Some new occurrences of gonnardite.

(With Plate X.)

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Summary.—This zeolite, hitherto recorded only from Chaux de Bergonne, France, has been found as zoned spherules with thomsonite (var. faroelite), on specimens from Aci Castello and Aci Trezza, Sicily, and Capo di Bove, Rome, from Weilberg, Rhineland, and from Klöch, Styria. Three chemical analyses confirm previous results; optical data suggest some variation in composition within a spherule. There is a striking resemblance between X-ray fibre photographs of gonnardite and of thomsonite, and between X-ray powder photographs of gonnardite and of natrolite. The Klöch occurrence, where the gonnardite is accompanied by phillipsite, is described in detail.

DURING a routine examination of a number of zeolites recently acquired by the British Museum, specimens from Aci Castello and Aci Trezza, Catania, Sicily, labelled mesolite, or phillipsite, were found to have optical properties substantially different from those of either mesolite or phillipsite; the refractive indices were near those of mesolite, but the birefringence, although weak, was too high for mesolite, and the straight extinction of the fibres precluded their being a fibrous phillipsite. X-ray powder photographs closely resembled those of natrolite, but more careful examination showed that the mineral is gonnardite, a zeolite hitherto only recorded from Chaux de Bergonne, Gignat, Puy-de-Dôme, France, and this identification is confirmed by chemical analysis and by a more detailed optical study. On the three Sicilian specimens, the gonnardite forms white spherules, up to $\frac{1}{2}$ inch in diameter, on a vesicular basalt, and is accompanied by needles of calcite, small drusy spherules of columnar phillipsite, and chabazite crystallized in the phacolite habit. On re-examination of a number of other fibrous zeolites gonnardite was found as a few white spherules, up to $\frac{1}{2}$ inch in diameter, alone in a cavity in leucite-tephrite from Capo di Bove, Rome (B.M. 82805; pl. X,E), and also accompanying very fine cruciform twins of phillipsite in a cavity in basalt from Weilberg, Rhineland (B.M. 1908, 308(20)). About the same time, one of us (H. M.) observed a zeolite in the basalt of Klöch, Styria, which gave X-ray powder photographs closely resembling those of natrolite, but had too high a refractive index. Comparison with type material from Chaux de Bergonne, presented by Prof. A. Lacroix (B.M. 1930, 166), shows that the Klöch zeolite, too, is gonnardite.

With more adequate supplies of material available, three new semi-micro chemical analyses of gonnardite have been made (table I); these

TABLE I. Chemical and optical data for gonnardite.

	A.	B.	C.	D.	E.		A*.	B*.	C*.	D*.
SiO_2	42·80	43·20	42·75	41·85	42·3	Si ...	11·7	11·8	11·7	11·3
Al_2O_3	28·15	27·90	27·36	27·02	28·1	Al ...	9·1	9·0	8·8	8·6
CaO	4·26	3·61	7·77	9·29	10·0	Ca ...	1·2	1·0	2·3	2·7
Na_2O	12·65	13·16	8·15	7·25	6·7	Na ...	6·7	7·0	4·3	3·8
K_2O	0·13	tr.	0·15	n.d.	n.d.	K ...	0·04	tr.	0·05	—
H_2O	11·85	11·74	13·44	14·37	14·1	O ...	41·6	41·5	41·0	40·2
Sum	99·84	99·61	99·62	99·78	101·2					
						H_2O...	10·8	10·7	12·2	13·0
D_4^{20}	2·28†	2·27†	2·27†	2·26‡	2·26–2·36					
						(Si,Al)	20·8	20·8	20·5	19·9
α′§	1·498	1·497	1·506	1·506	– –	(Ca,Na,K)	7·9	8·0	6·7	6·5
γ′§	1·502	1·499	1·508	1·508	· ·					
Elongn.	β	+	—	—	+					

A. Klöch, Styria. B.M. 1955, 313.
B. Aci Trezza, Sicily. B.M. 1954, 184.
C. Aci Castello, Sicily. B.M. 1954, 45.
} Anal. A. A. Moss.
D. Chaux de Bergonne, France. B.M. 83037. Anal. M. H. Hey (1932).
E. Chaux de Bergonne, France. Anal. F. Pisani (F. Gonnard, 1871); optical data by A. Lacroix (1896).
A D**. Empirical and semi-empirical unit-cell contents, using the cell-dimensions determined on specimen *D* (Hey, 1932). The assessed probable error of ±0·05 for the cell-sides leads to a probable error of approximately ±3 % in the cell contents (1·2 in O); it is probably an underestimate.

† ±0·01. ‡ ±0·02. § ±0·002 to 0·003.

confirm the unit-cell formula found earlier, [$(Ca, Na)_{6-8}(Si,Al)_{20}O_{40}\cdot 12H_2O$], with Al near 9 (M. H. Hey, 1932). The unit cell is near that of thomsonite, except for the halving of the *c*-dimension, and the composition is only a little more silica-rich than some faroelites. It is interesting to note the very small percentage of potassium in all the analysed specimens, despite the fact that all are accompanied by phillipsite, of which potassium is an essential constituent; the formation of a potassium-natrolite by base-exchange shows clearly that potassium can enter most zeolite structures but the strong preference for sodium and calcium has been noticed before.

X-ray rotation photographs of gonnardite resemble those of thomsonite, especially if the exposure has been too short to bring out the weak odd layer-lines of thomsonite, but powder photographs of the two

TABLE II. X-ray powder data for gonnardite (B.M. 1908, 272, Chaux de Bergonne, France) and natrolite (B.M. 1914, 769, Snake Hill, Hudson County, New Jersey). Camera diameter 6 cm. Cu-$K\alpha$ radiation. In the intensities columns, the three strongest lines are numbered.

Gonnardite.		Natrolite.		Gonnardite.		Natrolite.	
d.	*I.*	*d.*	*I.*	*d.*	*I.*	*d.*	*I.*
6·70	s	6·53	s	1·323	mw	1·627	mw
5·93	vs 2	5·87	vs 2	1·291	vw	1·600	mw
5·25	w	4·64	m	1·262	vvw ?	1·571	vw
4·74	ms	4·36	vs 3	1·237	mw	1·530	mw
4·44	s 3	4·14	ms	1·202	vw	1·510	vvw
4·22	mw	3·90	vvw	1·178	vvw	1·485	vvw
3·69	vw	3·64	vvw	1·157	vw	1·462	m
3·52	vvw	3·17	ms	1·129	vvw	1·431	vvw
3·23	ms	3·11	m	1·095	vw	1·415	w
3·12	m	2·95	m	1·080	vvw	1·386	mw
2·92	vvs 1	2·86	vvs 1	1·069	vw	1·367	vw
2·61	m	2·75	vvw	1·060	vw	1·341	w
2·48	m	2·67	vvw	1·048	vvw	1·324	w
2·36	w	2·58	m	1·039	vvw	1·306	mw
2·33	vvw	2·52	vvw	1·032	vvw	1·290	vvw
2·28	w	2·45	m			1·273	vw
2·22	m	2·41	m			1·261	vvw
2·16	vvw	2·33	mw			1·238	vvw
2·12	vwb	2·26	w			1·218	mw
2·07	w	2·19	m			1·193	w
1·98	wb	2·12	vvw			1·178	vvwb
1·895	mw	2·06	w			1·160	vvwb
1·851	w	2·02	vvw			1·142	vw
1·818	mw	1·96	w			1·130	vw
1·759	mwb	1·93	vvw			1·109	vvwb
1·697	w	1·876	mw			1·091	vw
1·647	m	1·831	vvw			1·080	vvw
1·607	w	1·799	m			1·060	vw
1·548	wb	1·754	w			1·050	vvw
1·486	mw	1·728	mw			1·037	vvw
1·442	w	1·700	w			1·022	w
1·398	wb	1·676	vw				
1·348	vw	1·647	w				

minerals are readily distinguished. On the other hand, while rotation photographs of gonnardite and natrolite are quite distinct, their powder photographs are remarkably similar and can be confused (pl. X, B, C); the most notable differences are in the region from $d = 2{\cdot}00$ to $d = 1{\cdot}30$ Å. Optically, gonnardite is distinguished from other fibrous zeolites giving straight extinction by its refractive index and birefringence; the latter is about 0·002 to 0·004, noticeably higher than that of mesolite ($< 0{\cdot}001$), while its refractive index, ranging from about 1·497 to 1·507, is higher than that of natrolite (γ 1·497), overlaps that of mesolite (1·505), and is lower than that of the most siliceous faroelite so far recorded (α 1·511). Mordenite, which has a rather similar birefringence, has a much lower refractive index (γ 1·480); stellerite, a variety of stilbite, has practically straight extinction, but a lower refractive index (γ 1·492) and higher birefringence (0·007).

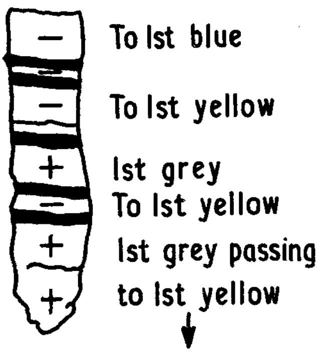

FIG. 1. Zones of varying birefringence and optical sign in gonnardite from Aci Castello, Sicily (B.M. 1954, 130).

A notable characteristic of the Sicilian gonnardite specimens that we have studied is the zonal structure of the spherules in which the mineral always crystallizes. As indicated in fig. 1, a small splinter under crossed nicols often shows several zones, some with positive elongation, some with negative, and all grading into one another; though owing to the finely fibrous structure it is not possible to be sure whether this gradation occurs within the individual fibres or is due to variations in the length and position of the several zones from fibre to fibre. X-ray photographs of fragments from different zones (taken from a specimen with a less complex zonal structure than that figured) show no differences, and all the zones are gonnardite: presumably there are differences in chemical composition between the positive, negative, and isotropic zones, but it was not possible to obtain enough material to analyse these zones separately. Some of the zones are visible to the naked eye in ordinary light as more glassy or transparent zones in the white surface of a broken spherule; this may be due to reduced scattering in the more nearly isotropic material.

All the specimens were examined optically (compare table I); four from Chaux de Bergonne showed very little variation in optics; about 50 from Klöch showed appreciable variations in the refractive index, α' in one specimen being as high as 1·503, while the analysed specimen had the lowest refractive indices of any examined; a specimen from Aci Castello (B.M. 1954, 130) gave the most complex zonal structure, and resembled the Aci Trezza specimen in refractive indices.

The zeolites of the Klöch basalt (H. M.).

All the new occurrences of gonnardite except that at Klöch are only known from a limited number of small hand-specimens, the precise provenance of which has not been established; much of the Klöch material, on the other hand, was collected by one of the authors (H. M.) and a full description of its occurrence is appended.[1]

Five kilometres north of Halbenrain near Radkersburg, on the Austro-Yugoslav frontier, lies the village of Klöch, and in the 'Klöcher Klause', about 350 metres north of the church, a series of basalt quarries, in which the basalt shows pronounced columnar jointing, have been opened. A detailed examination by K. Schoklitsch (1932) of this basalt, which was classified as nepheline-basanite by A. Sigmund (1895), has shown that, according to the Niggli system, its composition lies between that of the theralitic and the theralitic-gabbro magmas, and A. Winkler (1951) has given reasons for regarding the volcanic activity in these rocks as having occurred in lower Upper Pliocene times (Dacian stage), although it had long been regarded as of late Pannonic age.

In the first quarry north of Klöch, a column of basalt 10 metres thick was exposed, which was overlain by a vesicular basalt. In this basalt A. Hödl (1942) reported calcite crystals and large (up to 4 cm. long) crystals of aragonite with well-developed faces, together with smaller crystals (a few mm. across) of nepheline and analcime, which had grown out of the rock into the vesicles. In 1951, on the floor of the north corner of the same quarry, some particularly fine specimens of zeolites were collected, the best being crystals of phillipsite, and spherulites of gonnardite 1 cm. in diameter. Since then, other zeolites have been found in the same vicinity; according to P. Paulitsch (1952), chabazite occurs as colourless crystals 5 mm. in length all with $\{10\bar{1}1\}$ faces and sometimes twinned on (0001), and accompanied by scaly stilbite; Paulitsch has also reported (private communication) that some unusually well-developed crystals of thaumasite were also present; K. Kontrus (1952) has also described occurrences of phillipsite together with chabazite in the lens-shaped phacolite habit with the forms $\{10\bar{1}1\}$ and $\{01\bar{1}2\}$. These zeolites of Klöch have all formed in the vesicular hollows, which rarely attain the size of the hand. Small vesicles are occasionally filled completely by hydrothermal minerals, but drusy deposits are the most common. The oldest mineral in the vesicles is

[1] Our thanks are due to Herr W. Philippek of Graz, who first collected these associated zeolites at Klöch, for providing many of the specimens examined during the course of this investigation.

calcite, often occurring alone and frequently forming the base of the zeolites. The crystals are almost always very small, measuring only a fraction of a mm., often in comb-like aggregates but sometimes botryoidal.

Phillipsite[1] is the commonest zeolite and is older than the gonnardite. Occasionally it occurs as transparent, pseudo-tetragonal, prismatic interpenetration twins (Dana,[2] fig. 2); but it is usually found as translucent complex twins (Dana, figs. 3 and 4, and pl. X, D of this paper). The re-entrant angles are often absent, resulting in pseudo-rhombic-dodecahedra. The phillipsite specimens from Klöch are the equal of those from the best localities.

The more simple twins might, from their appearance, be harmotome, but, according to G. Kalb and H. Klotsch (1943), the pseudo-cubic multiple twins of phillipsite are characteristic.[3] Phillipsite has been found by A. Köhler (1932) in the Neuhaus (Burgenland) basalt, but the mineral from the basalt at Weitendorf (near Wildon, Styria) that was reported as phillipsite by A. Sigmund (1924, 1926) has been shown by F. Machatschki (1926) to be harmotome (see also H. Heritsch, 1936).

Chabazite was present in only one specimen as a lenticular crystal nearly 2 mm. long. Calcite crystals formed the base and much phillipsite was present. On one specimen some colourless spherules of a mineral reminiscent of hyalite were found, together with phillipsite and small calcite crystals. The mineral was anisotropic, fibrous, and had straight extinction, with positive and negative elongation and gave β about 1·520, and $\gamma-\beta > \beta-\alpha$, showing it to be thomsonite.

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[1] Identified by refractive index ($<1·501$) and density (2·216).

[2] Syst. Min., 6th edn (1892), p. 579.

[3] As a result of a detailed study of vicinal forms, these authors regard phillipsite (and harmotome) as orthorhombic and not monoclinic.

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EXPLANATION OF PLATE X.

A to C, X-ray powder photographs, 6 cm. camera, Cu–$K\alpha$ radiation.

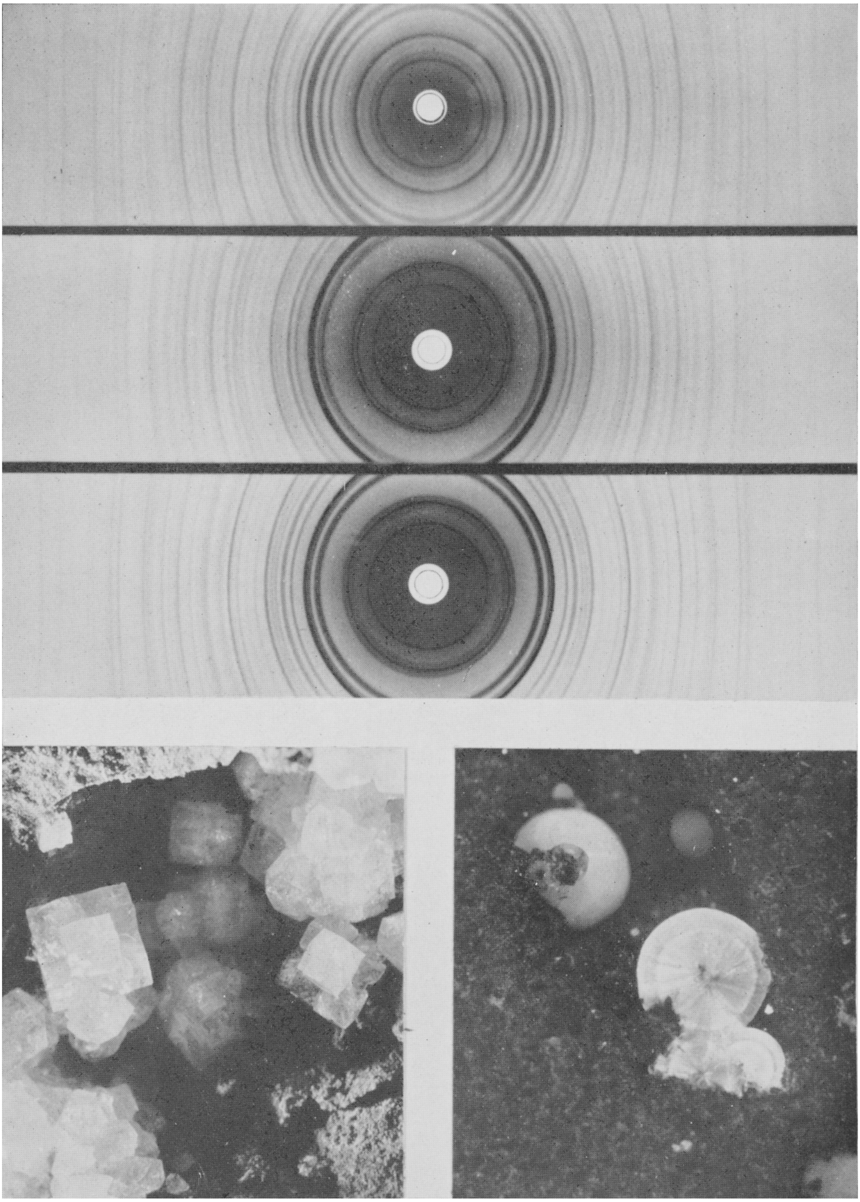
A. Thomsonite, Old Kilpatrick, Dumbartonshire.

B. Gonnardite, Chaux de Bergonne, France.

C. Natrolite, Snake Hill, New Jersey.

D. Phillipsite, multiple twins in cavity of basalt, Klöch, Styria. Approx. $\times 2$. Photo. by K. Kontrus.

E. Gonnardite, zoned spherule in leucite-tephrite from Capo di Bove, Rome (B.M. 82805). Approx. natural size.



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