = 30-55^\circ\text{C}$) and is sometimes almost completely absent (curve 5 of S-107). For mixtures of antigorite and lizardite the curve in the temperature range $200-700^\circ\text{C}$ is also nearly a straight line and the separation of the minimum of the major endotherm from the maximum of the exotherm ranges from 40 to 90°C with an average of 73°C (see curve 6, fig. 3). The d.t.a. curves of Egyptian serpentinites containing appreciable amounts of other minerals admixed with the serpentine-group minerals are given in fig. 4. The presence of a small amount of dolomite results in the appearance of an endothermic peak at about 850°C (curve 1). On the other hand, samples containing abundant dolomite show two endothermic troughs at about 760 and 900°C respectively (curve 2); the oxidation of magnetite impurity resulted in a low upward bow between 300 and 400°C (see Gheith, 1952). Curve 3 of S-123 is somewhat complicated owing to the possible presence of a little stevensite¹ (see Faust and Murata, 1953), some dolomite and goethite (a very shallow bow at about 380°C). Other impurities detected in the d.t.a. curves are: magnesite (curve 4), talc and biotite (curve 5). A curve of a lizardite specimen (S-7) showed a shallow endothermic trough at 1035°C due to the presence of admixed tremolite.

The d.t.a. curves of four specimens of talc-carbonates are given in fig. 5. Curves 1, 2, and 4 show a large downward bow between 100 and 200°C due to the constant loss of adsorbed water. The presence of magnesite in all the samples is indicated by a pronounced endothermic trough with a minimum ranging from 630 to 700°C . The expulsion of water from talc results in a somewhat shallower endothermic peak at $955-90^\circ\text{C}$. In specimen T-3 (curve 3) the amount of talc is more than that of magnesite. The presence of a small amount of dolomite in the Barramyia rock T-1 (as verified by X-rays) resulted in a small but very sharp endotherm at 850°C (curve 1). Other minerals detected in the d.t.a. curves are: chlorite (endotherm at 900 or 860°C , curves 2 and 3, respectively), magnetite (broad upward bow at about 350°C , curve 3) and antigorite (shallow endotherm at 790°C , curve 3).

Specimen T-4 from Gebel Atud gives a d.t.a. curve that is significantly different from those of the type locality (Barramyia). Two very sharp and pronounced endothermic troughs appear at 790 and 910°C and are attributed to the presence in this specimen of a considerable amount of dolomite, which is almost equal to that of magnesite. The amount of talc, on the other hand, is very much reduced as indicated by the appreciable decrease in the size of its endothermic trough. It must be emphasized here that in all the d.t.a. curves of talc-carbonates, no definite exothermic peak as described by Gad (1952) for the oxidation of FeO of his supposed breunnerite to Fe_2O_3 was observed. The identity of magnesite was ascertained by the optical and X-ray examination.

Minor elements in the serpentinites. The distribution of minor elements in serpentinites has a distinct bearing on the theory of the origin of these rocks. The studies by Faust, Murata, and Fahey (1956) and by Faust and Fahey (1962) revealed that the serpentine minerals derived from ultrabasic rocks through deuteric or subsequent hydrothermal replacement are notably richer in minor elements (particularly Ni, Cr,

¹ This explains the large endotherm at about 150°C and the decrease in the minimum temperature of the principal endotherm of clinochrysotile.

Co, and Sc) than those derived from various types of metamorphic limestones and dolomites, from contact metamorphic deposits, or from hydrothermal veins contained in such rocks.

In the present work the contents of Ni, Cr, Co, and Cu in ten specimens of serpentinites from different localities were determined spectrographically. In order to

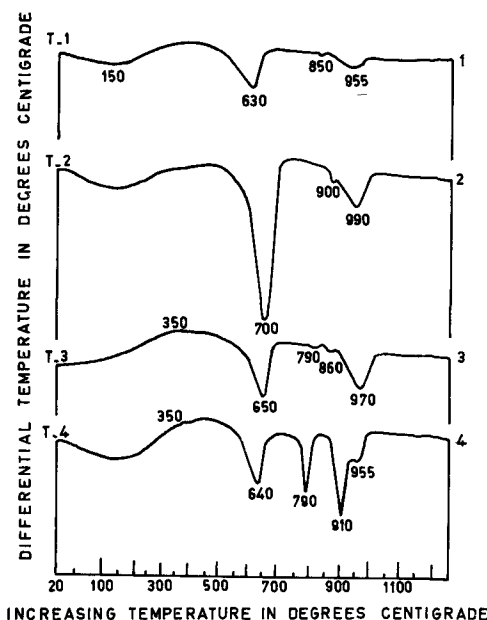


FIG. 5. D.t.a. curves of talc-carbonate rocks: T-1, magnesite, talc, and a little dolomite, Wadi el Barramyia; T-2, magnesite, talc, and a little chlorite, Wadi el Barramyia; T-3, magnesite, talc, magnetite, antigorite, and clinocllore, Wadi el Barramyia; T-4, dolomite, magnetite, and talc, Gebel Atud.

separate the admixed magnetite, chromite, and other opaques, each powdered sample was subjected to intense purification by means of a Frantz Isodynamic separator; the non-magnetic fraction only,¹ consisting of practically pure serpentine-group minerals, was analysed. The results of the spectrographic analyses are given in table IV. From the table it is evident that the samples examined may be divided into two distinct classes as regard their contents of minor elements. Class A includes specimens (S-11, S-83, S-110, S-65, S-17, S-77, S-104, and S-71) that are significantly rich in Ni, Cr, and Co. In the two specimens S-88 and S-70 of class B, on the other hand, these minor elements occur in very small to negligible concentrations. The distribution of Cu, however, is not uniform in the two classes. From the geochemical point of view class A, therefore, includes serpentinites formed in ultrabasic igneous rocks while class B

¹ Further purification was carried out for some samples by hand-picking under a binocular microscope.

includes serpentinites formed in various types of metamorphic rocks and in hydrothermal veins. It is interesting to note that the actual geological occurrence of the two specimens of class B confirms the above interpretation. Thus, S-88 (antigorite) occurs as hydrothermal veins in metamorphosed limestone and is associated with talc and carbonates, while S-70 (lizardite and clinochrysotile) occurs in a diopsidic calcite

TABLE IV. *Distribution of minor elements in serpentines. Anal. O. El-Farouk, National Research Centre, Cairo*

	No.	Co %	Cr %	Cu %	Ni %
Class A	S-11	0.01	0.50	0.0005	0.05
	S-83	0.02	0.50	0.0005	0.03
	S-110	0.02	0.40	0.0015	0.05
	S-65	0.015	0.10	0.0015	0.03
	S-17	0.02	0.40	0.0015	0.20
Class A	S-77	0.02	0.20	0.0005	0.20
	S-104	0.02	0.50	0.0005	0.20
	S-71	0.02	0.40	0.0005	0.20
Class B	S-88	nil	0.003	0.0010	0.002
	S-70	0.001	0.002	0.0030	0.005

S-11: Pale yellowish-green massive serpentinite (lizardite), Qena-Qoseir Road, central Eastern Desert.

S-83: Pale yellowish-green massive serpentinite with numerous black veinlets, Wadi Beitan, near Gebel Abu Dahr.

S-65: Dark green massive serpentinite (clinochrysotile), Wassif basin, near Safaga, north Eastern Desert.

S-77: Pistacho-green subtranslucent massive serpentinite, Wadi Umm el-Salatit, central Eastern Desert.

S-71: Contact between pale green and red massive serpentinite, Black Marble quarry, Wadi el-Miyah.

S-70: Pistacho-green translucent veins of serpentinite in marble. Black Marble quarry.

For location and description of specimens S-110, S-17, S-104, and S-88, refer to table V.

marble and is probably formed by the replacement of diopside and tremolite. The serpentinites of class A are generally rich in iron oxides and chromite while those of class B are almost free of opaque minerals and are consequently of paler colour.

Discussion and conclusions

A summary of the mineralogical composition and location of 39 specimens of serpentinites that were examined by X-ray methods and d.t.a. is given in table V. From this and from the chemical and optical data of several other specimens, Egyptian serpentinites may be classified mineralogically into three main groups: serpentinites composed of a single serpentine mineral; serpentinites composed of a mixture of two serpentine minerals; and serpentinites composed of serpentine-group minerals admixed with appreciable amounts (more than 20%) of paragenetically associated minerals.

The first group is the most common and is subdivided into lizardite-, antigorite-, and clinochrysotile-serpentinites according to the type of serpentine mineral present. Lizardite is found to be a common constituent of the serpentine rocks of Egypt; out

TABLE V. *Mineralogical classification of the serpentinite specimens studied by X-rays and d.t.a.*

No.	Locality	Petrographic description	Other constituents
<i>Lizardite</i>			
S-7	Qena-Qoseir Road	Mesh texture, dark green massive with large whitish-brown veins.	Tremolite, calcite, and some chromite and magnetite.
S-20	Wadi el-Barramyia	Dark green massive with numerous large brown crystals.	Dense inclusions of magnetite.
S-36		Pale green subtranslucent.	Some carbonates and chromite.
S-48		Pale green, fine-grained with reddish tint.	Carbonates and some chromite.
S-80		Brown with numerous black veinlets.	Olivine, carbonates, and magnetite.
S-82	Wadi Beitan	Pale yellowish-green.	Olivine and chromite.
S-84		Dark brown with greyish veins.	Iddingsite and carbonates.
S-101	Gebel Karabkansi	Brown with dark greenish parts.	Tremolite and few veinlets of pyrite.
S-102	Gebel umm el-Salatit	Pale green translucent.	—
S-108	Wadi Badia	Dark green massive.	Much talc and magnetite.
S-111	Wadi Zeidun	Pale green translucent massive.	—
<i>Clinochrysotile</i>			
S-45	Wadi el-Barramyia	Yellowish-green subtranslucent.	Few carbonates, chromite, and magnesite.
S-65	Wassif basin, NE. Desert	Dark green massive, some parts fibrous.	Little calcite and chromite.
S-103	Wadi umm Khariga	Very dark green nearly black, massive.	Magnetite.
S-123	Wadi Badia	Dark green massive.	—
<i>Antigorite</i>			
S-9	Qena-Qoseir Road	Pale green, subtranslucent, schistose, brittle, some parts black.	Siderite, chromite, and magnetite.
S-15	Wadi umm Esh el Zarga	Black massive.	Little dolomite, chromite, and magnetite.
S-21	Wadi el-Barramyia	Pale green with brown crystals.	Minor talc, magnetite, and chromite.
S-30		Dark green.	Few crystals of carbonates and much magnetite.
S-33		Pale green subtranslucent (picrolite).	Much goethite and martitized magnetite.
S-61	Saul Hamed	Dark green massive associated with chromite.	—
S-63	Gebel Atud	Pale green translucent massive.	Limonite.
S-81	Wadi Beitan	Dark green subtranslucent massive.	Little biotite, much talc and chromite.
S-88	Angouria	Dark green subtranslucent.	Large amount of carbonates and talc.
S-94	Gebel Moweleh	Yellowish-brown massive associated with opaques.	—
S-98	Wadi Bezah	Pale green translucent.	Pyrite and hematite.
S-104	Wadi Atalla	Pale whitish-green massive with dark parts.	Large amount of dolomite and magnetite.
S-106	N. end of Sukkari	Dark brown.	Much magnesite, some chromite and magnetite.
S-109	Wadi Alaqui	Black massive.	—
<i>Lizardite + Antigorite, L > A</i>			
S-12	Wadi Fatiri	'Bastite', dark green with serpent structure.	Clinopyroxene, chromite, and magnetite.
S-17	Wadi Zeidun	Black with silky lustre.	—
S-50	Wadi Fatiri	—	—
S-78	Wadi Beitan	Pale yellowish-green.	Calcite veins, chromite, and magnetite.
S-100	Bir Meneiga	Greenish brown massive.	Large amount of opaques and few carbonates.
<i>Clinochrysotile + Antigorite, C > A</i>			
S-37	Wadi Sikeit	Pale green, subtranslucent, fibrous.	{ Trace of magnesite. Dolomite.
S-39			
<i>Antigorite + Clinochrysotile, A > C</i>			
S-57	Gebel el-Rubshi	Dark greenish-brown massive.	—
S-110	Wadi Ghadir	Dark green, subtranslucent.	Few opaques.

of the 39 specimens given in table V, eleven were found to consist almost entirely (95 % or more) or chiefly (80 % or more) of lizardite. Antigorite-serpentinites are equally common, but four specimens only were identified as practically pure clinochrysotile. Orthochrysotile and clinochrysotile (Globe-type) were not detected in any of the specimens examined in the present work.

The following mixtures of serpentine-group minerals were identified: lizardite-antigorite mixtures in which lizardite is predominant; clinochrysotile-antigorite mixtures in which clinochrysotile is predominant; and antigorite-clinochrysotile mixtures in which antigorite is predominant. Mixtures of lizardite and clinochrysotile ($L > C$) were detected microscopically in few specimens but it was not possible to confirm this by d.t.a. and X-ray methods. This is partly due to the fact that the d.t.a. curves of lizardite, clinochrysotile, or mixtures of both are practically undifferentiable and partly to the possibility that clinochrysotile in these mixtures occurred in amounts too small (10% or less) to be detected in the X-ray pattern.

Minerals paragenetically related to the serpentine-group minerals and observed in the serpentinites examined include talc, carbonates (mainly magnesite and dolomite), tremolite, chlorite, and stevensite; magnetite, chromite, and goethite are other common associates. Relics of the original minerals that have undergone serpentinization consist of olivine, pyroxene, amphibole, or mica.

One specimen of 'serpentinite' (S-8) from the Qena-Qoseir road deserves special consideration owing to its peculiar chemical and mineralogical composition. Chemical analysis gave SiO_2 31.2%, Al_2O_3 14.09, Fe_2O_3 6.46, Cr_2O_3 0.16, FeO 6.91, MnO 0.81, MgO 27.25, CaO traces, Na_2O 0.09, K_2O 0.03, CO_2 0.94, H_2O 10.10, total 101.05%, which shows that its Al_2O_3 and FeO contents are much too high and its MgO and SiO_2 contents are much too low for a serpentine mineral. Optical, d.t.a., and X-ray examination revealed that the specimen consists mainly of compact colourless chlorite (clinochlore) and lizardite together with a trace of tremolite. The high FeO content may indicate that the lizardite is possibly a ferrolizardite. Chia *et al.* (1964, p. 86) described a ferrolizardite from Yun Ching, Peking that contains 6.22% FeO and 7.99% Fe_2O_3 and which they considered to be a new mineral species of the serpentine group; its d.t.a. curve is somewhat similar to that of the present sample. Specimen S-8 merges into a true massive serpentinite of a darker green colour (S-7), which consists of lizardite and minor tremolite but no chlorite. A similar chlorite-lizardite association from New South Wales has been recently described by Golding and Bayliss (1968). It is intended to carry out in the near future further geological and mineralogical investigation (using electron-probe technique) of the present occurrence in order to reveal its genesis.

Regarding the regional distribution of various types of the Egyptian serpentinites it was not generally possible to characterize each locality by a certain serpentine mineral. Some exceptions, however, have been observed. Examples are the serpentinites of Wadi Beitan, which are mostly of lizardite, and those of Wadi Sikeit, which are chiefly of clinochrysotile-antigorite mixtures. The serpentinites of the important mining occurrence of Barramyia are generally either chiefly antigorite or chiefly lizardite.

From the minor element determinations it is concluded that the serpentinites examined belong to two distinct types of paragenesis: serpentinites derived by deuteric and hydrothermal replacement of ultrabasic rocks and characterized by being notably rich in Ni, Co, and Cr, and serpentinites derived from metamorphic rocks and hydrothermal veins and containing negligible amounts of these elements. The first type of serpentinites (class A of Faust and Fahey, 1962) are the most common in the Egyptian

occurrences and are generally formed by the alteration of the ultramafic rock suite (dunites, peridotites, and pyroxenites), with the exception of a very few specimens that are derived from mica-peridotites.

The above conclusion as to the presence of two genetically different serpentinites is contrary to the prevailing views of Ibrahim (1952), Shukri and Amin (1955), and Mansour, Bassyuni, and El-Far (1956) that all Egyptian serpentinites are formed by hydrothermal alteration of ultrabasic rocks. However, further detailed studies are needed in order to solve conclusively the problem of the origin of the serpentine rocks of Egypt.

The talc-carbonate rocks associated with the serpentinites of Barramyia were found to consist mainly of mixtures of talc and magnesite in different proportions. Those of Gebel Atud, on the other hand, contain in addition, much dolomite, at the expense of the talc. Antigorite, magnetite, and goethite occur in minor amounts and, in a few cases, some chlorite. These talc-carbonate rocks are generally considered to be formed by CO₂-metasomatism of large serpentinite masses along peripheries and fracture lines (Shukri and Amin, 1955; El Ramly and Akaad, 1960). The presence of much dolomite in the Gebel Atud specimen, however, indicates that besides CO₂, lime-bearing solutions were also abundant. On the other hand, the relatively high content of Al₂O₃ in this rock and the presence of chlorite relics may suggest that the original material was partly a serpentinite and partly a tremolite-chlorite rock.

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